SOME ASPECTS OF EVOLUTION AND DIFFUSION IN EUROPEAN TECHNOLOGY

1450-1750

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by

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ABSTRACT

The latter part of the period of three hundred years in European history from c.1450 to c.1750 is one of the more neglected in the history of technology. The present study is concerned to show something of the growing sophistication of machine design in Europe in this period and the settings in which these developments took place. Their cumulative effect was eventually to bring much of the continent, no less than Britain, to within measurable reach of the prospect of sustained economic growth.

The nature of mechanical invention, the progressive adaptation of machines to new tasks and the manner in which new techniques were diffused are all matters central to the development of the thesis. What is revealed very clearly is that Germany and England were the most technologically progressive areas of Europe. At first Germany was the principal generator of new technology, but from c.1700 the direction of flow was setting decisively outwards from England.

During the 16th century the development of mining in Germany gave rise to a sophisticated tradition of mechanical engineering which was eventually able to provide effective solutions, as with the Stangenkunst and the float-flume, to a whole range of difficulties in this field, particularly those connected with the problem of pumping and fuel supply. The English solution, that is, the use of coal and steam, to the same dual problem as it assumed serious dimensions took on so distinctive a form that by c.1750 two divergent models of technological development existed in Europe.

It was not however the case that either was available for adoption in regions lying outside the narrow range of local conditions in response to which each had developed its characteristic forms. The German model was incapable, even in principle, of extension outside its range, while the English model remained likewise generally unavailable to Europe in the absence of yet further technological development.

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Chapter One INTRODUCTION

The idea which the present study first sought to develop was comparatively simple and straightforward. Since few would dispute that the complexity and range of mechanical devices at the disposal of Western Europeans underwent considerable development in the period c.1450 to c.1750, it appeared reasonable to suppose that some light might be thrown on how this development was achieved by selecting for examination a number of discrete mechanical linkages or mechanisms that seemed likely, prima facie, to have played an important part in such a process. Each mechanism selected would be approached with two objects in mind. The first would be to seek to establish the origins, in time and place, of the item in question, and, if it were possible, attempt also to discover the circumstances in which it came to be invented. The second would be to seek to trace its subsequent evolution and the paths by which it diffused, not only in space and time but also operationally as it was incorporated into a variety of new applications. Here one may remark that it is one of the curiosities of the history of technology that although invention lies at the heart of the discipline, little notice has been taken, with the honourable exception of Usher's essay, 'The emergence of novelty in thought and action', of what the act of invention involves in psychological terms[1]. This is something which must be examined further. For the moment, I wish to draw attention to another feature of invention, similarly neglected, which has to do with the physical form which a device or mechanism assumed at the moment of its creation. What is involved here is an analytical tool of great value, that is, the concept of skeuomorphism[*]. Whereas almost all who have written about invention have noted the step by step nature of technical development, which however expressed might be stated summarily as <u>nil per saltum</u>, no one has exploited the possibilities which such an evolutionary view of development carries with it as a corollary[2]. A newly invented device, ordinarily the result of a synthesis of pre-existing elements, will retain for some indeterminate period features or traces of the matrix from which it took its rise. Some of these features may well be skeuomorphic or redundant in character as far as the actual functioning or utility of the new device is concerned, and, as they are perceived to be such, will be purged away. Thus begins the process of critical revision. If, however, sufficient early evidence is available for the period before such revision has obliterated the path by which it travelled, then from the prototype (which may perhaps have no other existence than in the pages of a note book) something of the evolutionary history of the item in question may be securely established. Furthermore, the sequence forward in time is but part of what may be traced. It is also possible to move backwards from it. The redundant features carried over into the prototype may be sought for in pre-existing devices, and, if found, will permit the proximate milieu to be ascertained within which, or in terms of which the new concept, form or organizational whole was first realized. Here one returns directly to the question

Skeuomorph (σκεῦος, vessel; μορφή, form): an ornamental design the character of which is derived from the nature of the material of which it is composed.

of the modalities of perception established by gestalt psychology.

A classic experiment, published by Kurt Koffka in 1915, demonstrated the basic idea of homogeneities and forces of cohesion which hold a shape or figure together and render ineffective other stimuli which although present are able to become effective only if some new feature or inhomogeneity is introduced into the figure[3]. Such findings were to give concrete form to the earlier, almost mystical, idea of gestaltqualität or 'form quality', an attempt to name the tendency, noticed long previously, for the eye to see things in certain constellations or configurations. Such tendencies suggested that there must be qualities belonging to organized forms over and above the various sensory ingredients that were present in a given situation. It is, in short, only by recognizing the power of the organizing forces present in certain configurations that one can begin to appreciate the immense perceptual difficulty in breaking clear of one organizational whole in order to perceive another which is indeed seen but not seen as. The issue is one to which Russell Hanson devoted many luminous pages in his Patterns of Discovery, and one might take as illustration of the notion of seeing and seeing as that passage in which he sets Kepler and Brahe on a hill at dawn to watch the sun rise: "Let us consider Johann Kepler: imagine him on a hill watching the dawn. With him is Tycho Brahe. Kepler regarded the sun: it was the earth that moved. But Tycho followed Ptolemy and Aristotle in this much at least: the earth was fixed and all other celestial bodies moved around it. Do Kepler and Tycho see the same thing in the east at dawn?"[4] In one sense they do and in another they do not. They are, one might say, programmed differently, and the visual data presented to them will fall into different discourses.

Perhaps enough has now been said to establish, in outline at least, an elementary notion of what the phenomenon of invention involves in psychological terms, that is, the leap of stimulation, however mediated, from one strongly unified field to another. A gestalt, in brief, is not only organization but is a product of organization and is in its nature diametrically opposed to mere juxtaposition[5]. Once the new field has been established it begins to appear as almost trivially obvious, and rapidly induces a sensation in those for whom the leap is an established fact that it was not such a great affair after all. A powerful effort is needed to recreate even a semblance of what was once felt at the moment when the formation of the new concept first burst upon the conscious mind. On quite another level some light is also thrown upon the notorious difficulty of tracing an invention to its first source. Some other, with the same material before him as the inventor, might easily claim that he had the very thing in his own hands, an assertion which might, in one sense, be no more than the literal truth[6].

As for the second object mentioned above, that is, tracing the manner in which certain devices diffused, it seemed possible to hope that a series of such studies would disclose something of the speed with which new ideas were incorporated into the inventories of European engineers. In this undertaking one encountered advantage and disadvantage in about equal measure. An advantage was that single, 'detachable' ideas were not likely to encounter any appreciable resistance such as would be, for instance, the case with a complex machine such as the Newcomen atmospheric engine. With the bare idea alone needing to travel and at the level of operations requiring little in the way of professional expertise, there would be no threat to the status quo, and none of the resistance to change that vested interests might normally be expected to exert. Nor, were such interests overborne, would the further difficulty be encountered in transferring complex techniques, that is, of achieving a successful domestication in a new and possibly unpropitious environment. Given the availability of the idea, change on a small scale would, in other words, be able to take place unhindered by all such resistances. It would follow from this that the speed of diffusion would be, in a very real sense, a measure of the degree of integration and exchange of intelligence obtaining among the peoples of the west, and of the increasing velocity with which such transfers took place. Early references to such matters are hard to come by in contemporary sources although there is little reason to doubt that it was keenly apprehended from at least the beginning of the 17th century that fruitful possibilities for the gathering of intelligence lay open to the traveller in foreign lands. The drafting of enquiries for travellers undertaken by the Royal Society in the 1660s and 70s was an attempt to ensure that collection of information should become a matter of planned and conscious effort rather than a spasmodic and irregular gleaning[7]. Nor were such efforts an English idiosyncrasy. At much the same time Swedish engineers and mining experts such as Christopher Polhem and Erik Odhelius were sent on investigatory missions in Europe, submitting lengthy reports to the Bergkollegium in Stockholm on their return[8]. But apart from such quasi public peregrinations, the beginnings of large scale state-directed industrial espionage also reach back into the closing decades of the 17th century. Prussia maintained agents in both Holland and France in an attempt to secure the secrets of their silk and textile manufactures[9]. Thomas Lombe, in a free-lance capacity, undertook a similar mission in Italy[10]. Leibniz' idea (of about 1680) that "what would help....most would be to unite our labours, to share them advantageously and to regulate them in an orderly way" was in some way to being accomplished even if crudely and in the manner of "a disorderly rabble marching in the darkness"[11]. If there were buyers of industrial know-how there were also sellers. The higher artisanate itself moved freely, or was induced to move by handsome offers, despite the most ferocious penalties designed to prevent such migrations[12]. It is scarcely a wonder, in view of all this, to find that Montesquieu, observing the free flow of technical information in his time, should consider that, "à present (1728) toute se communique. Il n'y a que les Turcs qui ne profitent point des lumières de la société humaine"[13].

But here one must turn to the disadvantages encountered in seeking to trace the diffusion not of entire technologies but of single ideas. If these were as susceptible of such easy and unobtrusive assimilation as I have suggested, then there was little reason to suppose that many traces would remain to mark their progress. They were not in the least likely to cause a stir such as, say, the setting up of the first Stangenkunst in some place or other would occasion. Despite this particular difficulty and that more general one arising from the extreme paucity of 'real' machine drawings of any kind for the period between Leonardo's death in 1519 and the beginning of the 17th century, the problem turned out, in the case of the sector and chain at least, not to be insuperable. The history of this device forms the sixth chapter of the present study. It was selected for the reasons stated above, and examined in the manner outlined. The enquiry demonstrates, in my view, the validity of such an approach. The history of the sector and chain had not been investigated previously and was overlooked, curiously enough, even in a study which was concerned solely with anatomising the atmospheric engine of 1712 in order to display the currents of design on which Thomas Newcomen had drawn[14]. The enquiry into the origins of the sector and chain revealed, among much else, that this valuable mechanical invention had been made by Leonardo about 1488-89 and was the solution to the long-standing problem of how to connect straight line and circular motion in one continuously linked mechanism[15]. What was perhaps of even greater interest was to discover that sufficient evidence survived in Leonardo's notebooks to make possible an attempt to reconstruct the sequence of events which seem to have led Leonardo to discern the remarkable kinematic properties of the sector and chain. The subsequent diffusion of the idea throughout Western Europe and its employment as time went on in a bewilderingly wide range of uses demonstrates the falsity of the notion that Leonardo's ideas lay interred without issue for some three and a half centuries[16].

The line of approach through the investigation of such items was, however, greatly modified when research was begun on the idea of the mechanical transmission of power over considerable distances by means of assemblies of reciprocating rods. As Arber has remarked in another connection, "during the hunt the problem changes....problems do not remain static, but come to life and quietly assume the direction"[17]. So it was here. The history of the Stangenkunst or rod-engine soon revealed itself to be a subject of major importance requiring extended treatment, for the history of its development is inseparable from the history of mining engineering in Europe as a whole. The Stangenkunst, probably invented about 1540 in Slovakia, quickly revolutionized the art of mining. One has only to read those pages of book six of Agricola's De Re Metallica, devoted to mine pumping equipment, to realize how limited was its scope and how puny its resources[18]. By the end of the 16th century, however, everything had changed. The mining areas of central Europe at least, those areas roughly coterminous with German settlement, possessed pumping equipment which permitted shafts to be sunk to something approaching a thousand feet below adit and which could be served by such machines even if they lay separated by a mile or more of broken country from the nearest source of water power. No sooner had one begun to develop this line of enquiry than it became obvious that little real progress could be made until the question of nomenclature had been clarified. The source of the difficulty may be stated quite simply. It was clear that what some contemporary writers meant to indicate by the word 'Stangenkunst' was not at all what others intended. Did the word refer only to those machines working tiers of pumps by means of horizontally disposed transmission rods or only to those machines placed over or in the shaft which supplied power directly to the pumps through vertical transmission rods, or to both equally? Were there two genera or one only which embraced two species? Although no extended study of such machines exists in any language, it was obvious that the authors of such recent references as were available were naively unaware of the problem, perceived no difficulty, and, as a consequence, merely reflected the confusion that had first begun to build up about the question at the beginning of the 17th century[19]. But the literature of the history of technology in general yields few indications of any keen apprehension of the importance of semantic problems either, although it is unquestionably one of the greatest importance[20]. How does a new machine or device come to be named? Is it christened once only or many times? Is a new name bestowed on it at all, or does it merely take over the name of the device it has replaced? Nor is this the end of the matter, for what happens to its name (or names) when, in the course of development it begins to be modified or even diversified into a variety of types? I am not suggesting, of course, that there is any known general law covering such cases, or that in principle there might be. Language is altogether too polymorphic and anarchic to offer any such hope. Anything goes, and in any case, as Darmesteter long ago remarked, "it is not the function of a noun to define the thing but simply to call up the image of it"[21]. Each device requires, in short, to be investigated separately if one is finally to have any confidence that when one comes across what appears to be a reference to the thing in question it is actually what it seems to be. But if historians have neglected the problem, certain lexicologists have not, for to some working in that discipline it appeared that the creation of new technical facts would bring into existence precisely those conditions in which the generative resources of language might most readily be studied. The literature devoted to such researches, although difficult to come by and in general not very abundant, furnished nevertheless a number of models and concepts in the light of which I was able to pursue my quarry with somewhat more confidence. The result of these researches forms chapter two of the present study.

The way having been cleared, investigation into the invention, evolutionary history and diffusion of the Stangenkunst could then begin. Following the method employed in the sector and chain enquiry, it was a matter first of identifying the prototype and then of tracing the stages of development through which it passed, a process which in its main features appears to have been accomplished in a period of approximately fifty years, extending from c.1540 to c.1590.

The name of the inventor of the prototype is unknown and now almost certainly unknowable, so that the invention must be added to the long list of what Thomas Powell called inventa adespota, the masterless inventions. It is possible, however, despite this, to gain some idea of how it was first conceived. The notion of using water wheels to drive pumps by means of connecting rods and rocking rollers appeared first in Italy some time before 1450, and at about the same time, or even perhaps somewhat earlier, much the same combination of elements was coming into use, in Italy also, for the purpose of powering metallurgical bellows. By the beginning of the 16th century the addition of further rocking rollers and push rods to assemblies of this sort in order to drive multiple sets of bellows had resulted in what can only be described as miniature horizontal transmission lines. Vannocchio Biringuccio's description of the machine he had built at Bocheggiano about 1510 can be understood only in this sense, and he may even have been, as Beck thought, the originator of such devices. But whether he was or not, Girolamo Cardano's description of similar multiple bellows, published in 1550, makes it quite clear that the practice of using a single water wheel, equipped with push rods and rollers to provide the blast for many sets of bellows, was by then quite common[22]. The design of the prototype, vertically disposed Stangenkunst - the sipho septimus - as it appeared in Agricola's work, the invention of which was referred by him to the period around 1540, would seem to have sprung from the double conception of (a) using push rods in a vertical sense and (b) hitching them to tiers of suction pumps. What one might call the Agricolan prototype retained a number of redundant features, absent already in advanced machines of the 1560s, which indicate, unambiguously, a metallurgical provenance[23]. When, probably in the same decade, experimental work began on horizontal transmission lines in an attempt to extend the convenience of the new pumping technique to mining sites lacking water, there can be no doubt that the familiar push rod and rocking roller combination was again pressed into service[24]. But it had been evident to Biringuccio some fifty years earlier that although rod systems such as the one he had himself built might be extended, the multiplication of an already large number of moving parts would be attended by severe penalties. Unfortunately, no visual evidence survives of the earliest attempts to solve the problem, but from 1584 onwards the evolutionary history of field-rod construction may be followed in some detail, in small part from engravings, but, in the later stages, only from the evidence yielded by certain coins and medals[25]. When these radically modified machines came into common use such stability as existed in the matter of nomenclature was disturbed, and resulted in the terminological confusion already referred to.

The diffusion of Stangenkunst technology presents a number of interesting features not all of which are very easily explained. If, as I have supposed, such machines had their origin about 1540 in the mine towns of central Slovakia, or, as they were then called, the niederungarische Bergstädte, the rate of diffusion westwards was extremely rapid. By 1565 they had been introduced even into the remote mines of the Harz in north west Germany. Engineers expert in such matters, and whose names have for the most part been preserved, migrating as it would appear on their own initiative in order to derive profit from their knowledge, were the principal agents of this dissemination. But the administrators of state-directed mining corporations also sometimes played a part, as was the case, for instance, at Idrija in 1580 when incompetent local interests were bought out and the mercury mines put under expert management. Altogether, the speed of diffusion is easily explained in these early stages once it is realized what a money-saving device the new pumping engine was. From Freiberg in Saxony, where accurate records of costs kept from 1557-1570 have survived, it is clear that expenditure on pumping was reduced to ten per cent or even five per cent of what it had been before Stangenkünste replaced the machines previously in use[26]. One may judge that there was little disposition to cling to outmoded procedures once the new technique was available. At the linguistic frontiers of Germany, however, this expansion halted, and it was only in the 1640s that the technique was carried into Sweden. France, Spain and Italy were untouched by these developments. Whether the language barrier was really responsible forthis failure of transmission, or whether factors having to do with modes of economic organization enter into the matter also is difficult to say, but the fact remains that such machines were coming into use in France and Spain only after 1750. All these matters form the substance of chapter three of this study.

England, however, was a special case. Nowhere had mining assumed such a dominant position in the economic life of the state. Increasingly through the 17th century economic prosperity came more and more to depend on the winning of coal. By 1700 England had long passed the point of no return, the position where, should its mines fail, its industries could have been sustained by a resumed use of traditional fuels. It had, in terms of Mumford's categorization, entered the palaeotechnic phase of industrialization, whereas Europe at that time, and for more than a century longer, still lived by the self-sustaining rhythms of the eotechnic economy. Only certain restricted regions such as those lying about Valenciennes, Mons, Charleroi and Liége owed their economic vitality to coal. Yet the English coal mines on which so much rested were still equipped at the beginning of the 18th century, as the evidence of contemporaries makes abundantly clear, with pumping machines that were - one may say it without exaggeration - like those discarded in central and northern Europe some hundred or more years earlier[27]. The most productive (and wettest) mines in the country, those of Durham and Northumberland, were, not surprisingly, living under the constant threat of being drowned out. If in the face of such a generalized crisis in mine pumping, and one leaves aside the question of economics entirely, the conditions necessary for the diffusion of Stangenkunst technology still did not exist, one is at liberty to wonder what more was needed. In the event the Newcomen engine almost literally permitted the industry to keep its head above water. I have referred to the abundance of evidence relating to the art of mine pumping in the English mines in the second half of the 17th century. Nowhere is the Stangenkunst mentioned, and it would seem fair, in view of this silence, to conclude that the machine was unknown, or unknown at least to those who most stood in need of it. The argument from silence would seem to apply here in its most stringent form. Langlois and Seignobos regarded the argument as conclusive when two conditions were fulfilled: firstly, the authors of the documents in which the fact is not mentioned had the intention of systematically recording all the facts of the same class, and must have been acquainted with all of them, and secondly, the fact, if it were such, must have affected the authors' imaginations so forcibly as necessarily to enter into their conceptions[28]. I have let my 17th and early 18th century English authorities speak for themselves in chapter four of this study. Although Langlois'and Seignobos' conditions can never yield a logically conclusive case, it would seem reasonable to suppose that in terms of rationality at least their conditions, if met, may sometimes yield a high degree of certainty, as in the present case I think they do[29].

But why had Stangenkunst technology failed to travel to England? It could hardly have been on account of English reluctance to bring in foreign experts, since the Tudors had been busily engaged since the close of the 15th century in just such exercises, and the zeal to learn from

Europe continued undiminished during the 17th century. Unless one is disposed to accept that the whole business of transmission was during these centuries a matter of blind chance, the most obvious answer may be the best. For a complex technology to travel easily during the 16th and 17th centuries perhaps the settings where it might be most readily employed needed to be disposed at relatively short intervals. It is tempting to suppose, if the validity of the metaphor be accepted, that diffusion would proceed somewhat in the manner of a powder train. A substantial gap would not easily be jumped, and between the westernmost salient of Stangenkunst technology around Liége and the North Sea coast stretched a broad belt of half drowned marshes and polders, terrain suitable for tjaskers and wipmolen, but hardly for anything else. But for the metaphor to serve it is necessary for the phrase 'settings where it might be most readily employed' to be precisely understood. There is some reason to suppose that the German miners from the Tyrol, brought into England after 1567 to work the veins of copper in the hills of Cumberland, included engineers thoroughly familiar with Stangenkunst work. The state of the art had not at that time perhaps reached a very advanced stage, but Daniel Hochstetter's machines were certainly superior to anything in use in England before the first Newcomen engines began work. What seems to have happened is that the Cumberland copper venture failed before the new technique had had sufficient time to become fully domesticated. It is possible also that mining operations elsewhere in England were at too rudimentary a stage of development in the last quarter of the 16th century to stand then in need of such sophistication[30]. A century later, when the need existed and had indeed become acute, one has the curious spectacle (in 1673) of the Royal Society seeking information regarding the methods of deep mine pumping in use at Liége, and yet failing, apparently, to acquaint itself with the first-hand experience of men such as Walter Pope and Edward Browne, whose knowledge of continental mining practice (and much else) was certainly comprehensive enough to have aroused widespread interest among the circles of English coal owners had intelligence of it ever reached their ears[31]. Lacking both knowledge of how things were ordered in Germany and pursuing their operations too far removed geographically from those scenes of technical accomplishment for casual discovery to be possible, men like Thomas Liddell of Ravensworth or Ralph Delaval of Lumley Park had to manage as best they could with such strange mechanical confections as were available, some of which, without fear of exaggeration, one might suppose to have sprung directly from the imaginings of some local mute, inglorious Ramelli.

The development of the Stangenkunst was exclusively the work of German engineers, and reflects that high level of accomplishment in the invention and building of machines for which that country was famous. The eminence of Germans in this field was widely acknowledged by other Europeans in the 17th and 18th centuries. Thus one finds Thomas Powell in 1661 talking of "those Germans (who) are said to have their wits at their fingers' ends", while

Pierre Grignon, a little over a century later, could write of Germany as "la patrie des machines"[32]. Certainly in no other language is to be found anything approaching the wealth of literature on metallurgy, and mining, and the legal institutions connected with that art, or anything to equal the number of technical dictionaries, the histories of inventions or the great technical encyclopaedias which document the whole field of technical development. A history of technology, in brief, which declines to accord due place to this technical primacy cannot but fail to be deficient.

As has already been remarked, the history of the Stangenkunst is also intimately connected with much larger issues central to the development not only of western European technology but also, although it is difficult to speak other than in general terms, to the development of a new kind of consciousness, the product of large scale capitalistic enterprises, often managed by state officials, engaged in fine calculations of cost effectiveness and profitability, and employing great numbers of master engineers and whole armies of other craftsmen. This absorption with efficient management led eventually to the setting up of full-blown institutions of higher technical instruction such as were established at Schemnitz in Slovakia and Freiberg in Saxony, schools in a sense for the whole of Europe[33]. The investigation of such questions as the impact of growing technical expertise and capitalistic enterprise on European consciousness, while plainly lying outside the scope of the present study, ought not, however, to pass without comment. The mind is inseparable from what it contemplates, and it may scarcely be questioned that developments such as these brought the states of western Europe (and not only England) to an advanced level of cultural and psychological preparation such as would permit them, once the revolutionary and Napoleonic wars were over, to begin, with great speed, to reproduce on their own territories the elements of that peculiarly English technology which had been slowly developed over the previous century and a half, and which had only begun to be locally and fitfully absorbed on the continent, despite the expenditure of much money and energy, during the latter part of the 18th century[34]. Apart from these wider issues something must be said also about those technical developments with which Stangenkunst technology was connected. All the elements involved acted and reacted on each other in a complex sequence of cause and effect to create the typically European kind of industrial economy based on wood fuel, standing in the starkest possible contrast to the English model based on coal and coke.

Before these two diverging models of economic and industrial development began to come into existence it is possible to discern what those pressures were whose gradually intensifying force was to bring them into existence. A history, not yet written, whose object would be to trace the stages by which the assarting of the great forests gradually ceased to be a matter of indifference or even one regarded as meritorious work, but rather a process posing a threat to the prosperity of whole regions, would permit one to assess the period at which not only growing populations but a more powerfully organized technical capacity for production were exerting pressure upon supplies of timber as a building material and as a fuel. Pecquet placed this time at the end of the 12th century[35]. As regards improved technical capacity, the exploitation of the cam from the 11th century onwards as a means of mechanizing the whole range of basic industries was, one would guess, the starting point of an era of intensive exploitation of resources. The fact that the earliest notices of the employment of rivers for the rafting of floats of timber in northern Europe should appear in the early 13th century and thereafter become common is a secure indication of what was taking place. As long as the quantities of iron or other metallic ores capable of being treated remained small, as they necessarily would be if only manually operated furnaces were available to the metallurgical industries, the necessary fuel could easily be conveyed to the point of consumption by carts. The implied radius of provisionment would be on a modest scale, the cost of cartage not yet rendered uneconomic by the necessity for long hauls. The scale of the demand for fuel and indeed the entire ecology of industry was changed once water powered bellows, hammers and stamps began to come into general use. But even the rafting of timber from distant sources became unequal to demand, and by the beginning of the 14th century at latest the construction of artificial channels or flumes was resorted to in the important mining areas in order to augment the natural reticulum of rivers and streams along which fuel was delivered. But for such systems to be feasible certain climatic conditions had to obtain. Winter precipitation had to be in the form of snow, but equally important was the need for temperatures to remain consistently low enough for such snow as fell to accumulate steadily until the spring melt set in. It was then that the year's supply of billets of timber, stockpiled during the felling period of the previous autumn and winter, could be thrown into the foaming flumes to be carried swiftly, at trifling cost, many miles to the points of consumption. This was how great industries, as well as great cities such as Paris, Vienna and Berlin, were supplied with fuel well into the 19th century[36]. In the mining region of Slovakia the forest law forbade the brewing of beer and the keeping of goats, and enactments of this sort, designed to conserve fuel for the mines and the metallurgical industries, could be paralleled elsewhwere, as well as in the sanguinary codes of law which made the theft of billets from the flumes (Holzdieberei) an offence punishable by death. The stringency of the fuel crisis could equally well be traced in the attempts made to find ways of using wood more economically. Increasing attention was given to improving the efficiency of boilers and to designing ingenious worm flues. In the salt industry, another unwritten history, the preliminary concentration of brine by means of evaporating sheds began to be practised from the middle of the 16th century, and such Strohkunste or Leckwerke, as they were called, were for the next three centuries among the largest and most imposing industrial structures to be seen in Europe. The earliest European pipeline, that which was built in 1617-19 in Bavaria and extended thirty-one kilometres from Bad Reichenhall to Traunstein, was constructed precisely because local fuel reserves in the Bad Reichenhall area had been exhausted and all other expedients for processing the brine yielded by the Plattenfluss (the silver flood) had proved valueless. Seven pumping stations lifted this brine a total of one thousand feet in order to permit it to run under gravity to Traunstein where wood for firing the pans was plentiful.

The consequences of wood shortage and high fuel prices for domestic users may be guessed at from the numerous works describing the construction of economical stoves. The quantum of discomfort, not to say suffering, resulting from the shortage of firing must certainly have been considerable. Faujas de Saint-Fond could speak of the people of northern France suffering horribly from want of fire in severe winters[37] but William Sharpe in England, speaking in the same vein of Dorset and Wiltshire, remarked that between such counties and those like Durham where cheap firing was plentiful, the disparity in the incidence of ague was "by general computation as eight to one and in some particular situations...a great deal more". Wet clothes and cold food were the lot of the labouring class in Dorset[38].

The climatic prerequisites for float-flume operations did not exist in England so that when, there also, the effects of timber shortage began to be felt in the 16th century, a solution of another kind had to be sought. In this way began that long apprenticeship in the use of coal and coke that Nef has so admirably described. Both the English and the continental pattern flourished but it is unnecessary to remark on which proved ultimately to have the superior staying power. In England, as is well known, a severe penalty had to be paid in terms of despoliation and pollution of the environment. What a history of European forest exploitation would reveal in detail is the price that had to be paid for clinging to an eotechnic system. The baleful effects of deforestation on the environment had been noted by Plato in the Critias: in Attica the shingle plains, where once there had been springs, were now dry places although the old shrines to the water spirits yet remained. Once "for its mountains it had high arable hills....what now remains compared with what then existed is like the skeleton of a sick man, all the fat and soft earth having wasted away and only the bare framework of the land being left"[39]. It was not otherwise two thousand years later in northern Europe. The rivers were seen to flood more often and more dangerously than formerly and yet in summer dwindle in volume until they lost much of their value for transport. The hydrological cycle was so seriously disturbed in the Saxon Erzgebirge that deliberate choices had to be made between whether to use what water flow was available for flume fuel delivery systems or for the leats which provided water power for pumping and winding engines[40]. There is, unfortunately, no general history which one might set beside Nef's work in order to see the total situation in something like authentic historical perspective. It might well be wondered, however, whether the ransacking of the earth's interior for fuel was more harmful than operations directed to the same end on its surface. An appendix to the present study sets forth some further information on the timber fuel economy of Europe.

In the fourth chapter of the present study I have attempted, as previously noted, to show that England was far from having absorbed best continental practice in a number of important respects at the beginning of the 18th century. Yet by 1700 in the matter of coal-fuel technology it had established a commanding lead even if the fundamental importance of that technology had not yet been fully grasped in Europe[41]. As the 18th century progressed, however, both this and the central importance of coal itself was beginning to be seen more and more clearly as the true basis of English prosperity. The hard lessons of domestic fuel shortage were sharpening the apprehensions of European statesmen generally. Louis XV's arrêt of 1744 was an attempt to bring some method and regularity into the mining of coal in France on which it was judged the national prosperity would increasingly depend, while in his memoir of 1786 Heinitz dwelt at some length on the importance of coal for the Prussian state and the need to discover new mines if anything was to be left for posterity[42]. By that time indeed it was becoming a part of conventional wisdom in both England and Europe that coal was the key to material wealth and power. Faujas de Saint-Fond was to recollect in 1784 that many years before he had met "chez Benjamin Franklin à Passy; des Américains d'un rare mérite, et qui avoient des connaissances profondes sur l'état politique et commercial de l'Angleterre, s'y trouvoient, je ne les nommerai pas, parcequ'ils ont joué depuis cette époque un grand rôle; mais je leur entendis dire avec plaisir qu'aucun publiciste ne connoissoit la véritable cause qui contribuoit à rendre les destinées de l'Angleterre si heureuse, 'On ne s'est pas encore doute', dit l'un eux, 'que ce sont les mines de charbon qui font tant de miracles: nous savons que c'est presque une trahison nationale de dire çela en France' "[43].

John Williams, in his Natural history of the mineral kingdom of 1789, fearing the exhaustion of the coal pits and noting that "the very existence of the metropolis depends upon the continued abundance of this precious fossil", saw also that "when our coal mines are exhausted the prosperity and glory of this....island is at an end. Our cities and great towns must then become ruinous heaps for want of fuel, and our....manufactures must fail from the same cause"[44]. I have introduced these remarks to show that despite the divergent experience of Europe and England in the matter of fuel systems, that of Europe was coming under increasing strain and that interest in the English experience was constantly growing through the 18th century. Nowhere was that interest so early manifested or so clearly visible as in the matter of the atmosperic steam engine. As early as 1720 parties of English engineers who had separately engaged themselves some time in 1718-19 to travel into Europe to set up such machines, were ready to begin work. By July of that year Isaac Potter had already selected a site at Königsberg in Slovakia, and in October John O'Kelly was ready to begin work at Tilleur near Liége. Their efforts, after many vicissitudes, bore fruit, and by the 1730s the technique had been successfully domesticated in both areas. In

Slovakia, indeed, the machine had been successfully adapted to situations far more demanding than any that then existed in England. Apart from this, yet further material exists which provides clear evidence of an innovative capacity able to grasp the potentialities of the machine not yet perceived by the English engineers themselves. Joseph Fischer von Erlach had already recognized its value for water-returning purposes in 1722, and by 1736 Johann Artner had drawn up plans for a machine with ratchet gear such as could be used for driving stamps[45]. It would certainly be a matter of some difficulty to find evidence for similar initiatives in England at so early a date.

The history of the diffusion of the Newcomen engine into Europe had not previously been studied in a comprehensive manner, and it seemed for this reason that it would be an enquiry well worth undertaking. Chapter five of this study follows in some detail the fortunes of the early engine builders in eastern and western Europe. A number of interesting points emerged. On one level the contradictory statements of such modern general historical works on the period as contain fleeting references to the subject could now be assessed. The machine was neither the plaything of aristocratic dilettanti, as Mathias supposed, nor the long hoped for miraculous solution of the problem of mine drainage which Dickinson saw as the European mine owners' paramount desideratum[46]. More fundamentally, the manner in which the technique was successfully mastered more or less simultaneously in both western and eastern Europe revealed very clearly the nature of the difficulties which had to be overcome. These were so various that in the event one is left wondering how success was finally achieved. The often cited enemies of innovation - vested interests, institutional rigidities and shortages of material resources - were really almost the least of the matter. In purely human terms also one cannot help feeling that Potter and O'Kelly would have done better to have remained at home, for both paid a high price for their temerity.

But what is of greater interest than anything else is the fact that the atmospheric steam engine during the 18th century and for much of the 19th was so symbiotically linked to the mining of coal that even in an extreme case such as that afforded by Schemnitz it could not in any significant or lasting way break clear of the coal-fuel matrix in which it had first come to maturity. In a word, every attempt to make use of it for pumping mines other than those producing coal proved to be a losing game. Thus it happened that the failure to find coal near Schemnitz, despite keenly conducted searches, finally led to the laying aside of the machines there. The problem was experienced even more severely at Vedrin, Poullaouen, Dannemora and Persberg.

Along the great northern coalfield extending from Aachen to Valenciennes, however, it was otherwise, for here, in a favourable environment, steam engine technology could prosper. Well over a hundred machines were constructed in the period 1740-1790. Although the totals of coal production from the various fields were small by English standards, the region as a whole was transformed, and this despite difficulties of terrain and meagre seams of great geological complexity such as would have been deemed impossible to work profitably in England[47]. Altogether, the task of transferring the European economies to a coal-fuel base was an infinitely severer one than had been encountered by the English and could only be achieved when networks of railways and the power of steam-driven locomotives became available to redress the balance of advantage which natural endowment and easy access to water transport had previously generously tilted in England's favour[48].

Some mention must finally be made of the source materials made use of in the course of preparing this study. Evidently, in seeking to establish machine prototypes and their evolutionary histories, the sine qua non was to locate a sufficiency of visual material. In general terms, as well as in relation to the themes with which I have dealt, it is the 16th century for which sources are hardest to come by. For the 17th century the situation eases steadily as one approaches its closing decades, and by the 18th, such material swells to considerable volume. It was a major difficulty for my purposes that apart from the work of the Bohemian engineer, Vavrinec Kricka, of c.1560, there was nothing for a period of nearly two hundred years to match the collections of machine drawings of the Italian engineers of the 15th century such as Taccola, Martini and Leonardo. Fortunately, many of the gaps in the visual evidence could be made good by a fair number of verbal descriptions of machines occurring in the literature. Although ordinarily verbal descriptions are of limited value if unaccompanied by a frame of reference, they may often be construed with considerable security when the nature of the discourse to which they belong has been established. It was in this connection particularly that the elucidation of Stangenkunst nomenclature proved valuable, nowhere more than in the analysis of the stages through which the technique of horizontal transmission line construction was to pass. Details of vignettes of mining scenes shown on certain coins and medals minted at Clausthal and Zellerfeld during the second half of the 17th century, when set beside the technical dictionaries which began to become common in Germany after 1673, threw light on each other and thereby made possible an essay in interpretation which otherwise could scarcely have been attempted. "A dictionary writer", as William Sharpe shrewdly observed, "is not obliged to be a controversialist"[49].

As far as the themes of this study are concerned, it is not perhaps without some interest to note the scantiness of the contribution it was possible to levy from the machine books. Such a situation is a reflection, no doubt, of the special interests with which their authors were concerned, but it was worthwhile nevertheless to subject their work to the pressure of the argument from silence, for Besson, Ramelli, Errard and Zonca, whatever part imagination was subsequently to play in their work, had still to select their themes, and these could only be provided by the active elements of technical experimentation with which they were familiar. This is a point which Keller makes when he comments that they were not independent of changes "in the real technology" of their period[50]. They were certainly aware of such examples of it as were displayed in the works of Agricola and Cardano. It remains the case, however, that their machines reflect only dimly the significant mechanical advances made or being made in the Germany of their time. The significant exception in this respect is the work of Jean Errard, whose Premier livre des instruments mathématiques méchaniques was published at Bar-le-Duc in 1584. Errard, living and working in a region that was still juridically part of the empire, was undoubtedly closer to and more familiar with contemporary developments in Germany than any of the other machine book authors. There is nothing fanciful about his engraving of a slitting mill which he mentions as having been already built and proved by a certain Charles Desrue, or for that matter with certain others of his machines. A similar degree of realism, of straight reportage, is present, for example, in his engraving of an early type of rod transmission line. This type fits so well into the known later pattern of development that it is difficult to doubt that here also he was recording actual achievement even if it were not something that had been sired in his own stable.

During the 17th century journals of travels began to be published in some numbers, many of which contain references to technical matters. Taken together, these were of considerable value in building up a picture of technical advance (or lack of it) in Europe. In general, those authors whose journeys traced the usual route of the grand tour through France and Italy proved to be of only negative value for my purposes, since they were passing too far west of the great divide which ran across Europe, separating the progressive centre from the Latin countries, a divide traced in rough fashion by the line of the Meuse, Rhone and Adige. Their picture contrasted strongly with that called up by those who had travelled into Germany. The use of machines for all manner of operations drew the admiration of men such as John Dee, Fynes Moryson, Philip Skippon and Edward Browne. Browne, whose work is especially rich in descriptions of mining and metallurgical operations, visited regions into which few ventured and even fewer described. His descriptions of the Slovakian mine towns were repeatedly drawn upon by French and German writers of the 17th century and were even used extensively by Brückmann in his Magnalia Dei of 1730. For the 18th century the principal primary sources made use of were technical works such as those of Leupold, Jars, Poda, Delius, Beckmann, Ferber and Krünitz.

Modern works, that is, those published since about 1850, bearing on the themes of this study are not numerous. On the history of coal mining there is Rouff's study dealing with developments in France in the period 1744-1791 and besides this a number of local studies having to do with the northern coalfields. A general history of European coal mining has yet to be written. The literature on wood transport (float-flume technology) although extensive, was inaccessible, and that on the Stangenkunst non-existent. For the history of the atmospheric engine in Europe a number of excellent papers exist on particular aspects of that history. A very valuable recent work is that of J. Vozar on the career of Isaac Potter in Slovakia. Rather older is an excellent paper by C. Bjorkbom on the negotiations of 1725 between John O'Kelly and the Bergkollegium in Stockholm regarding his proposal to set up machines in that kingdom[51]. What I have attempted in chapter five of this study is not only to provide a critical synthesis of such studies but also incorporate into the story a considerable amount of hitherto unexploited material contemporary with the period of diffusion in question.

Notes

1. A.P. Usher, A history of mechanical invention, Cambridge (Mass.) 1969, ch.4. I do not overlook J. Jewkes, D. Sawers, R. Stillerman, The sources of invention, London 1969, who themselves, op.cit. p.20, express surprise at "the comparative disregard of one, if not the main, spring of economic progress". It is, however, the economic and social contexts of invention with which they are most concerned.

2. One should note, however, R.U. Sayce, Primitive arts and crafts. An introduction to material culture, Cambridge 1933 (rev.ed. New York 1963), a work rich in ideas germane to this subject.

3. K. Koffka, 'Zur Grundlegung der Wahrnehmungspsychologie' (Towards the foundation of a psychology of perception), Zeitschrift für Psychologie, Vol.73, 1915, pp11-90.

4. N.R. Hanson, op.cit., London 1962, p.5. A further excellent example is afforded by C. Babbage, Reflections on the decline of science in England, London 1830,pp.210-11, "A striking illustration of the fact that an object is frequently not seen from not knowing how to see it, rather than from any defect in the organ of vision" arose, he says, from a discussion he had with Herschel on the dark lines seen in the solar spectrum by Fraunhofer. Herschel enquired whether Babbage had seen them

and finding he had not said, "I will prepare the apparatus, and put you in such a position that they shall be visible, and yet you shall look for them and not find them, after which.....I will instruct you how to see them, and you shall see them, and not merely wonder you did not see them before, but you shall find it impossible (hereafter) to look at the spectrum without seeing them". The fact, if not the mechanism involved, had been recognized indeed long before the foundations of gestalt psychology had been established. So: J. Glanvill, Scepsis scientifica, London 1665, p.161, "For though the images, motions or whatever else is the cause of sense, may be alike as from the object: yet may the representations be varyed according to the nature and quality of the recipient".

5. K. Koffka, Principles of gestalt psychology, London 1935, p.680. See also R. Arnheim, Visual thinking, London 1970, p.313, "....all productive thinking discerns between essential principle and accidental embodiment". K. Duncker, 'On problem solving', Psychological monographs, Vol.58, No. 270, found (p.111) that perceptual structurings played an indispensable role with many of his subjects more or less as visual images did with visual types. "Just as the latter need visual images if anything is to be realized clearly and to be kept stably in mind, so many people appear unable to make their thought-material precise, to survey it, and keep it in stable

form, unless it is fortified, and....imbued with such perceptual structurings".

6. This is not to ignore the possibility of simultaneous invention, or that someone taking the first step (i.e. not carrying the idea through to a fuller or more complete stage), someone else may take the second. And what shall one say of a situation where men working together produce an idea? Plainly here there is also a kind of dialectic of invention. Nevertheless, like Jewkes et al., I assume that the web-like unity of technical progress can be broken down into stages separate enough to be examined independently.

7. For examples of these enquiries see the Philosophical transactions of the Royal Society, No. 20, p.360, 1666 for Turkey and No. 25, p.467ff, 1667, for Hungary, Transylvania etc.

8. M.W. Flinn, 'The travel diaries of Swedish engineers of the 18th century as sources of technological history', Transactions of the Newcomen Society, Vol. XXXI, 1957-59, pp95-109, has drawn attention to the volume and value of such reports.

9. H. Krüger, Zur Geschichte der Manufakturen und der Manufakturarbeiter in Preussen, Berlin 1958, p.40.

10. For a brief sketch of Lombe's career see R. Jenkins, 'Historical notes on some Derbyshire industries', Transactions of the Newcomen Society, Vol. XIV, 1933-34, pp168-170.

11. G.W. Leibniz, Philosophical writings, trans. M. Monroe,

London 1934, pp.237-38. The passage is from an undated paper entitled 'Precepts for advancing the sciences'.

12. In 1669 service in the galleys was decreed for artisans attempting to leave France without licence.

13. C. le Secondat, Marquis de Montesquieu, *Voyages* (ed. A. de Montesquieu), Vol. 2, Bordeaux, 1896, p.262.

14. J. Needham, 'The pre-natal history of the steam engine', *Transactions of the Newcomen Society*, Vol. XXXV, 1962-63, pp.3-58. Needham agreed in discussion that he had overlooked the beam but even then made no mention of the sectors and chains which were part of it.

15. cf. F. di Giorgio Martini, *Trattati di architettura, ingegneria e arte militare*, Vol. 1, Milan 1967, f.45v, f.46, and f.46v, for his concern with this problem.

16. L. Reti, 'Leonardo and Ramelli', *Technology and Culture*, Vol. 13, No. 4, 1972, pp.577-605, has drawn attention to a number of parallels which suggest that Ramelli drew quite heavily on the note-books.

17. A. Arber, *The mind and the eye*, Cambridge 1954,p.15.

18. G. Agricola, op. cit. Basel 1556. It is interesting to find G.E. von Löhneyss, *Bericht vom Bergwerk*, Zellerfeld 1617, pt.3, p.3, describing how in the old days the miners toiled like beasts, "die armen Leute wie Vieh haben ziehen", at the work of

pumping. The machines of 'today', he says, had relieved them from such heavy labours.

19. See for instance R.P. Multhauf, 'Mine pumping in Agricola's time and later', Bulletin 218, Contributions from the Museum of History and Technology, Vol. 1, Washington 1959.

20. W. Endrei, L'évolution des techniques du filage et du tissage du moyen âge a la révolution industrielle, Paris and The Hague 1968, p.9, remarks in this connection that 'les documents clairsemés doivent être relayés par les méthodes philologique et ethnographique".

21. A. Darmesteter, The life of words as the symbols of ideas, London 1886, p.45.

22. (i) V. Biringuccio, De la pirotechnia, Venice, 1540, p.111. See note 21, chapter three of this study for my reconstruction of this machine.
(ii) G. Cardano, De subtilitate libri XXI, Nuremberg 1550, p.40.

23. Such redundant features are already absent in Vavrinec Kricka's drawings of such machines in his note-book of c.1560. G.E. von Löhneyss, op. cit., plate XI, shows that the old Agricolan type was still in use in the Harz in 1617. But see note 21, chapter three of this study for justification of this assertion of a metallurgical provenance.

24. Juanello Turriano's artificio at Toledo was completed in 1569. It seems not unreasonable to

suppose that he carried knowledge of such devices with him into Spain, adapting for his special purpose a technique developed originally in mine work. At the end of book XV of his MS, Viente y uno libros of c.1565, he talks of float-flume construction as if he had recently conceived the idea whereas, of course, such techniques had long been in use in Germany. cf. Bk XV, 'De los arboles', f.249r. I am indebted to Dr. Alex Keller for the transcription of the passage in question. As for the artificio, a parallel may be drawn perhaps with Rennequin Sualem's work at Modave and Marly-le-Roi in the next century.

25. Coins and medals minted at Clausthal and Zellerfeld after 1647 proved a valuable source of information. According to Leibniz, Brunswick (whose principal mints these were) was regarded as having the most handsome coinage in Germany.

26. These percentages are derived from Bergverwalter (principal engineer) Martin Planer's report on the Freiberg mines which he presented to a ducal commission of enquiry in November 1570.

27. See chapter four, pp.244-260 of this study. After 1712 atmospheric steam engines were frequently used in England even where catchment works might easily have been constructed to render water power available, a prodigality which greatly displeased such critics as Gabriel Jars, William Sharpe and Johann Ferber.

28. C.V. Langlois & C. Seignobos, Introduction to the study of history, New York 1898, p.256.

29. W. Lange, 'The argument from silence', History and theory, Vol. 5, 1956, pp.288-301, offers a detailed critique of Langlois and Seignobos' criteria, and concludes that any argument of this form "depends for its effect largely on the skill and good sense of its craftsman". It is not for me, therefore, to pass judgment on my own use of it.

30. It seems likely that about the end of the 16th century most English coal 'mines' were in fact drift works in which drainage would be taken care of by means of adits or the drifts themselves. As long as the demands of the market could be met by such means, that variation of Gresham's law pertaining to mines would infallibly operate. It is worth noting in this connection that even late in the 18th century English mines were by continental standards still very shallow. This much appears from the tables of pit depths to be found in W. Sharpe, A treatise upon coal mines, London 1769, pp.52-55.

31. See for instance J.C., The compleat collier: or the whole art of sinking coal mines, Newcastle 1708, p.29, for an expression of earnest yearning for intelligence "of such noble engines...as are talked of". It is not without interest also to note the headlong eagerness of such men to invest

in atmospheric engines as soon as they got 'wind' of them.

32. (i) T. Powell, Humane industry, or a history of most manual arts, London 1661, p.184.
(ii) P. Grignon, 'Mémoire sur les soufflets des forges à fer', Mémoires de physique sur l'art de fabriquer le fer...Paris 1775, p.199, note a. Shortly after Grignon's time, however, the picture was changing. When J.J. Ferber visited the Le Creusot iron works at Mont Cenis in Burgundy to inspect the work of William Wilkinson he was taken aback by the enormous power of the cylinder blowers serving the blast furnaces. Such blowers "hatte ein solche enorme Force, wie ich noch niemals bey andern arten Gebläse bemerkt habe", an enormous force surpassing that produced by any other kind of bellows he had ever seen. Mineralogische und Metallurgische Bemerkungen in Neuchâtel, Franche Comté und Bourgogne im Jahr 1788, Berlin 1789, p.62.

33. These academies were established in 1763 and 1765 respectively. A.G. Werner lectured on geology at Freiberg.

34. C. Ballot, L'introduction du machinisme dans l'industrie française, Paris and Lille 1923, p. VIII, was convinced that "les machines dans la France devant '89, étaient plus largement repandues qu'on ne le croit communement" and that by 1780 various inventions had been taken up on a scale large enough to justify the expression 'machinisme'.

"D'autre part....a ce moment (1815)...l'introduction du machinisme est un fait accompli, la transformation économique est achevée". (Op. cit., p.2). Upper Silesia experienced similar development in the 1790s.

35. A. Pecquet, <u>Loix forestières de France,</u> Vol. 1, Paris 1782, p. IV. The word <u>deaforestare</u> (with a pejorative connotation) makes its appearance rather before 1200. Pecquet notes that in the capitularies of Charlemagne judges are ordered to promote actively forest clearance. "Le même principe de peu de valeur de bois qui donnoit lieu à ordonner des defrichemens, faisoit défendre les nouvelles plantations de bois".

36. The Schwarzenberg float-flume (Holzschwemmkanal), completed in 1824, permitted the hitherto untouched forest reserves of the Böhmerwald to be exploited as an additional source of fuel supply for Vienna. The Holzschwemmkanal discharged billets into the river Mühl in quantity equal to something like the thermal equivalent of 25,000 tons of coal per annum.

37. (i) F. Kessler's <u>Holzsparkunst</u>, Nuremberg 1618, appeared in a French edition the next year: <u>Espargne-bois....invention de certains et divers fourneaux artificiels, par l'usage desquels on pourra annuellement espargner une infinité de bois</u>, Oppenheim 1619. (ii) Faujas de Saint-Fond, Voyage en Angleterre, Vol. 1, Paris 1797, pp. 178-9, "dans plusieurs prov-

inces la plupart des habitants des campagnes, et même de certaines villes, souffrir horriblement faute de feu, être obligés de rester au lit...".

38. W. Sharpe, op. cit., (note 30), p.11. It was not uncommon for the inhabitants of this region of England to seek to alleviate the fuel shortage by collecting cow dung, blending it with chopped straw and then smearing it on walls to dry.

39. Plato, Critias (Vol. VII Loeb classical library), London 1929, pp. 271-5.

40. K. Löffler, 'Flösse und Bergbau', p.68, in H. Wilsdorf, Bergbau:Wald:Flösse, Berlin 1960.

41. J.R. Harris, Industry and technology in the eighteenth century; Britain and France, Birmingham 1972, shows very clearly the extent of the enormous lead the English had built up over their rivals in terms of coal-fuel technology. If the gap had formed over a century and a half the period of emulation is not so impressively large.

42. F.A. von Heinitz, Mémoire sur les produits du règne mineral de la monarchie Prussienne et sur les moyens de cultiver cette branche de l'économie politique, Berlin 1786.

43. B. Faujas de Saint-Fond, loc. cit (note 37.ii).

44. J. Williams, op. cit., Vol. 1, Edinburgh 1789, pp.160 and 172.

45. The atmospheric engine set up by J. Fischer von Erlach in the Schwarzenberg gardens in the Rennweg in Vienna in 1722 was essentially a water-returning

device. He was clearly alive to the possibilities of using the engine for generalized industrial purposes. Johann Artner's sketch is reproduced in J. Koran, 'Naše banská technika za feudalismu', Sbornik pro dejiny prirodnich ved a technicky, Vol. 2, Prague 1955, p.50 and fig. 11 (with German text).

46. P. Mathias, The First Industrial Nation, London 1969, p.135, "steam engines abroad remained almost confined to the laboratories of aristocrats". H.W. Dickinson, A short history of the steam engine, Cambridge 1938, p.45, "The need for unwatering mines economically was almost as pressing on the continent as in Britain".

47. See chapter five, p.349 of this study for a description of these conditions.

48. The high cost of fuel in Europe brought a series of responses. C. Combes, Traité de l'exploitation des mines, Vol. 3, Paris 1845, p.443, remarked that improvements in steam engines in the previous twenty-five years had reduced coal consumption to such an extent that it was now possible to use them "même sur les mines métalliques d'une richesse moyenne, et dans les contrées où le prix de la houille est assez élevé". These improvements were chiefly the work of "mécaniciens et constructeurs du comté de Cornwall". For other responses to the high cost of fuel see D. Landes, The unbound Prometheus, Cambridge 1968, pp.180-182.

49. W. Sharpe, op. cit., (note 30), p.26.

50. A. Keller, Early printed books of machines, 1569-1629. University of Cambridge, PhD dissertation No. 5710, p.151.

51. (i) J. Vozar, 'Isaac Potter, constructor of the first fire engines in Slovakia', Studia VII historica Slovaca, Bratislava 1974.

(ii) C. Bjorkbom, 'Ett projekt att byggn en Ång-maskin i Sverige år 1725', Daedalus, Tekniska museet årbok, Stockholm 1936.

Chapter Two THE VOCABULARY OF TECHNOLOGY

In so young a discipline as the history of technology it is small wonder for surprise that there should be many areas, properly belonging to the discipline, which have, as yet, received little or no attention. One of these is the critically important question of the ways in which a technical vocabulary is generated in order to denote some new machine or technique. The unravelling of the factors involved in such a process is plainly a very complex undertaking the difficulty of which is frequently increased by a very simple but often ignored fact, that a machine evolves, often rapidly, away from its original formulation so that in a short time a vocabulary that sufficed to mark off such a prototype from the other devices in the technical milieu in which it first found its place may very soon prove inadequate. The frustrations arising from the failure of language to keep pace with such changes, and the consequent slide into ambiguity that results from such failure, will inevitably produce a wide variety of ad hoc responses which, while they perform a valuable function in the areas in which they enjoy currency, inevitably create yet further confusion in the minds of contemporaries and even more perhaps in the mind of the historian attempting to elucidate, long afterwards when the technology itself may very well have disappeared altogether, the question of what words actually denoted and what shifts of meaning they underwent during the time they were in use.

It would be no difficult matter, in fact, to compile an anthology to illustrate the fundamental nature of the problem of language and how it has been perceived. In such an undertaking one might choose as one's starting point John Locke's observation in his Essay concerning human understanding, that "....though words, as they are used by men, can properly and immediately signify nothing but the ideas that are in the mind of the speaker, yet they in their thoughts give them a secret reference to two other things. First, they suppose their words to be marks of the ideas in the minds also of other men, with whom they communicate; for else they should talk in vain and could not be understood... But in this men stand not usually to examine whether the idea they and those they discourse with have in their minds be the same, but think it enough that they use the word as they imagine in the common acceptation of that language, in which they suppose that the idea they make it the sign of is precisely the same to which the understanding men of that country apply that name"[1]. It is easy, in short, "to perceive what imperfection there is in language and how the very nature of words make it almost unavoidable for many of them to be doubtful and uncertain in their signification"[2].

The rapid growth in the number of technical dictionaries, at least in Germany, from 1673 onwards and the production of multi-volume technical encyclopaedias during the course of the 18th and 19th centuries bear witness to this growing consciousness of the need for precisely defined terms[3]. Henning Calvör's work on the development of mechanical engineering in the Harz mining region and Johann Beckmann's investigations into the history of inventions, to mention the work of only two writers, reflect the same drive for clarity of nomenclature[4].

In the second half of the 19th century the investigation of language on comparative and historical principles began to yield a deeper understanding of the real nature of the difficulties involved in its study. Arsène Darmesteter noted in 1886 that "a determinant necessarily picks upon a particular quality which serves to denote the object" but which will indicate etymologically little of what seems essential since "it is not the function of the noun to define the thing but simply to call up the image of it...". Hence arises the weakness of characterization in virtually all determinants for "....words, rough interpreters of these inner worlds (of complex images) allow only an infinitely small part of them to appear...It is because language does express and does display but a feeble part of this subjective world that there exists an art of writing. If language were the expression of thought....(it)....would be a natural fact like breathing"[5], a sentiment echoed slightly later by Michel Bréal when he remarked that, "we feel with pain the misunderstandings which stream from the uncertainty and confusion of language"[6].

The logic of language was seen at this time to rest entirely on analogy and on the fact that actual usage was determined by something like a volonté générale for the people were all powerful and infallible because their errors sooner or later made the law. A body such as the Académie Francaise, attempting to legislate for language, and to put it in a strait-jacket as if it were a dead language, would evidently labour in vain, for only dead languages were dead.

By the beginning of the 20th century historians (and one might add philosophers) no less than lexicographers were conscious enough of the polymorphic and anarchic tendencies of language to take nothing for granted. One might choose Hime's poignant cry, after he had endeavoured to elucidate the origins of gunpowder, as marking this stage. Take "for example" he says, "a word W which has always (sic) been the name of a thing, M, (it) is applied to some new thing, N, which has been devised for the same use as M and answers the purpose better. W thus represents M and N for an indefinite time, until M eventually drops into disuse and W comes to mean N and N only. The confusion necessarily arising from the equivocal meaning of W during this indefinite period is entirely due, of course, to neglect...to coin new names for new things. Had a new name been given to N from the first, no difficulty could possibly have ensued, and our way would have been straight and clear (sic). But as matters have fallen out, not only have we to determine whether W means M or N whenever it is used during the transition period, but we have to meet the arguments of those....who insist that because W meant N finally it must have meant N at some byegone time when history and probability alike show that it meant M and M only"[7]. Hime's statement, a certain naivety apart, and although it understates the difficulties by describing a relatively simple hypothetical case, may serve to introduce important work done in the last twenty years, mainly in France, in the field of lexicology.

Lexicologists such as Wexler, Gilbert and Dubois, interested primarily in the resources and generative processes of language, have turned to technology and specifically to the invention of new machines and techniques because such inventions necessarily demand the creation of vocabularies adequate to describe them and thus permit examination of the process of linguistic creation and the stages through which it passes[8]. Such research had, however, to be undertaken with careful consideration of the procedure most likely to reveal the intricacy of the process. The point is well put by Wexler in his study of the formation of railway vocabulary in France. One had to begin not with the words whose success was registered in the dictionaries but with the historical situation itself: "nous nous proposions d'étudier au microscope l'acte de denomination d'un objet nouveau. Il s'agissait, en d'autres termes, de reconstruire tout le procédé si mal resumé dans les dictionnaires par une date d'apparition. Depuis les premières descriptions périphrastiques (qui échappent nécessairement aux dictionnaires) jusqu'à la naturalisation definitive, consacrée par des emplois métaphoriques ou même proverbiaux il est evident que ce procédé comporte plusieurs étapes....En portant non des mots...individuels mais d'une situation nous nous attendions à trouver, et nous avons trouvé en effet, que le terme qu'on finit par adopter n'est que le résultat d'un choix multiple, l'aboutissement d'une période de flottement plus ou moins prolongé"[9]. The point is obvious once it has been stated. The rejected procedure, that is the tracing, for example, of the modern word "chemin de fer" back through the literature will result in the neglect of all those other words which were once its rivals, and will fail to reveal the richness of the creative sources of language. The later works of Gilbert and Dubois, taken with Wexler's, permit one to see the formation of a specific technical vocabulary as falling essentially into three stages. The first of these begins with the emergence of the new technique or machine. The initial need will be for new terms which will sharply distinguish the new machine or activity from those already in existence, for without these communication will be impossible. A lexical inflation takes place, polymorphic and anarchic in character, as words are coined in an attempt to capture the new idea. Stage two may be defined as corresponding to Wexler's "flottement" or "concurrence" and may be more or less prolonged, a state of affairs that in itself calls for analysis and explanation. The final stage involves a lexical deflation and the emergence of a stable vocabulary as knowledge of the technique or machine is diffused and vulgarized. Such a process begins as soon as the new entity passes into general engineering practice and intensifies as it moves from there into the public domain, that is, into the general consciousness of society at large. In other words, it becomes progressively more and more subject to the same processes of minimalisation at work in ordinary language, "la langue commun étant definie comme la minimisation des différences individuelles". The specificity each word once had in a number of private vocabularies is lost since it is impossible for individuals to control the language that will come into employment once the entity is, so to speak, public property. "La fixation du vocabulaire, comme sa deflation, dépend des conditions de la communication, il n'est pas le résultat d'une discipline librement consentie. L'abandon relatif des vocabulaires individuelles est la consequence de la vulgarisation des techniques"[10].

The insights yielded by such studies are undoubtedly of great value although it should be noted that the examples selected for examination fall mainly in the modern period, and, in addition, concerned techniques which took on, almost immediately, an international character. Furthermore, Wexler's study, valuable as it is, remains a special case for it has to do with the linguistic consequences following the importation of a foreign technique into France. Then again the fact that the volume of communication appears to be crucial in the process of deflation seems to suggest that as one moves in search of some 'new' situation further back in time when both the volume of communication was probably significantly weaker, and the chance of some part of it surviving in the form of documents of one sort or another becomes progressively less good, the more difficult will it become to reconstruct the situation obtaining at the moment when a new technique came into existence. The very nature of language itself will tend to obliterate the path along which it has travelled. Having entered these caveats I propose nevertheless to use the insights offered by these studies in discussing the problem of vocabulary in relation to certain machines used in mine pumping in Germany in the 16th and 17th centuries and in particular in attempting to unravel the difficulties surrounding the use of the term Stangenkunst[11].

The publication in Basel in 1556 of Georgius Agricola's posthumous work De Re Metallica is a natural starting point for such an enquiry since book six of his work contains a long and meticulous description of all the water-lifting devices then in use in the mines of Saxony, Bohemia and Hungary. Probably Agricola had begun to collect materials for the work as a whole from as early as 1527 and it seems likely that he had completed its composition by 1550. The dedication is in any case dated 1st December 1550. His description of water-lifting devices, despite his complete eschewal of historical detail, nevertheless reveals clearly enough what historically the main lines of development in their elaboration had been[12]. He describes three kinds of heavy duty machines: the chain of dippers, the rag and chain pump and the water bag hoist. The first, dating from remote antiquity, was, despite the variety of its forms (eloquent testimony of its former usefulness) already virtually a museum piece and was, as Agricola remarks, rarely used by miners[13]. It had fallen into disuse pari passu with the development of the rag and chain pump and water bag hoist as more efficient and less costly alternatives. These had ended up by usurping its place. Probably from 1400 or soon after it was these machines which were used whenever large quantities of water had to be lifted from the mine sumps[14]. The suction pump in Agricola's day was considered suitable only for short lifts of not more than one hundred feet where the volume of water flowing into the sump was small, a fact which has, it seems, been responsible for deflecting the interest of historians away from the task of examining its subsequent development. Just as the rag and chain pump had banished the chain of dippers, so the rapidly developing forms of machines employing suction pumps were to bring about the abandonment of the rag and chain pump in its turn in large-scale operations. This was to take place well before the end of the 16th century, at least within the frontiers of German settlement[15]. As early as 1559 Johann Matthesius was to remark that the rag and chain pump had been laid aside (at least in Joachimsthal) on account of its costliness, "weil nun die heinzen grosser unkost halber abgehen"[16].

The earliest drawing of a rag and chain pump occurs in the Liber Tertius de Ingeneis of Taccola compiled in 1439[17]. It is not known whether or when it was first used in the mines of central Europe but by the time Agricola was writing such machines were capable of lifting water from depths of two hundred and forty feet. This probably represents something like their final stage of development, since Agricola mentions a situation in which three such machines were used in series to drain a shaft some six hundred feet deep[18]. However, it is when one comes to examine the names applied to this machine in Germany that real uncertainty and confusion begin. A recent attempt to sort out matters did not end too well, its author citing one of the best authorities, wrongly as will appear, in contradiction of his own conclusion as to which words in German indicate the rag and chain pump[19]. The fact is that although the machine was in universal use in Germany in the 16th century there was nothing like a stable nomenclature, a difficulty scarcely to be glimpsed in the non-German works dealing with mining and mine pumping. The most frequently used name for the rag and chain pump in Germany - Heinzenkunst - itself poses a problem of etymology since none of the German dictionaries offers to translate Heinzen, the first element of the compound noun. Kunst in the sense of ingenium - machine - is not cited in the literature before 1518 but can be safely taken to have borne such a meaning already in the 15th century. As for Heinz or Heinzen in isolation, only the Grimms offer some guidance. Heinz is frequently found occurring as a name for peasants, labourers and for men generally. In Nuremberg, for instance, workers engaged in supplying the town with water were called Rohrenheinzen, literally pipe men. Matthesius referred in 1559 to "ein geschaufelt Heintzenrad....den man tritt", a man (powered) treadmill with paddles which one trod upon, in order to set pumps in motion. Heinz without Kunst is mentioned as being an animal name applied to draught oxen, rather as neddy in English is applied to horses[20]. The English horse-gin might therefore be regarded as analogous to the heinz (ox)-gin. If, as seems likely, the historical sequence in mine pumping is: chain of dippers - rag and chain - Stangenkunst - steam engine, then one can imagine a notable feature of the first (i.e. human or animal drive) being selected as a name for it and passing across to the second. Possibly also the word Heinzelmännchen, little people, the dwarfs inhabiting mines, may be connected with the name. But did Taschenkunst, literally 'pocket' machine, signify the same thing as Heinzenkunst, or should one understand that word to indicate a Kannenwerke (a pot machine) that is to say, a chain of dippers, what Agricola calls a situla?[21]. Perhaps one should seize gratefully on what Hardanus Hake has to say on the subject when he describes how, in 1535, a certain Michael Teussler set up the first rag and chain pump at the Wildemann mine in the Oberharz. Hake, clearly conscious of the problem of nomenclature, took pains to be perfectly explicit; Teussler, a master-miner, set up the first Heinzenkunst (ox-gin?) or Rohrwerk (pipe-machine) through which Taschen (pockets) move. This was the well-known Paternosterwerk (chain of beads machine or paternoster pump) which also goes by the name of Taschen (pouch) or Puschelkunst (bunch or tuft machine): "...hat zuerst 1535, ein Steiger, Michael Teussler, eine Heinzenkunst, oder ein Rohrwerk, darin Taschen gehen, in die Grube der Wildemann gehanget. Es ist dies das bekannte Paternosterwerk, das auch Taschen oder Puschelkunst gennant wird..."[22]. Hake was writing some time between 1581 and 1583. Krünitz in 1801 was seemingly to add yet another synonym to the list when he talked of the "Paternosterwerke oder Kettenkunst" (chain-machine)[23]. Six names in two short passages, five of them the result of a quite legitimate selection of a salient feature of the machine, would seem enough to warn anyone touching upon the question of nomenclature of the danger of taking anything for granted. At the end of the 17th century indeed a further difficulty appears. In the dictionaries of mining terms which then began to appear, the earliest of them compiled by professional engineers, a distinction is regularly drawn between the Heinz and the Taschenkunst, words which one might otherwise take to be synonymous[24]. It is abundantly clear, however, from the definitions which accompany these terms that although both were what in English would be called rag and chain pumps, they differed greatly in terms of the amount of work each was able to perform. The Heinz was evidently a heavy duty machine and was spoken of as having an iron rope (ein eisern Seil) whereas the Taschenkunst, with only a chain (mit einer Kette) was a more lightly constructed device stated to be capable of lifting water not more than three Lachters, about twenty feet. Now Agricola in the German glossary annexed to De Re Metallica makes no such distinction as this. All such machines, whether water driven and capable of lifting water from two hundred and forty feet or smaller ones worked by hand, are called Heinze. The word rags (pilae) is rendered as Taschen[25]. In the engravings of these machines the rags, even those of the small ones worked by hand, are shown strung out along chains of identical construction[26]. In the Bergbuchlein of 1534, moreover, the glossary at the end of the work makes it quite clear that the word used to describe the chain was "ein eyseren Seyl" and not "Ketten": "Heyntz: ist ein Rorwerck, darinn ein eyseren Seyl mit Taschen, damit man ein gross Wasser hebt, man heysst es eysern Seil, und nit Ketten"[27]. It would appear from all this that the 17th century Taschenkunst was indeed genuinely different from the Heinz and that the difference lay in the fact that it was constucted with a Kette. The word "Kette", chain, would seem therefore to be no such thing but rather to signify rope, a fact which would no doubt account for the Taschenkunst's feeble lift of twenty feet. The word for rope, Seil, having been long before pre-empted as the word for the chain of the Heinz, was not available when a rag and chain pump with an actual rope emerged as a cheap form of the machine. To avoid ambiguity it would seem, therefore, that the word for chain, Kette, had perforce to serve as rope.

Given this distinction, it would certainly appear that by the end of the 17th century Heinz (without kunst) had won out over its rivals in ordinary mining speech. Abraham von Schönberg in 1693[28], Balthasar Rössler in 1700[29], the anonymous Berg-Register in 1704[30], and Johann Hübner in 1712[31] all make the distinction between Heinz- and Taschenkunst. Henning Calvör in 1763, always careful in his use of terms, used the phrase "von der Heinzen-kunst" as his marginal caption when he came to discuss Hake's account of Teussler's work at Wildemann[32]. One might well consider all this as fairly conclusive evidence of a lexical deflation but for the fact that at the end of the 18th century and the beginning of the 19th a number of writers reveal much the same kind of variable nomenclature in describing the machine as had Hake at the end of the 16th. Johann Lempe in 1799 in his description of the machines in book six of Agricola's De Re Metallica entitled his section on the rag and chain pump as "Beschreibung der Büschelkunst oder Heinze". But worse is to follow, for in remarking that such machines were no longer in use in the mines of Saxony he noted that they were also called "Bulgenkünste oder Paternosterwerke", "hat....unser Sachsische Bergbau nicht mehr dergleichen Büschel oder Bulgenkünste oder Paternosterwerke wie sie auch heissen"[33]. Krünitz in 1801 was to speak of the Paternosterwerke oder Kettenkunst"[34] while Beurard in his Dictionnaire Allemand-Français contenant les termes propres à l'exploitation des mines of 1809 renders pompe à chapelet as Heinz, Eimer, Kasten, Paternosterwerk and Taschen[35]. Wexler is at pains to stress in the introduction to his study the importance of a copious documentation if the 'situation' procedure is to be successfully employed and perhaps the documentation in the case of the Heinz would not satisfy his criteria. Unless there are further distinctions to be discovered such as that which has removed the Heinz-Taschen Kunst difficulty it would appear that the period of "flottement" never really came to an end. It is possible, of course, that the process of stabilization or lexical deflation was disturbed by reason of the fact that the Stangenkunst was already displacing the Heinzenkunst as the principal water-lifting engine from as early as the middle of the 16th century. It did not disappear altogether, of course, but, confined to more and more marginal situations, would perhaps escape the pressures making for stability of nomenclature.

It is in fact to the problem of determining the meaning of the word Stangenkunst that I now wish to turn, a word which illustrates no less perfectly than Heinzenkunst the force of Darmesteter's observation concerning the weakness of characterization of virtually all determinants.

A late development in the meaning of the word Kunst in German, as has already been noticed, is one which signifies a static device or a mechanism of some sort, especially a water-driven machine. In 1545 Johann Matthesius of Rochlitz in Meissen was appointed rector of Joachimsthal (slavonice Jachymov) "die Perle des Bergbaues".(the pearl of mining towns). He had spent all his life among mines and miners and he drew freely on this experience in the sermons hè delivered to the miners and their wives at Joachimsthal. Matthesius used the word Kunst in both senses when he spoke to his congregation of a well-constructed adit as easily the noblest technique practised in mining, "ein geraumer...Stoln ist freilich die Schönste Kunst auff dem Bergwerck",and of that fine machine (schöne Kunst) which drew foul air from the workings[36]. As for the word Stangen its original meaning was spear or bar. Stangenholz (bar wood) signifies a young tree of about six to eight inches in diameter in the stem below where it begins to branch out and it is easy to see how the first element of the word was adopted in engineering parlance to signify any spar, bar or beam of about that size[37]. However, if one were to speak now of Stangenkunst it would not be immediately clear, to say the least, what idea the compound noun sought to identify, what such a machine would look like or what its mode of action would be. It is not, of course, my intention to suppose anything so absurd as that the historians and chroniclers of mining of three or four hundred years ago were in this position, still less to suppose that they showed any interest in questions of etymology. To such men it was doubtless as clear as daylight what machines of this sort looked like in their time in the regions with which they were familiar, and few indeed stopped to reflect, as Agricola had done, that the significance of a word might change and cause it in the course of time to present a blank face to the future[38].

The first writer to use the word Stangenkunst was Johann Matthesius in 1551 when he recorded the setting up of the first such machine in the valley in the short chronicle of Joachimsthal. This he published in 1562 as an appendix to his sermons. The language of the entry in the chronicle carries no suggestion that he felt any difficulty with the word[39].

It is of interest here to note the very different reaction to the machine of the anonymous author of a report on the town of Rammelsberg in the Harz and its mines, published in 1565, who had never before seen or heard of such a device as had shortly before been set up there. He had not, it appears, managed to learn its name from the foreigner (Auslander) who had constructed it and could only call it periphrastically a water engine with a crank (Wasser-Kunst mit dem Krummen Zapffen), thus drawing attention to the one feature, the crank, which evidently none of the other water-lifting engines previously in use there possessed[40]. But of the writers of that time or since who have interested themselves in mining history few have also taken pains to examine the problem of machine nomenclature carefully, and doubtless cultural lag, or linguistic inertia, has served to compound such attitudes, if indeed it did not constitute their very basis.

At this point a preliminary statement setting forth the different notions as to what a Stangenkunst actually was, a classic product of linguistic imprecision, will serve to establish the nature of the problem to be resolved.*

Definition(i) The Stangenkunst was a machine consisting of a water wheel placed over or in the shaft and from whose crank (or cranks) hung one (or two) shaft rods. Such reciprocating rods served to actuate columns or tiers of suction pumps placed one above the other reaching from the sump up to the point of discharge. Writers adopting this definition are Hübner (1712), Minerophilus (1730), Frisch (1741) and Calvör (1763). To their number may be added, with some reservations, Matthesius (1562) and Meltzer (1684).

(ii) The Stangenkunst was a machine consisting of a water wheel, placed at some considerable distance from the pumping shaft it served which transmitted power to the vertical

* In order to understand the nature of the problem at the outset it may prove helpful at this point to draw attention to the tabular presentation at the end of this chapter.

shaft rods and pumps by means of a double set of horizontal field rods. A large number of writers, including both primary authorities and modern historians, have adopted this definition, which, as the dates of the more recent authorities noted below indicate, is the one now generally accepted. They are Becher (1682), Leupold (1725), Wolf (1742), Saverien (1753), Poda (1771), Morand (1776), Rinman (1788), Krünitz (1801), Richter (1806), Beurard (1809), Benseler (1853), Scheuchenstuel (1856), Fritzsche and Wagenbreth (1955), Multhauf (1959), Reti (1967) and Wilsdorf and Quellmalz (1971)[42].

(iii) The Stangenkunst was a name to be applied indifferently to a machine whether of the type described in definition (i) or (ii), This is the position adopted by Löhneyss (1617). Löhneyss, however, contradicts himself and at one point takes up a position which would place him with those writers in (ii). It should also be noted that such authorities as Berward (1673), von Schönberg (1693), Rössler (1700), the anonymous (1704), Herttwig (1710), Lehmann (1751), and Lempe (1799) do not use the

> word Stangenkunst at all. Despite this, however, what they have to say does throw considerable light on the problem of nomenclature and will be drawn on later in the course of the discussion[43].

Johann Hübner's admirably clear definitions from his technical dictionary of 1712, the distillation of a long-matured interest in mining affairs, are well suited to set forth the vertical party's views in a brisk and businesslike way. Rod-engines (Stangenkünste), he says, are machines with cranks (Krummen Zapffen) which set in motion the shaft rods (Kunst-Stangen) which work the columns of pumps (ein Satz dem andern zu). They are capable of raising water cheaply from over one hundred Lachter (670 feet), whereas field-rods (Feld-Gestänge) are what their name suggests and reciprocate horizontally. As for the word rods (Gestänge) used on its own, it may signify either rails, such as waggons run on, or field-rods, whether of the single or the double type. He also distinguished between the exposed or visible field-rods and those which enter the mine through an adit and act along its length to the point where they are redirected through 90^{o} into the shaft they are to pump. These were called road, drift or gallery rods (Strecken-Gestänge). Any single horizontal rod machine was called a tugger (Geschleppe). It is interesting to note also that wherever the prime mover is distant from the shaft Hübner consistently talks of its power being transmitted via the field rods to the engine-pumps (Kunst-Zeuge)[44]. Johann Frisch does not enter into as much detail as this but makes the same point: water wheel, crank and vertical shaft rods working pumps constitute a Stangenkunst. If the rods have first to traverse the surface before reaching the engine shaft, then such are called field rods (Feld-Gestänge) which "aquae ductus fodinae ope perticarum per campum"[45].

It is with the work of Henning Calvör, historian and political arithmetician, that discussion begins and one rises from the level of unadorned assertion. He sees clearly that machines evolve and that the modern student must bear this in mind in reading the accounts of the old historians. The technical expressions they use must not be assumed to mean what they mean now. On the question of the Stangenkunst he quickly turns to the evidence of the older writers, and from what they have to say seeks to establish what path the machine's development has taken. He is in no doubt that the machine consists of a water wheel (Kunst Rad) with a crankshaft that is hung over or in the mine-shaft. To the crank are fixed reciprocating rods (Schiebendes Gestänge) which work the pumps (Satze oder Pompen) placed one above the other from sump to run-off point, usually an adit (Stollen). He then draws attention to what is certainly the case, that none of the writers who record the earliest known instances of the setting up of rod-engines has anything at all to say about "a water wheel far removed from the shaft"(ein von der Grube weit entferntes Kunstrad) "with field-rods such as we have nowadays" (als wir jetzo haben). Johann Matthesius in 1562 and Petrus Albinus in 1590 who record the machine erected, or hung as one should say in order to follow German idiom, at Joachimsthal in Bohemia in 1551, Christian Meltzer who wrote of the first one hung at Schneeberg in Saxony in 1554, Hardanus Hake in c.1581 and the anonymous author of the report of 1565, who recounts the story of the building of the first machines at Rammelsberg in 1565, are all silent on this point. But in any case one has the evidence of today to go on, Calvör continues, that then, as now, in the whole region stretching from the Harz to Schneeberg it was still usual for wheels to be 'internal', that is, over or in the shaft (Denn, wie nach dem Zeugniss deren, die vom Harze das Bergwerk zu Schneeberg besehen, jetzo die Kunst inwendig über dem tiefen Stollen ist...)[46]

Calvör points out that the various accounts of the Rammelsberg machine make it clear that the Stangenkunst constructed there was certainly internal to the mine since they mention specifically that it was set up in the deep (in die Tieffe gerichtet) just as they are now (wie itzund) with wheel hanging over wheel (Rad über Rad gehangen)[47]. Calvör does not fail to draw attention to the anonymous reporter's final comment on the machine, for its frank tone of unfeigned admiration is too good to miss: "Nothing could touch it", he says (keine bessere Wasserkunst...als diese). It will be remembered that the Anonymous did not know what to call this wonder. But that it was a Wasser-kunst and one with a crank was clear enough. Calvör concluded, as Löhneyss had before him in 1617, that it was a Stangenkunst. As for the passage which refers to the wheel hanging over wheel, a word of explanation is perhaps necessary. Where the shafts were discontinuous and no one principal shaft existed which might serve as a central drainage and pumping shaft it was necessary to lead spent water from one wheel to another through a pipe, either to another point on that level or to the level below so that it might be set to work again. By the time the spent water issued from the adit (Mundloch), literally mouth hole, it might have run for many miles[48]. It would be to anticipate matters best dealt with later to follow Calvör's discussion further into, for instance, the question of when field rods first came into use. What is important to notice now is that for Calvör (and for most other writers as well, he adds) they are a later development although he cannot do more than pass on the traditional lore of the Harz about when they were first employed in the region, that is, at the beginning of the 17th century at Clausthal.

One comes now to those writers of somewhat uncertain witness, Johann Matthesius and Christian Meltzer. The work of both is interesting by reason, paradoxically, of its very ambiguities. It is, of course, in the work of Matthesius that the earliest known use of the word

Stangenkunst occurs. In 1562 he published his sermons under the title Sarepta oder Bergpostilla, and added to them, as an appendix, the short Joachimsthal chronicle[49]. This summary record begins in 1516 when a wild spot (in sylvis inter deserta ferarum) previously known as Conradsgrün, a patch of meadow in a wilderness much frequented by bears, was renamed Joachimsthal. Although the chronicle itself is an austere document it is not difficult to feel the pride the settlers took in the building up of their town, 'the pearl of minetowns' as Sternberg later called it. Under the year 1551 occurs the simple and, one would have thought, unambiguous statement that "Hat Michel Mittelbach die erste Stangenkunst im Thal auff Sanct Görgen am Arlsberg gehangen"[50]. It is, however, a very notable fact that when one searches Matthesius' sermons, all of them delivered later than 1553, for further information about the Stangenkunst and its builder there is none to be found. This is not because in talking to his flock of heaven and heavenly Bergwerk Matthesius forgets the here and now. Far from it. What is particularly baffling is that where in the twelfth sermon, dated 1559, he chooses to speak at length of the various hydraulic engines (Wasserkünste) and their qualities, the word Stangenkunst does not appear. In summary, what he has to say is this: when it is impossible to clear a mine of water by leading it off through an adit it is then that engines have a valuable role

role to play, whether they are set in motion by men or by wind or water. Where there is a stream flowing on the surface one can easily set up a pump (Zeug) to drive water upwards and thus convey it to castles and high places (auff Schlösser und höhen bringen), and in many places such engines are at work[51]. But where it is a case of underground water that has to be raised then one must lead surface water to the shaft. (Da aber die Wasser unter der Erden sollen übersich bracht werden muss man vom tage Wasser in die Gruben furen). Tage Wasser means literally 'day water'. Altogether this was an impossible statement for Matthesius to make if since 1551 it had been possible to transmit power by means of field rods from a distant source to a mine. Nor was his audience one which could possibly have let such misinformation pass. However, one must let Matthesius continue: For this business mechanics have found out splendid and workmanlike machines, especially those equipped with piston rods and pumps in tiers, worked by men, wind or water that lift water to the surface (literally to 'day') or to the adit. Matthesius then goes on to mention several machines in particular. I will here mention, he says, only the Ehrenfriedersdorf wheel pump (Ehrnfridistorffischen Radpompe) since now the expensive Heinz has been laid aside. Now such a pump can be set up and maintained without great expense. It is cheap and is easily maintained and does not have to pause between deliveries for as long as the water bag hoist, and yet all the same lifts water from a reasonable depth. One such delivered seven Schock of water an hour, that is, 420 buckets each containing nearly one Eimer, when the machine-master recorded its output (about 90 gallons a minute)[52].

Matthesius then mentions that a similar machine, (ein solche Pompekunst) was at work at the Elias mine. Here the work was done by men on a 40-foot treadmill working pumps through gearing and not directly off the crank of the treadmill itself. The crank (krumpe Zapffen oder Korbel) was like that of a grind stone handle (wie ein Schleifstein) and served to lift the heave-arm or bell-crank (Hebarm) which lifted the piston rod. The lower pump delivered water into a chest (Troge) which served as sump for the one above. This double tier of pipes (zwey Rhorberg) worked as a unit[53].

The account concludes with a few remarks on the traction wheel or water bag engine (Kehrrad oder Bulgen-kunst) that was used for bringing up water speedily from great depths (zu schnellen Wassern und grossen Tieffen). At Abertham mine such a machine lifted water from more than 450 feet (über siebentzig Lachter) but was very dangerous on account of the fact that its iron chain alone weighed ten tons (200 Centner). For several years it had been giving so much trouble that many now wished to see it scrapped.

If the Stangenkunst had been known in Joachimsthal since 1551 it has to be admitted it had left little trace. Matthesius' machines are like nothing so much as those described by Agricola only a few years before, an impression powerfully reinforced by gathering from the chronicle all the notices it contains relating to the installation of machines.

1517: the first Gopel (horse-whim) at St. Andrews Mine.

1521: the large stamp (Bochwerk).

1522: the first Heinzenkunst at St. Christina Mine.

1538: the water bag machine (Kehrrad) at Abertham turned on.

1540: a Wasserkunst set up at St. Lorenz Mine at Abertham.

1551: the first Stangenkunst at St. George's mine.

1552: the Abertham engine breaks down.

1554: the Abertham engine breaks down again.

What more need be said? The machine of 1540, whatever kind it was, could hardly have been a Stangenkunst, yet the Stangenkunst of 1551 had disappeared by the time of the 12th sermon unless we are to discover it under another name at Elias. But the Elias machine was just like the Ehrenfriedersdorf wheel pump according to Matthesius, which is of course none other than the <u>sipho septimus</u> of the <u>De Re Metallica</u> of 1556. <u>Sipho septimus</u>, Agricola's seventh variety of suction pump engine, consisted of a water wheel with a crank working three suction pumps in series. A short length of shaft rod attached to the crank lifted a bell-crank lever the free end of which was connected to the middle of a curved rod like an inverted U. One end of the inverted U-shaped rod joined to the pump rod of the topmost suction pump, while to the other was fixed another short length of shaft rod which lifted the second bell-crank lever. This lever lifted a second curved rod and its attachments, and so on down to the third pump. The third, bottom, pump sucked water from the sump and delivered it into a chest in which the second pump stood. This in turn exhausted the water it lifted into the chest from whence it was drawn by the topmost pump exhausting to the adit. When one reads in the German translation of Agricola's De Re Metallica the account of this machine the elements on which the eye falls and upon which, necessarily, so much emphasis must rest are Pompen and Stangen. It is, of course, a Kunst and one which has a round crank (ein rondtgekrumpt Eisen) on the end of its axle (Zapffen)[54]. But what was it to be called? Or better still, what was it to be called if the cumbersome name of a Saxon tin mine (Ehrenfriedersdorf) failed to catch on? Only Agricola (in 1556) and Matthesius (in 1559 and 1562) were ever to use it, the latter doubtless taking over the name given to it by his old friend Dr. Agricola.

In the light of these questions it is entirely appropriate that the work of 1684 of Christian Meltzer von Wolckenstein, historian of Schneeberg, should next be searched for hints as to what may have happened terminologically[55]. Meltzer is not an easy writer, being much given to Ciceronian periods, but the approach to the rhetorical climax of the passage in which he eulogizes the Stangenkunst is really quite impressive. Machines of steadily mounting power are one by one mentioned - and dismissed - until finally the machine par excellence makes its appearance as the final stage of a carefully planned climax. Wretchedly enough, however, when the moment of apotheosis comes Meltzer cannot make up his mind about what the correct name of the thing really is. At the very moment that the marginal gloss announces the Pompen und Stangen-kunst (pump and rod engine) the text prefers to hedge its bets with Pompen oder Stangen-kunst (pump or rod engine). Nor is this all, for on the very next page, with what might be regarded as a taste for a peculiarly wilful sort of symmetry, the names change place so that the marginal gloss of page 100 becomes the name in the text on page 101 and vice versa. But Meltzer's very uncertainty is enlightening. In his day the developed form of the machine with field rods, in some cases by then working lines of rods of up to three miles in length, had been in existence for eighty years, perhaps even longer[56]. It was ultimately to usurp the name Stangenkunst, as I hope to show, and Calvör is, as far as I know, one of the very last writers to insist on restricting the name to the older form of the machine (the over the shaft variety). Is it any wonder then to find Meltzer wavering? He knows, of course, that the machine he is describing, like all those set up at Schneeberg by Bernard Wiedemann in 1554, was not and could not possibly have been of the horizontal or field-rod variety for it hung in the Catherina Neufang shaft and had only vertical shaft rods. It, or rather the latest in the series of replacements, was still there indeed (Also hanget doch biss dato). The machine was, indubitably, a Stangenkunst, and the Schneeberg chronicle did indeed speak of all such as"Pumpen und Stangenkünste". But were he to use the chronicler's terminology himself his readers might take him to mean a field-rod machine, for by Meltzer's time it seems probable that that was how most men, except for the purists, used the word. An emphasis on Pompen at the expense of Stangen in one place while at the same time establishing the terms as synonymous in another obviated this difficulty and plainly left little doubt about what sort of machine it was that was being discussed. All of which marks Meltzer, if this interpretation is correct, as a careful writer, even if rather Canute-like in his efforts to stem the tide of popular usage. At the same time Meltzer's term cannot but remind one of Matthesius' Pompekunst and the possibility of equating it with his own Pompen (oder Stangen) Kunst[57].

One must turn now to examine the position of those writers adopting definition (ii), that is, those who hold that the Stangenkunst is always and only a machine delivering mechanical energy over a distance by means of field-rods. The earliest statement of such a view seems to be that contained in the six pages Joachim

Becher devoted to the machine in a posthumously published work, the Närrische Weissheit und Weise Narrheit of 1682[58].

The rod engine (Stangenkunst) is so called, he says, because it is made up of bars (Stangen) by means of which one is enabled to work pumps at a great distance. The machine was first invented and put to use in the Hungarian mines, in central Slovakia, in a situation where a small stream was a good German mile from the mine (allwo ein kleiner Fluss ist eine starcke teutsche Stunde von dem Bergwerck). This is Becher's opening statement and might well be taken as a classic statement of the heroic view of invention. But what heroism: "A great water wheel was built on the stream one hundred feet in diameter with a crank at its centre to which the first of the horizontal rods was joined.....But this work had perished at the hands of the famous rebel Father Johlina"[59].

Johann Beckmann long ago remarked that Becher's failing was a certain over-confidence and yet his words are not to be too readily discounted. Given the difficult circumstances in which the book is said to have been written, and characteristically it was a situation a little larger than life, one would not expect perfect accuracy and yet it is difficult to prove him wrong or to catch him in a mistake[60]. To reduce matters to essentials Becher is saying that the machine was invented in Slovakia, that large works famous throughout Europe were based on it and that he himself had recently found a way of reconnecting the circular motion of the water wheel back into a rotary motion at the end of the transmission line. With few of these statements is it possible to quarrel seriously[61]. He was, however, manifestly mistaken in thinking that the machine could possibly have begun life with mile-long horizontal rods (at least in mine pumping work) although, length apart, it must be said that in so thinking he is in a numerous company, as will now appear.

Jacob Leupold's description of the Stangenkunst, which has as its title "Von Stangen-Kunst oder Feld-Gestänge" (On the rod, or field-rod, engine) declares his position immediately[62]. He is, however, hardly an independent witness for his opening sentences are little more than a montage made up from the more readily accessible works on the subject, a method entirely reasonable given the encyclopaedic nature of his undertaking. He is, however, uncritical and unbalanced in his presentation. He relies heavily for his general remarks on Becher's passage mentioned above but he also throws in a good deal of what seems a rather dilettantish 'cabinet' or armchair technology as well: the Marly machine looms large and further distorts the picture. It is precisely the presence of this sort of material that begins to raise doubts in one's mind about how far he was in touch with the reality of the mines. An example touching this very point is presented as it happens by his principal illustration of rod-engines[63]. This shows a landscape across which run various sorts of field rods. It is not an original piece of work but is a composite figure made up, without acknowledgment, from two earlier figures of very different date. The top of the picture (fig. 1) is from Löhneyss' plate no. 11 (of 1617), the bottom (figs. 2 - 5) is from Rössler's plate no. 13 (of 1700). But is is not for plagiarism, a mere peccadillo after all, that Leupold is to be criticised. What is seriously wrong is that he saw apparently no incongruity in juxtaposing the field-rod technique of the early 17th century with that of nearly a century later despite the fact that during those years rod techniques had changed out of all recognition. This much leaps to the informed eye immediately and was obvious to Calvör. Leupold, he says, seems to suggest that the machines of today are still made like this (....das die Künste hier jetzo noch also beschaffen sein) but that was a grievous error (darin er sich aber sehr geirret)[64]. However acute a critic Leupold may be in other respects, as is seen for instance in his skill in taxonomy and in tracing the genealogies and metamorphoses of mechanical conceptions, such errors make him a dangerous guide to follow as far as practice is concerned. This is why, by contrast, Becher's obiter dicta are so valuable, for whatever one may think of his swagger he was a successful engineer whose career led him to travel widely through Europe. His reflections, and especially a divertimento like the Närrische Weissheit, could hardly fail to contain a number of observations, recollections, and sometimes most illuminating comparisons as between continental and English practices and technique, from Vienna to the Lothians, such as are scarcely to be found elsewhere. But what of Leupold's synonym for Stangenkunst: Feld-Gestänge, a word, it may be noted, that was eventually to drive Stangenkunst almost completely from the field? There seems little reason to doubt that Leupold was merely reflecting current usage and that Feld-Gestänge was already solidly established by 1725. In 1716, nine years before the appearance of Leupold's Theatrum Machinarum Hydraulicarum, Christian Wolf, virtually Leupold's patron, published his Völlstandiges Mathematisches Lexicon. I have not been able to examine the first edition of the work, but that of 1742, p.490, contains the entry Feld-Gestänge and a definition which begins "ist eine Stangen-Kunst". This is what I suspect is to be found in the first edition, which definition Leupold may well have followed. Certainly Saverien in 1752 and Morand in 1776 were later to rely on Wolf[65].

Johann Krünitz, whose enormous technical encyclopaedia had by 1801 reached its fifty-fifth volume (up to the letter K) discloses, under the words Kunst-Gezeug, Kunst-Zeug, the lexical exuberance of late 18th century technical usage surrounding the rod-engine (the date of publication of the volume in question is 1801)[66]. Kunst-Gezeug, Kunst-Zeug, both of which terms may be translated as machine-pump, are, he says, generic terms for all manner of pumping engines of which the Wasser-Feld oder Stangenkunst (water-field or rod engine) is but one kind. However, the names Kunst-Gezeug or Kunst-Zeug or even just Kunst or Satz or Kunst-Satz were also in particular applied to that machine which lifted water from mines and was composed essentially of a motor wheel, piston rods, pistons and piston barrels and rising pipes. As for the long rods which were connected to the Kunst-Gezeug, whether they hung in the shaft or reciprocated in the field (entweder in die Grube oder in das Feld schieben) they were called engine-rods (Kunst-Stangen), or push rods (Zug Stangen) or engine bars (Kunst Gestänge). Krünitz was not concerned, of course with the historical derivation of these terms but was merely reflecting contemporary technical usage which on this showing would appear to have been in an extraordinarily fluid state. But fluidity, or better, polymorphism, should not be equated with ambiguity, and at a later stage in the discussion I shall show that virtually all of Krünitz' terms(with the exception of Wasser-Feldkunst) were coeval with the earliest form of rod engine, that is, the over-the-shaft machine, and may as a consequence all be traced back in largely unaltered form to the middle years of the 16th century.

Like Krünitz, Richter and Beurard, in their technical dictionaries of 1806 and 1809 respectively, reflect contemporary usage so that it is no surprise to find Richter directing users of this dictionary looking up the word Stangenkunst to refer to Feld-Gestänge, evidently the more commonly employed of these two synonymous terms[67]. Beurard defines both terms: Stangenkunst as "machine hydraulique à tirans" and Feld-Gestänge, more logically but in defiance of idiom, as "tirans d'une machine hydraulique qui portent....le mouvement qu'ils ont reçu...pour le transmettre où il est nécessaire"[68]. Benseler, the historian of Freiberg and its mines, equates Feld-Gestänge with Stangenkunst. Not surprisingly, he finds that such machines have been in use in Freiberg only since 1747 when the first one was built from Krumm-hennersdorf to the principal adit of the Elias mine. It had forty-two feet of turning points (Wendesdocke) and 2,800 feet of field rods[69].

It remains now only to examine the position of the modern members of the 'horizontal' school. They form in fact quite a large group, for Fritzsche and Wagenbreth (1955), Multhauf (1959), Reti (1967) and Wilsdorf and Quellmalz (1971) have all touched on the problem of rod-engine nomenclature[70]. Unfortunately, a common error which all commit not only vitiates their work but reveals rather blatantly its superficiality and highly derivative character. Lest this should be thought rather a harsh judgment it is worth considering the case of a curious double confusion into which Henning

Calvör fell in 1763 and the extraordinarily long-term mischief it has caused. It has already been suggested, in note 50, how Calvör went wrong. He evidently misread the date (1551) of the entry in the Joachimsthal chronicle, relating to the setting up by Mittelbach of the first Stangenkunst in the valley, as 1550, and then, it would seem, connected 1550 with the form of words used by Petrus Albinus in his Meissnische Bergk Chronica of 1590. Albinus' statement, "Im 1551 hat man die erste Stangenkunst gehengt" (the first Stangenkunst was set up in 1551) does indeed suggest, if one takes Albinus to be an independent witness as Calvör did, that the machine was invented in Joachimsthal in that year. Calvör evidently thought that Albinus possessed information unknown to the chronicler of Joachimsthal who made no such claim for priority and had in any case quoted a different date! However, the fact is that Albinus, who says he took all his information from Agricola's Bermannus and from Matthesius, that is, from the latter's sermons and the chronicle printed with them, is plainly not an independent witness, and was doing little more than rephrasing Matthesius' information and setting down the date correctly as 1551. This date Calvör also quoted thinking his two authorities to be in disagreement. Calvör therefore ended up with two dates instead of one. It explains also the origin both of his marginal caption "Von Einführung der Stangenkünste", on the introduction of rod-engines, and his claim in the text that "Die

Stangenkünste....sind Anno 1550 im Joachimsthal erfunden worden" (rod-engines were invented in 1550 in Joachimsthal). Since then, for the best part of two hundred years every historian who has had occasion to comment on the question of when the Stangenkunst was introduced, has neglected to consult the authorities independently of Calvör and has faithfully repeated the latter's double error. Of all the modern authors cited above only Wilsdorf and Quellmalz half extricate themselves and avoid any reference to 1550. They retain 1551, however, as the date of invention. But what is worse is that they all, without exception, regularly neglect to take account of Calvör's careful analysis in which he is at pains, as has been seen, to distinguish between what idea it was likely that the word Stangenkunst was intended to indicate in the beginning and what it had come to indicate in his own time, that is, a machine with field rods. A particularly glaring example of such neglect may be found in Wilsdorf's and Quellmalz's work which renders the entry in the Joachimsthal chronicle for 1551 as "Erfindung des Feldgestänges" (the invention of field-rod engines)[71]. The situation is finally not without a certain irony since Calvör, the 1550 error apart, was a careful writer and acute critic and is consequently a really valuable source for anyone wishing to understand the course of the Stangenkunst's development.

One must now turn to definition (iii) and to

Georg Löhneyss, the only writer who seemingly subscribes to it. His attempt to define the nature of the Stangenkunst, taken as a whole, cannot be said to be attended with any great success although the very nature of his failure is in itself highly instructive. His report on mining, the Bericht vom Bergwerk of 1617, was long ago exposed as a particularly audacious piece of plagiarism but that would hardly matter (since it is known whom he plundered) if only sharp wits had gone with sharp practice[72]. This unfortunately was not the case for he was either a very muddled or a very careless writer. Even so, the confusion over nomenclature that, as I have suggested, caused Meltzer trouble in 1684 may also have been responsible in some degree for Löhneyss' self-contradictions in 1617. Löhneyss twice refers to the machine as the "Stangenkunst mit den krummen Zapffen" (rod engine with crank) but evidently thought that from the very first it had, or could have had depending on need, field rods as well as shaft rods. Calvör objected strongly to this for it seemed to him a gratuitous and unhistorical assumption to make, and in any case suspect since Löhneyss was alone in making it[73]. Even without Calvör's warnings, however, it soon becomes clear that Löhneyss is not the most reliable of guides. In his chapter on the Stangenkunst he describes the vertical shaft rod type plainly enough and yet when one turns to the engravings which illustrate the two varieties of the machine then in existence, the over-the-shaft type working vertical rods, and the machine acting at a distance through intermediate field rods, one finds that Löhneyss restricts the term Stangenkunst to the latter. For the other he has no general name at all and contents himself with labelling the parts of which it is composed[74]. However, this cannot reflect his real position either since a large part of the chapter mentioned above is actually taken from the anonymous report of 1565 on Rammelsberg and its mines, that is, the section of it which is devoted to the marvellous feat of Matthias Eschenbach of Misnia, Meissen in Saxony, in setting up the first water engine with crank (Wasserkunst mit den krummen Zapffen) in the Rammelsberg mine. Löhneyss unhesitatingly took this to be a Stangenkunst although the word itself is nowhere used in the report, and the description itself emphasizing how Eschenbach placed wheel over wheel (Rad über Rad) in the shaft clearly indicates that the ensemble cannot have had, or needed, field rods. But what, given these three contending definitions or opinions, is one finally to conclude? The answer to such a question, taking the matter step by step, appears to be as follows:

(i) Rod-engines (Stangenkünste) had only vertical rods at the time, about 1540, when the first prototypes made their appearance. It was necessary to name them. A lexical inflation took place and a number of neologisms were soon in use: Stangenkunst (1551), Pumpen und Stangenkunst (1554), Ehrenfriedersdorf Radpompe (1556), Pompekunst (1559) and Wasserkunst mit den krummen Zapffen (1565), all of which have already been discussed. But besides these there were at least two other terms also in use in the 1560s to signify the ensemble of wheel and pumps: Zeug und Kunst and Zeuge. Both occur and are used interchangeably in a report delivered in 1570 to a commission empowered by August, elector of Saxony, to look into the condition of the Freiberg mines. The report was the work of Martin Planer, Bergverwalter (chief engineer) of the Freiberg mines, who had set about scrapping the old water bag hoists (Bulgen-Künste) and equipping the mine with the new machines in the fourth quarter of 1557. By 1570 he had built thirty-eight of them. Planer was content to call his machines collectively Kunsten und Zeugen or simply Zeuge. When he referred to a single machine he called it a Zeuge und Kunst, a term little different from Krünitz' Kunst-Zeug of 1801[75]. The meaning of Kunst in Zeuge und Kunst is clear enough and has already been commented on but what did Planer mean by Zeuge? Like Gezeug, of which it is an abbreviated form, Zeug is a collective noun indicating gear, equipment in general. The meaning of Planer's term might therefore be periphrastically expressed as "the equipment pertaining to and driven by a water wheel", that is, machine pumps.

All the elements from which the neologisms of 1551-1570 were coined - Stangen, Kunst, Pumpen, Pompe, Rad, Zeug, Zapffen - had, of course, long been in common use when the appearance of the new machine began to draw them into new combinations with new significances[76].

(ii) While this was taking place a further complication arose in matters of nomenclature as the original machine began to be developed further. Engineers unable to lead water directly to the pumping shaft but wishing to avoid the heavy expense of man-powered or horse-driven machines looked for ways of bridging such inconvenient gaps. A period of experimentation began, probably as early as the 1560s. The crank of a water wheel situated some way off from the shaft was equipped with horizontal field rods. The rod line led to the eye of the shaft, or along an adit, where it was joined to the vertical rods in the shaft. Once water was turned onto the wheel, horizontal and vertical rods reciprocated together and so permitted the energy of the wheel to work the distant pumps. There were now two kinds of rod-engines: those with and those without field rods, and this new situation could not but disturb the terminological status quo. Could one word properly be applied to both? One has seen Löhneyss' reaction to the problem and it is full of interest. When it came to pictures he evaded the issue and gave the machine without field rods no name at all, or so it might appear. He did, however, name its parts. The water wheel was "der Kunstradt", the column of pumps "die Satz". One must refer again to Krünitz and recall that among his many terms for the machine without field rods one finds both Kunst-Satz and Satz. In the light of all this it seems at least possible that one or other of these terms or perhaps both of them may have found a place among the neologisms existing before the field-rod machine was invented. However this may be, after Löhneyss' time the word Satz was regularly used as a term denoting the column of pumps worked by a water wheel over the shaft. Berward, for instance, in 1673, in the earliest of the technical dictionaries, talks of the "Satz an der Kunst" and is followed in this by virtually all his successors[77]. Although this is not quite the same thing as calling the machine a Satz or a Kunst-Satz, these words were, so to speak, always waiting in the wings for the call to come. What is not clear is for how long a time they had been in use before they were cited by Krünitz in 1801. On the evidence available for the period 1693-1710 it is clear that for those writers such as von Schönberg (in 1693), Rössler (in 1700) and Herttwig (in 1710), who avoided the use of the term Stangenkunst in any sense, the preferred terms for the over-the-shaft machine were Kunst and Zeug, used synonymously[78]. In summary, then, one may say that by Löhneyss' time the domain of the word Stangenkunst had begun to shrink: it was beginning to be confined as a term to denoting the machine with field rods. The fact that Becher (in 1682), Leupold (in 1725), Krünitz (in 1801), Richter (in 1806) and Beurard (in 1809) were to use the word in this way is some evidence of its long-term stability. It was not, however, the only word in use to denote the field rod machine, for a number of writers use instead the term field-machine (Feld-Kunst), as for instance Berward (in 1673), von

Schönberg (in 1693), Rössler (in 1700), the anonymous (in 1704), Hübner (in 1712) and Calvör (in 1763)[79]. From 1673 then, if not before, Stangenkunst was in competition with Feldkunst and seems even to have been the less frequently used of the two terms. Despite this it might well appear that the graphic quality of the word Stangenkunst, evoking an image of the highly visible engine bars of the field-rod machine, constituted some guarantee of its ability to hold its ground against the competing word Feldkunst. In the event, however, it was Feldkunst that was to drop out of use, or rather to change its meaning, a process that was certainly underway in the 1770s. But Stangenkunst was not to be left in splendid isolation for pari passu with the fading away of Feldkunst in its old sense a new name for the field-rod machine began to emerge.

(iii) The new word was Feldgestänge, a term that had long been in use but usually with a very much more restricted meaning than the one it now began to acquire. At first it had meant simply field-rods and may possibly have come into existence almost as soon as the rods themselves. Feldgestänge plainly had a much more specific reference than Kunst-Stangen which meant engine rods in general, that is, both vertical and horizontal rods. Neither term occurs in the literature before 1673. The sequence of events which resulted in Feldgestänge acquiring the meaning of field-rod engine and Feldkunst losing this specific connotation is obscure, although the two were in competition from the 1720s. By 1781, however, both changes were an accomplished fact as the first volume of Jacobson's Technologisches Wörterbuch which appeared in that year makes clear. Feldkünste, field machines, are defined as: all those machines concerned with lifting water from mines amongst which one includes hand pumps, horse-driven pumps, rag and chain pumps, field rod engines and so on (Feldkünste, alle maschinen oder Kunstwerke, wodurch das Wasser aus den Gruben geschafft wird. Hierzu gehoren die Handpumpen, die Rosskünste, die Paternosterwerke oder Kettenkünste, die Feldgestänge, u.s.w.). Elsewhere the definition of Feldgestänge carries the whole weight of information that before this time would have been found under either Stangenkunst or Feldkunst[80]. By the time that Richter published his dictionary in 1806 the weakening of Stangenkunst in the face of Feldgestänge is even more plainly visible: the reader seeking a definition of Stangenkunst is referred to Feldgestänge[81]. The progress of the word after this was evidently rapid, and in modern German works the usurpation is complete. Synecdoche had done its worst.

TABLE I. Chronological list of citations.

Machine	Name	Citation dates
Rod-engine without field rods	(i) Stangenkunst	1551, 1590, 1617, 1684, 1712, 1730, 1741, 1763, 1859.
	(ii) Ehrenfriedersdorf Radpompe	1556, 1559, 1562.
	(iii) Pompe(n)kunst	1559, 1562, 1684.
	(iv) Kunst-Gezeug, Kunst-Zeug, Gezeug, Zeug.	1559, 1562, 1570, 1693, 1700, 1704, 1710, 1712, 1751, 1782, 1799, 1809, 1859.
	(v) Wasserkunst mit dem krummen Zapffen	1565.
	(vi) Pumpen und Stangenkunst	1554.
Machine with field rods	(A) Stangenkunst	1617, 1682, 1725, 1742, 1753, 1771, 1776, 1784, 1789, 1801, 1806, 1809, 1853, 1856.
	(B) Feldkunst	1673, 1693, 1700, 1704, 1710, 1730, 1763, 1771, 1801*.
	(C) Feldgestänge	1725, 1742, 1753, 1776, 1781, 1789, 1806, 1856.

*1801: Wasserfeldkunst.

TABLE II. Time range of citations.

	1550	1600	1650	1700	1750	1800	1850
(i) Stangenkunst	• •	•	•	• • •	•		•
(ii) Ehrenfrieders-dorf Radpompe	•••						
(iii) Pompe(n)kunst	••		•				
(iv) Kunst-Gezeug, Kunst-Zeug, Gezeug, Zeug	•• •		•	••••	• • •	•	•
(v) Wasserkunst mit dem krummen Zapffen	•						
(vi) Pumpen und Stangenkunst	•						
		1600	1650	1700	1750	1800	1850
(A) Stangenkunst		•	•	• •	• •• ••	•••	••
(B) Feldkunst			• •	••• •	• •	•	
(C) Feldgestänge				• •	• •••	•	•

NOTES

1. J. Locke, An Essay Concerning Human Understanding (Everyman edition), Vol. 2, London 1964, Ch.2., p.13. The essay was first published in 1690.

2. Ibid, Ch.9, p.76.

3. An interest in inventions in general and new machines in particular goes back much further than this of course and forms a notable part of Western European consciousness from the 16th century onwards. In Germany the rapid development of mining and machine building from the end of the 15th century provided a particularly propitious milieu for the growth of a technical literature quite without parallel in the rest of Europe. Its luxuriant abundance in the 18th century is simply staggering.

4. (i) H. Calvör, Acta Historico-Chronologico-Mechanica circa Metallurgiam in Hercynia superiore oder Historische-Chronologische Nachricht und theoretische und practische Beschreibung des Maschinen...wesens... auf dem Oberharze, Brunswick 1763.

(ii) J.G. Beckmann, Beiträge zur Geschichte der Erfindungen, Leipzig, 4 vols., 1782-1805.

5. A. Darmesteter, The Life of Words as the Symbols of Ideas, London 1886. The quotations from Darmesteter's work in the order in which they appear in this chapter are to be found on pp.45, 67 and 69. His remark, on p.109, that in language "the people is all powerful and...infallible because its errors

sooner or later make the law" is really the leit-motif of this entire chapter.

6. M. Bréal, <u>Semantics: Studies in the Science of Meaning</u>, London 1900, introduction LIV. Bréal's remark that "progress in language is never uniform and the caprice of a literary record may happen to show one and the same date for a usage which was fresh from the mintage of the moment and for one which is the last remnant of a forgotten and unintelligible past" is worth bearing in mind. Again it is highly probable that many instances of conflicts of definition arose by reason of the different milieus in which writers were working. A historian's use of technical terms is likely to differ in some degree at least from that of a professional engineer since he will be further from the springs of invention constantly re-shaping the language of the work place, and will in any case be likely by temperament and training to refer instead to the printed literature for his definitions, despite the fact that the tide of usage may have ebbed or flowed considerably in the meantime. An engineer, by contrast, could not but be aware of the usage current among the workmen, and if he were then to compile a technical dictionary it is obvious which way he would have to go. Antiquarianism was for the scholars. And this is to say nothing of regional differences in

nomenclature. J.J. Ferber, Physikalische-Metallurgische Abhandlungen über die Gebirge und Bergwerke in Ungarn, Berlin and Stettin 1780, p.69, remarks that the vocabulary in use in the Slovakian mines was quite different from that of Saxony, "bedient man sich vieler anderer Redensarten und Benennungen, als in Sachsen....". The most interesting of his instances has to do with the name for a horizontal gallery leading off a shaft. In Saxony this was called a Querschlag (cross-cutting) but in Hungary, a Kreuzgestänge - literally a place where an engine cross (Kreuz) redirected the motion of the reciprocating rods (Gestänge) in the gallery down the shaft to where the pumping was to be done. But all galleries were called Kreuzgestänge whether they had a machine working along them or not.

7. H.W.L. Hime, Gunpowder and ammunition, London 1904, p.8. Notwithstanding Hime's strictures on men's lack of inventiveness in finding new names for new things, many notable instances of invention spring to mind and throw considerable light on the whole question of how machines and techniques come to be named. Montaigne might complain (in his Journal of a Voyage, 1580-1) about the lack of clocks in Italy without ever indicating whether he meant the mechanical or non-mechanical variety but he was plainly the victim of 'horloge'. A German with the

distinguishing term Raduhr (wheel hour) available, would not have been in any difficulty. At times attention seems to be fixed on the function of a device rather than its form, as in trier, éprouvette and pulverprobe, all names for devices for measuring the potency of gunpowder. Doubtless such abstraction had much to do with the learned and professional milieus in which such devices were elaborated and it is more often the case that concrete considerations are given weight, so that typically a name arises from the simple process of picking out a feature that sets the new thing distinctively apart from the old. The German names for a device for speeding up the evaporation of brine preparatory to boiling illustrate both possibilities: the people's names, 'Strohkunst' (straw machine) and 'Leckwerk' (leak work), as against the cabinet coinage, 'Luftgradierhaus' (air graduation house) and its French equivalent, 'bâtiment de graduation'. The powerful force of analogy is often apparent: 'Pulverwurst' (powder sausage), a pungent term for the charge of gunpowder used in rock blasting in mines in Saxony. A particularly good example of this kind of inventiveness is the German term for cross-head guide: 'Joch der Kolbenstange' (yoke of the piston-rod). Onomatopoeic processes play a part also, as such names as clack-valve, snorehole, snifting valve, pump (plump) and petard, reveal.

8. P.J. Wexler, La Formation du Vocabulaire des Chemins de Fer en France 1778-1842, Société de publications Romanes et Françaises, Vol. XLVIII, Geneva and Lille 1955.

9. P.J. Wexler, op. cit., pp.7-9. The term chemin de fer, despite its illogicality, eventually vanquished its rivals. The objection, repeatedly urged, that it was unsuitable because it suggested the idea of a total sheeting or paving of iron, made no difference. Before ever the first metal rails were laid down at Indret on Loire by William Wilkinson in 1778 the term 'chemins ferrée was in use for metalled roads.

10. J. Dubois, op. cit., pp.107-8. The whole of Dubois's article, despite its technical obscurity, is worth careful study.

11. It ought to be said here that this pumping machine was the sine qua non for the intensive development of deep mining in Europe. Before it became available it was a matter of extreme difficulty and great expense to lift water from deep workings driven far below adit, the level of free drainage. The maximum lift was about 400 feet. Even before the end of the 16th century rod-engines (Stangenkünste) were able to lift water cheaply from something like double this depth.

12. The glossary annexed to Ulrich Rulein von Calw's Ein Wolgeordent und Nützlich Büchlein/wie man

Bergwerck suchen und finden sol/....mit anhangenden Bercknamen den aufahenden Bergleuten vast dienstlich, Worms 1518, and reprinted in 1534 in Augsburg, brief though it is, provides valuable information about the water raising devices in use in the period immediately before Agricola began work. Three devices are named and defined, two of which were heavy duty machines. Of these two the first in importance was the 'Kunst', the machine par excellence. The Kunst was a waterbag hoist driven by a'Kehrrad' or double-bladed reversible water wheel: "Kunst ist damit man ein gross Wasser hebet, treibt ein Wasser das ander, die brauchet man auff Bergkwergen, die man tieff absencket, und seer Wasser notig sind" (the bag hoist is the means whereby great quantities of water are lifted, one water driving another, which one sets up in mines which, sunk deep, are greatly encumbered with water). Next in importance was the 'Heinz', the rag and chain pump: "Heyntz ist ein Rorwerck, darinn ein eyseren seil mit Taschen, damit man ein gross Wasser hebt, man heysst es eysern seil, und nit Ketten" (the rag and chain pump has a pipe through which an iron rope with balls passes, whereby one lifts large amounts of water.. It is called an iron rope and not a chain). Lastly, for small lifts the pump was available: "Pumpen ist ein Rore, darein ist ein strudel gemacht, die legt man inn einer sumpff, da zeucht ein knab ein zimlich Wasser, 2 oder 3 Lachter" (a pump is a pipe in which a valve is placed which one stands in a sump from which a labourer sucks up a tolerable quantity of water from 2 or 3 Lachter (thirteen to twenty feet). A.G. Sisco and C.S. Smith, Bergwerk and Probierbüchlein, New York 1949, unaccountably omit von Calw's glossary in their translation of the 1518 edition of his work. I have taken the passages quoted from it here from J.F. Lempe, Magazin für die Bergbaukunde, Vol.9, Dresden 1792, where the edition of 1534 is to be found reprinted in full: Kunst, p.53, Heyntz p.52, Pumpen, p.53.

13. G. Agricola, De re Metallica, trans. H. Hoover, London 1912, p.175.

14. Ibid, p.176. It may be of some interest to note in this connection that in 1437 Erhard Hann of Zabern, gun-founder of Salzberg, made a proposal to the proprietors of the salt works at Bad Reichenhall in Bavaria, that he should build a rag and chain pump to lift the brine from the springs at that place. Since, however, he was required by his contract to bear all the costs should it fail to work, one might conclude that such machines were then still something of a novelty (at least outside mining milieus).

15. For a detailed study of the diffusion of these machines (Stangenkünste) see chapter three, pp. 165-185.

16. J. Matthesius, Sarepta, ...sampt der Joachimsthalischen Kurtzen Chronicken, Nuremberg 1562, p.145.

17. Mariano di Jacopo detto il Taccola, Liber Tertius de Ingeneis..., ed. J.H. Beck, Milan 1969, f.4v.

18. G. Agricola, op. cit., p.194. This was at Windschacht, about one mile from Schemnitz (central Slovakia).

19. R.P. Multhauf, 'Mine Pumping in Agricola's Time and Later', Bulletin 218, Contributions from the Museum of History and Technology, Washington 1959, p.116, note 9. Multhauf observes, incorrectly, that "Calvör and others, however, seem to use Taschenkunst for the ordinary chain of dippers which seems better suited to its literal meaning". Perhaps, but I have yet to find a single German writer who uses the word Taschenkunst for anything except the rag and chain pump. The chain of dippers, Agricola's situla, finds a place only in Agricola's work, seemingly a curious instance of antiquarianism on his part.

2o. (i) J.L.C. and W.C. Grimm, Deutsches Wörterbuch, Vol. 4, pt.2, Leipzig 1877, p.890.

(ii) J. Matthesius, op. cit., p.145b.

21. See note 19 above.

22. Quoted by H. Calvör, op. cit., p.35. Multhauf

missed this passage but is right, I think, to suggest that the idea of dippers is better suited to the literal meaning of Taschen (pockets, pouches). It seems likely that the word passed across from the older machine, a notion supported by the fact that other synonyms for the Heinz, Eimerkunst (bucket machine) Kastenkunst (box machine) and Bulgenkunst (bag machine) seem no less awkward as shorthand descriptions of the rag and chain pump. Both dippers and rags were strung out along the chain like beads and would not look altogether unlike, a reason, perhaps, for emphasizing the pipe work (Rohrwerk) which was a new and distinctive element of the Heinz.

23. J.G. Krünitz, Oekonomische-Technologische-Encyclopädie, Vol. 55, Berlin 1801, p.299.

24. A. von Schönberg, Ausführliche Berg-Information, zu dienlichen nachricht vor alle die beydem Berg-und Schmelzwesen zu schaffen....Mit einen vollkommenen register und anhang aller beym Berg und Schmelzwerck gebrauchlichen....Redens-arten sambt deren....Erklärung, Zwickau 1693, pp.48 and 97, is the earliest writer to make this distinction.

25. G. Agricola, De re Metallica libri XII, Basel 1556, 'Rei Metallica nomina Latina Graecaque Germanice reddita: Index Primus', p.539.

26. Five varieties of these machines are illustrated

in book six.

27. Von Calw, op. cit., p.52.

28. A. von Schönberg, op. cit., pp.48, 97.

29. B. Rössler, Deutlicher Klarete Bergmännische termini und Redens Arten, no page numbers. This glossary forms an appendix to his Speculum Metallurgiae Politissimum oder Hell Polierter Bergbau Spiegel, Dresden 1700.

30. I.M.P. a.W., Das Neu-Eroffnete Berg-Werck mit allen deroselben hauptsachlichen Wercken und zubehorigen Theilen...wozu angehanget ein sehr nützlichen Berg-Register der bergmännischen Redens Arten, Hamburg 1704.

31. J. Hübner, Curieuses und Reales Natur Kunst Berg Gewerck und Handlungs Lexicon, np. 1712.

32. H. Calvör, op. cit., p.35.

33. J. Lempe, 'Beschreibung der Förderungsmaschinen und Wasserhebezeuge der Alten: nach dem Lateinischen des Agricola', Magazin für die Bergbaukunde, Vol. 13, Dresden 1799, pp.142-3.

34. J.G. Krünitz, op. cit., p.299.

35. J.B. Beurard, op. cit., Paris 1809, pp. 135, 235, 259, 326, 467. Still further synonyms may be found in H. Veith, Deutsches Bergwörterbuch mit Belegen, 2 vols., Breslau 1870-01, cf. Ballenkunst and Rosenkranzkunst.

36. J. Matthesius, op. cit., p.145a.

37. J.L.C. & W.C. Grimm, op. cit., Vol. 10, pt.2, Leipzig 1905, p.814."Stangenholzer sind, in

technischer Bedeutung, beziehlich der Holz verwendung...". The word 'beam' in English provides a native example. Its position with its German and Dutch cognates in the series baum - boom - beam reveals its original meaning as tree, but one now surviving only precariously in Hornbeam. The Oxford English Dictionary, Vol. X, Oxford 1933, p.822, sub. stang shows the word in use in England in the late 16th century as in "stang (bar) the door", 1595.

38. G. Agricola (ed. of 1912), introduction, p. XXX.

39. J. Matthesius, op. cit., sub 1551 in the Jochimsthalischen kurtzen Chronicken. The entry is cited in full on p. 72 of this chapter.

40. Vom Rammelsberge und dessen Bergwerk, ein Kurzer Bericht durch einen Wohlerfahrnen und Versuchten desselbigen Bergwerks etlichen seinen guten Freunden und Liebhabern des Bergwerk zu Ehren und Nütz gestellet. Anno 1565. For the anonymous author to talk of the machine having a 'bent axle' (crank), (krummen Zapffen), virtually identifies it as a Stangenkunst. H. Calvör reprints this report as appendix II of his own work and records his thanks to von Heynitz, vice-Berghauptmann at Zellerfeld, for making such a scarce work available to him. It may well have been the copy plagiarized by Berghauptmann von Löhneyss of Zellerfeld in his Bericht vom Bergwerck of 1617.

41. (i) J. Hübner, op. cit., p.154.

(ii) Minerophilus, <u>Neues und Curieuses Bergwercks Lexicon</u>, Chemnitz 1730, p.631.

(iii) J.L. Frisch, <u>Teutsch-Lateinisches Wörterbuch</u>, Berlin 1741, p.319b.

(iv) H. Calvör, op. cit., p.36. Calvör's position requires some amplification since it was not a dictionary he was compiling but a work of historical analysis. He believed that the first Stangenkünste were of the type described in definition (i). At the point (p.37) where he turned to discuss the date of the introduction of the early form of the machine to the Harz he commented that his attempt to establish who had first introduced the present-day machines with field rods had been unsuccessful. His research had failed to yield either a name or a date. The field rod machine is called a 'Feldkunst' (field machine): "Ich habe aber nach dem Urheber der jetsigen <u>Feldkünste</u> auf hiesigen Bergwerken, und dem Jahre ihrer Einführung, umsonst geforschet". However, when he came to discuss the Feldkunst he was to declare that in essence it was nothing more than a development of the early form of the machine that worked directly over the shaft. In strict logic, therefore, the field rod machine should be called a Stangenkunst as well, a point he was very clearly working towards when he referred to it as the field-acting rod-engine (Feld schiebende Stangenkunst).

(v) J. Matthesius, op. cit., p.145b.

(vi) C. Meltzer von Wolckenstein, Berglaufftigt Beschreibung der Churfurstliche Sachsische freyen und im Meissnischen Ober, Erz-Geburge Löblicher Bergkstadt Schneebergk, Schneebergh, 1684, pp.90-101.

42. (i) J.J. Becher, Närrische Weissheit und Weise Narrheit, oder ein Hundert Concepten und Propositionen, Frankfurt 1682, pp.265-270. This passage forms part of an appendix to the main body of the work under the title Kurzer doch Grundlichen Bericht vom Wasserwercken und Wasserkunsten. Whether this piece was separately composed or not I do not know but both contain material relating to Becher's experiences in England (1679-1681), and both are written in the same easy-going conversational style.

(ii) J. Leupold, Theatrum Machinarum Hydraulicarum, Vol. 2, Leipzig, 1725, p.45ff and plate XXVI.

(iii) S. Rinman, Bergverks Lexicon, Vol. 2, Stockholm 1789, p.881: stånggång (Stangenkunst eller Feldgestänge).

(iv) J.G. Krünitz, op. cit., p.251 et seq.

(v) C.F. Richter, Neuestes Berg-und Hütten Lexicon, Vol. 2, Leipzig 1806, p.379.

(vi) J.B. Beurard, Dictionnaire Allemand-Français *contenant les termes propres à l'exploitation des mines, à la minéralurgie et à la minérologie*, Paris 1809, p.444.

(vii) G. Benseler, *Geschichte Freibergs und seines Bergbaues*, Freiberg 1853, p.1156.

(viii) C. von Scheuchenstuel, *Idioticon der Österreichischen Berg-und Hüttensprache zum besseren Verständnisse des Österr. Berg-Gesetzes und dessen Motive für nicht Montanisten*, Vienna 1856, p.232.

(ix) O. Fritzsche and O. Wagenbreth, 'Die Wasserhaltungmaschinen bei Agricola und sein Einfluss auf ihre Entwicklung', p.112, *Georgius Agricola 1494-1555 zu seinem 400 Todestag*, Preussische Akademie der Wissenschaft, Berlin 1955.

(x) R.P. Multhauf, op. cit., p.118.

(ix) L. Reti, *El Artificio de Juanelo en Toledo; su Historia y su Tecnica*, Toledo 1967, p.24.

(xii) H. Wilsdorf and W. Quellmalz, *Bergwerke und Hütten Anlagen der Agricola-Zeit*, Berlin 1971, p.160.

43. (i) G. von Löhneyss, *Bericht vom Bergwerck, Wie man dieselben Bawen und in guten wolstandt bringen sol......*, Zellerfeld 1617, Ch.3 Von den Stangen-Kunsten, p.62.

(ii) Of the writers who do not use the word Stangenkunst neither Herttwig nor Lehmann have been previously cited: C. Herttwig, *Neues Vollkommenes*

Berg-Buch bestehend in sehr vielen und raren Berg-Handeln und Bergwercks Gebrauchen, Dresden and Leipzig 1710; J.C. Lehmann, *Kurtze Einleitung in einige Theile der Bergwercks Wissenschaft*, Berlin 1751.

44. J. Hübner, op. cit., p.154 (Stangenkünste), p.614 (Feld-Gestänge) and pp.704-5 (Gestänge). It should be noted that although he described the Stangenkunst in a detailed and unequivocal manner and might consequently be thought of as preferring this term before others, he does nevertheless refer also (p.907) to the "Kunst oder Kunstzeug" and defines these terms in a manner which clearly implies that both were synonymous with Stangenkunst. He remarks further that in several places such machines were called Wasserkünste. Minerophilus, op. cit., p.631, repeats Hübner's definition of Stangenkunst word for word.

45. J.L. Frisch, op. cit., Vol. 2, p.319b (Pertica: Stangen-Künste), Vol. 1, p.257b (Feld-Gestänge).

46. H. Calvör, op. cit., p.37.

47. Ibid, p.37. It is curious, to say the least, that Calvör should here rely on Löhneyss and not make use directly of the anonymous' Rammelsberg report of 1565 that he had gone to so much trouble to get. Löhneyss had taken the passage that Calvör quoted almost word for word from the report of 1565. However, Calvör drew

on the report itself to record the anonymous' tribute to the efficiency of the new machine.

48. Ibid, plate 12, which reveals how elaborately water for the wheels was threaded through the Rammelsberg mine workings in Calvör's day.

49. It was a very popular work and went through many editions.

50. J. Matthesius, Jochimsthalischen kurtzen Chronicken: "Michel Mittelbach set up the first Stangenkunst in the valley at the St. George (mine) on Arlsberg". In view of the curious role this simple statement is to play in the later stages of this discussion it would be convenient here to anticipate matters somewhat in order to mention the curious double error into which Calvör fell in 1763 in his discussion on the invention of the Stangenkunst. He misquoted the year as 1550 and then compounded his error by taking the statement of a later chronicler, referring to the events of 1551, as independent evidence that the machine had been invented in Joachimsthal in that year. But Petrus Albinus in his Meissnische Bergk Chronica, Dresden 1590, ch.8, p.74, says explicitly that he had done no more than draw on Agricola's Bermannus and Matthesius' Sarepta for his information on Joachimsthal for they had both so thoroughly described the valley, "dieses Thals

Topographiam und die Gebirge so darumb liegen haben......beschreiben" that they had left him nothing to do beyond excerpt material.

51. J. Matthesius, op. cit., p.145b.

52. Loc. cit. The tin mines of Ehrenfriedersdorf in Saxony lie (or lay) some fourteen miles south of Chemnitz (Karlmarxstadt). In calculating the machine's performance I have taken Matthesius' Eimer to be a Bohemian Eimer, a measure equal to 13.5 imperial gallons.

53. Matthesius' account of these machines is not altogether easy to translate, but contemporary idiom and context alike indicate that the suffix "berg" as in Rhorberg and Pompenberg (which occurs earlier in the passage in question) conveys the sense of 'on end', that is, of things placed one above another. Pumps in tiers is how such relays were described in England in the 18th century by Borlase and Pryce. The contemporary French term was "répétition de pompes".

54. G. Agricola, Vom Bergkwerck xii Bücher, Basel, 1557, p.CXLIX.

55. C. Meltzer von Wolckenstein, op. cit., pp.99-101.

56. An engraving by Daniel Lindemeier dated 1606 showing a panorama of the mines of Clausthal and Zellerfeld in the Harz is the earliest piece of visual evidence for the use of double field-rods. Over a dozen runs of rods are shown, some of

them evidently of considerable length.

G. von Löhneyss, director of the Zellerfeld mines, could speak already in 1617 of field-rods of up to one thousand Lachters in length (over 1¼ English miles).

57.(i) The entry sub 1554 in the Schneeberg chronicle relates that in "Dieses Jahr brachte auch Bernhard Wiedemann zuerst die Pumpen und Stangenkünste allhier in Anwendung und zwar in St. Catharina Neufang, dessen Tiefftes er auf seine eigenen Kosten gewaltigte worauf denn allenthalben die Bulgenkünste abkamen, und in Statt deren Pumpen-und Stangenkünste angeschafft wurden". C. Lehmann (ed.), <u>Chronik der freien Bergstadt Schneeberg</u>, Vol. 1, Schneeberg 1837, p.229. The water-bag hoists (Bulgenkünste) were immediately scrapped in favour of the new machines, as was to be the case at Freiberg after 1557.

(ii) The time-range chart of mining terms at the end of this chapter serves to illustrate both the position at the time Meltzer was writing and the difficulty he found himself in.

58. J.J.Becher, op. cit., pp.265-270.

59. Becher talks of the place as the great mine in Hungary "....das grosse Bergwerck in Ungarn". Since the only great mine in Hungary that lacked on site surface water was Windschacht near Schemnitz it would seem that this was the place

that Becher had in mind. The works there were destroyed in 1679 during the course of a razzia on the place by Pater Josua's guerillas. Becher's small stream (kleiner Fluss) would seem to have been the Schemnitzer Bach.

60. According to V.G. Buchern, Das Muster eines Nützlich Gelehrten in der Person Herrn Doctor J.J. Becher, Nuremberg and Altendorf 1722, p.30, Becher, journeying by sea to undertake some work at Lauderdale's mines in Scotland, was caught in a storm and, tossed about for 28 days, wrote the Närrische Weissheit to keep his mind off his situation (welche Reiss er 28 Tage auf der See aufgebracht und die Närrische Weissheit, wie auch das Lumen Trinum im Hochsten Sturm geschrieben hat). This was in 1680.

61. Wherever I have been able to trace Becher's statements back to their source I have found them to be well based.

62. J. Leupold, Theatrum Machinarum Hydraulicarum, Vol. 2, Leipzig 1725, p.45ff. It is worth noting here that he is the earliest writer to use Feld-Gestänge as a synonym for Stangenkunst. The Grimms, op. cit., Vol. 7, p.816, it may be noted, take this to be a 19th century usage: "In der neuern Österr. Bergsprache gleichbedeutend mit Feldgestänge".

63. Ibid., plate XXVI.

64. H. Calvör, op. cit., p.38.

65. C. Wolf, _Vollstandiges Mathematisches Lexicon darinnen....alle Kunst-Wörter und sachen.... beschrieben worden_, Leipzig 1742. A. Saverien, _Dictionnaire universel de mathématique et de physique_, Vol. 1, Paris 1753, p.365. J.F.C. Morand, _L'art d'exploiter les mines du charbon de terre_, Vol. 2, Paris 1776, p.1038. It was not only Wolf's definition which was adopted by Saverien and Morand for both also reproduced his atrocious engraving of antiquated field-rods. Like Leupold they were, in this, armchair technologists.

66. J. Krünitz, op. cit., p.251, et seq. By Krünitz' time one of the terms used earlier to denote the field-rod engine, "Feldkunst", had lost this specific meaning and had come to denote water pumping or lifting in general. This would seem to explain why in referring to the machine he calls the term synonymous with Stangenkunst a Wasser-Feldkunst (to expand the terms of his Wasser-Feld oder Stangenkunst) in order to render the general term more specific. I do not mean, of course, to suggest that Krünitz was coining the term, and doubtless it was current usage. As one term shifts its meaning it necessarily affects others.

67. C.F. Richter, op. cit., p.379.

68. J.B. Beurard, op. cit., p.444.

69. G. Benseler, op. cit., p.1156. The index makes the identification plain. Feld-Gestänge:p.1307, p.1315 Stangenkunst: p.1156.

70. All cited in full in note 42.

71. The first victim of Calvör's mistake would seem to have been D.J. Merkel, Erdbeschreibung von Kursachsen, Vol. 1,Leipzig 1796, p.106: "Unter der Erfindungen und Einrichtungen zur Verbesserung der Bergbaues in Sachsen gehören besonders: die Erfindung der Wasser-Künste 1550". Next were E.V. Dietrich and G.A. Weber, Kurze Übersicht der Geschichte des Bergbaues im Königlich Sachsischen Erzgebirge, Annaberg 1822, p.81: "Die Stangenkünste waren um das Jahr 1550 zuerst in Gebrauche". Despite the claim made in its title one finds in H. Veith, Deutsches Wörterbuch mit Belegen, Vol. 2, Breslau 1871, p.306, that the citation from Matthesius is given as "1550 hat M(ittelbach) die erste Stangenkunst im Thal gehangen". In our century the syren Calvör has lured many more into error. Fritzsche and Wagenbreth, op. cit., p.112, "Bei grosserer Entfernung der Wasserkraft vom Schacht....die erstmalig um 1550 in Erzgebirge auftraten" (1955). Multhauf, op. cit., p.118, "Its introduction to the Erz-gebirge has been put as early as 1550" (1959). It is not really arguable that

Reti, op. cit., p.24, has escaped: "A mitad del siglo XVI se introdujo en la region de los Montes Metalicos (Erzgebirge) un sistem para transmitir energia a grandes distancias... llamado Stangenkunst" (1967). Wilsdorf and Quellmalz, op. cit., p.160, "1551: Erfindung des Feldgestänges" (1971). This entry leaps to the eye since it is printed in bold capitals. F.M. Feldhaus, Die Technik der Vorzeit, Munich 1965, p.841, takes a totally independent line in error for he confounds the events of 1565 (at Rammelsberg) with those of 1551 (at Joachimsthal).

72. G. von Löhneyss, op. cit., p.62. The extent of Löhneyss' plagiarism is well described by W. Hommel in (i) Eine Plagiator als 17 Jahrhunderts and (ii) Über den Berghauptmann Löhneysen: eine Nachtrag, Köthen, Anhalt 1912 (both reprinted from the Chemiker Zeitung of that year). Hommel writes entertainingly and reveals that Ercker and Agricola suffered no less from Löhneyss' raids than the anonymous.

73. H. Calvör, op. cit., p.38: "Löhneisen gedenket unter allen Schriftstellern am ersten der Stangenkünste...das Feldgestänge mit verstehet".

74. G. von Löhneyss, op. cit., figure 10.

75. Martin Planer's report was reprinted by R. Wengler

under the title "Bericht des Bergverwalter Martin Planer über den Stand des Freiberger Bergbaues im Jahre 1570", Mitteilungen des Freiberger Altertumsverein, Vol. 35, Freiberg 1899, pp.57-83.

76. Most of these words have a long history. Zeug (an abbreviation of Gezeuge), a collective noun meaning equipment, gear, occurs in a document of the 10th century which glosses: armamenta-ziuhc. Matthesius uses the word Zeug for water-lifting machines in general in 1559. Pompe is first cited in 1468.

77. G. Berward, op. cit., p.28.

78 (i) A von Schönberg, op. cit., pp.59 and 111.

(ii) B. Rössler, op. cit., glossary sub these words.

(iii) C. Herttwig, op. cit., pp.249 and 432.

79. These writers all use the word Feldgestänge in the limited and literal sense of field-rods as in the typical phrase: "Feld-gestänge sind die Stangen an einem Kunst-Zeuge, die über Feld schieben mussen".

80. J.K.G. Jacobsson, Technologisches Wörterbuch, Vol. 1, Berlin and Stettin, 1781, p.697 (Feld-künste), p.696 (Feldgestänge). Jacobsson was a Prussian government factory inspector in Königs-berg (Kaliningrad). If the shift in meaning of Feldgestänge had become definitive by 1781 when Jacobsson was writing it had long been in

competition with Stangenkunst and Feldkunst. Leupold's use of the word as a synonym for Stangenkunst in 1725 has already been noticed. It is used similarly by J.F.C. Morand in L'Art d'Exploiter les Mines du Charbon de Terre, Vol. 2, Paris 1776, p.1037: "....elle est connue sous les noms de Feld oder Strecken Gangen, Feld-Gestängen; on l'appelle aussi Stangen-Kunst, ce qui veut dire littéralement machine ou angin à barres".

81. C.F. Richter, op. cit., p.379. Canonical recognition of the 'new' word was conferred by C. von Scheuchenstuel, op. cit., p.232, a work written specifically as a non-technical man's guide to the technical terms employed in the mining laws of the Austrian empire.

Chapter Three THE ORIGINS AND DEVELOPMENT OF THE STANGENKUNST

One of the more striking manifestations of the vitality which informed western European economic and technological development in the later Middle Ages was the astonishing spread of Saxon miners throughout the length and breadth of Mitteleuropa in search of new deposits of metal-bearing rock. There seems little reason to doubt that the achievement of mechanization in the metallurgical industries in the period immediately preceding these movements, the earliest evidence for which can be securely attested for the year 1010 at Schmiedmühlen in the Oberpfalz, was powerfully connected with this phenomenon[1]. Once stamps and bellows and hammers were water powered, productivity and profits must have increased many times over if one may judge from the rather later evidence offered by the English iron smelting industry[2]. Pari passu with increased productivity went a rapid acceleration in the rate at which surface and easily accessible ores were extracted and local fuel resources depleted.

But success here manifestly brought in its train a host of pressing new problems. The deeper the mines were dug the more urgent became the problem of drainage, for it was not always possible to drive adits to lead off water from the workings. The need to find new methods for raising such water began to be felt ever more sharply. Problems of timber supply arose also, for shafts and galleries had to be lined and supported, and this is to say nothing of the ever-growing quantities of charcoal needed by the smelters. Both created severe problems of transport as the radius of the provisioning areas was inexorably extended. The use of rivers for floating out timber from the forests and for rafting out trains of logs was an early response. Probably well before 1200 streams too small for manned and steerable rafts began to be exploited as float-flumes, 'Triftwasser', that is, as conveyors of free-floating billets. From this it was but a small step to build artificial flumes. Such channels, 'Holzschwemme',designed to catch the waters of the spring snow melt, filled rapidly once the thaw began and bore away to the smelters the billets, cut and stacked during the winter, that were then thrown into them[3]. Like the improvements in pumping machinery these responses were for the most part probably beginning to be vigorously exploited for the use of mines only in the 15th century for there seems little reason to doubt that before about 1400 mines could not be worked significantly far below adit, the level of free drainage. It would be a breakthrough in pumping that would set in motion in earnest the sequence of responses that have been sketched here[4].

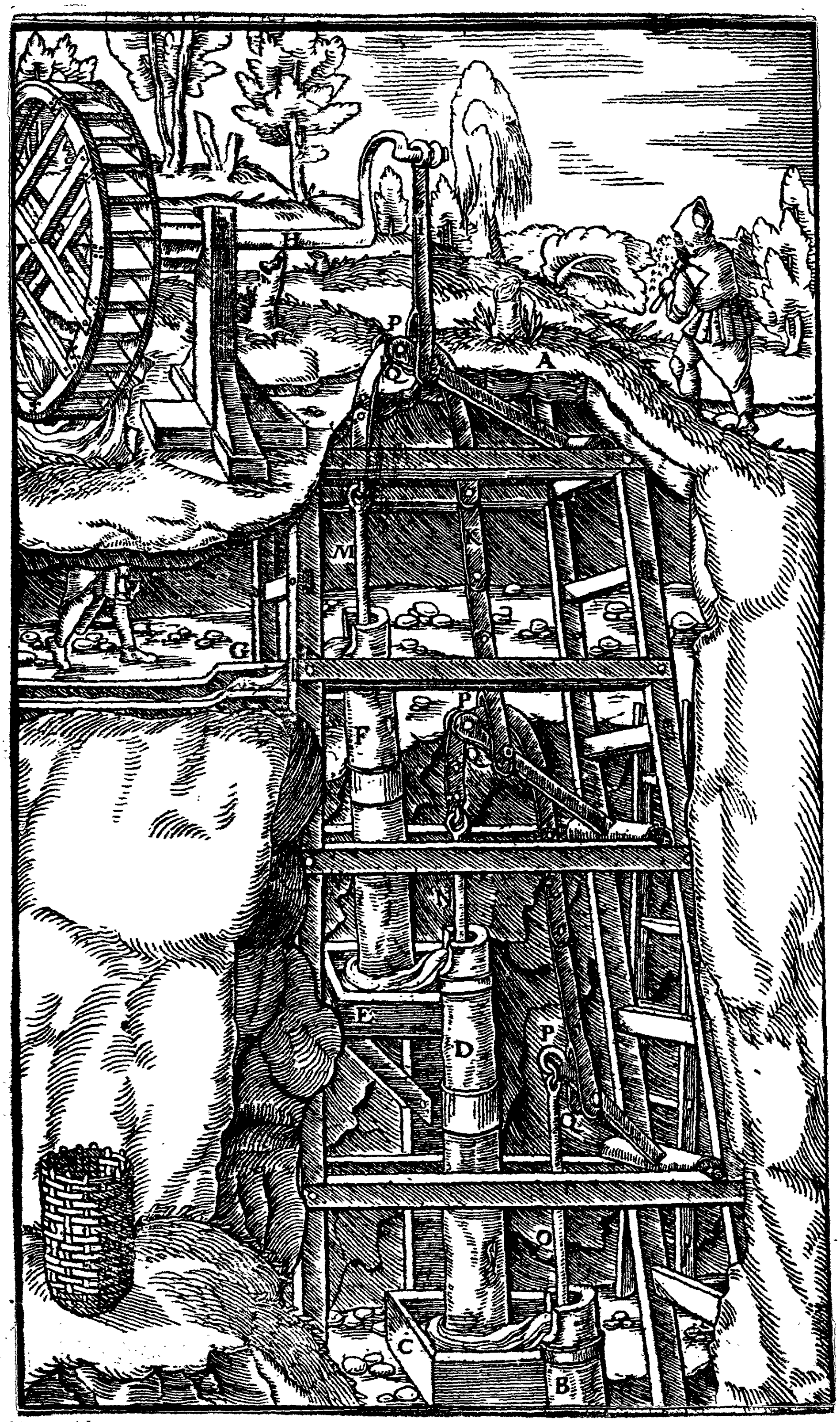
Sometimes at least such difficulties were avoided by simply abandoning drowned out pits and depleted areas (effectively the two were usually synonymous) and moving on to new sites where simple extensive techniques could continue to be employed. The German diaspora of the 12th, 13th and 14th centuries was the outcome, one would guess, of just such a concentration on easily worked outcrops and their abandonment once difficulties of pumping, ventilation and fuel supply became severe. Such procedures, in short, bore as little relation to the relatively sophisticated methods of Agricola's day as primitive Germanic slash and burn agriculture bore to the balanced and intensive rotations of Carolingian Europe, for, like the latter, any sustained mining operation presupposed a well-established set of interdependent techniques.

Nevertheless this medieval Drang nach Osten presents several interesting features. Not only did Saxon miners move eastwards along both the northern and southern slopes of the Carpathians but others moved south-eastwards through Slovenia, Croatia and Serbia into Macedonia, the language of the peoples of these regions preserving numerous lexical items of German provenance relating to mining tools and techniques and to metallurgical operations[5]. Then too the increasing scale and importance of mining activity may be traced in legal institutions of steadily increasing number and complexity which parallel these developments. The earliest document to survive is an agreement of 1185 entered into by Albrecht, Bishop of Trent, and the elected representatives of the mining entrepreneurs in his see. Almost as early is a code regulating affairs at the Zezzen mine near Friesach in Carinthia. In Bohemia the code of Iglau of 1249 enjoyed such a great reputation that it was taken as the basis for a general code for

for the whole of Bohemia issued by Wenceslaus II in 1300: the Constitutiones juris metallicae[6].

Recent research has begun to reveal that parallel with the growth of this written law there developed an extensive literature of mining[7]. It is the result of an undue concentration on printed sources, in short, that has made Agricola's work of 1556 appear virtually unprecedented, whereas a more accurate view of his achievement would be one that presented his work as the consummation of a two hundred year old tradition. During that period German miners were developing the array of machines that were to be displayed in book six of De Re Metallica. Although, as has already been mentioned, even the barest outlines of this process are difficult to trace in Agricola's work, certain tendencies are clear enough since, for all his eschewal of historical detail, Agricola leaves no room for doubt about which were the valued machines for raising water in his day. The rag and chain pump and the bag hoist were for heavy service, the chain of buckets already a museum piece. Certain other pumps were useful in a limited way, however, especially a type that had been developed in the 1540s. This was the seventh variety of pump which Agricola called simply sipho septimus. It was already, despite its novelty and limited performance, a highly valued machine. It was cheap, useful and easy to construct. Its main features have already been described, so that here it will suffice to say only that in Agricola's description it consisted of two or three suction

Fig. 1.



Sipho septimus: the Ehrenfriedersdorf Radpompe: the ur-Stangenkunst of c.1540.
Source: G. Agricola, De Re Metallica, Basel 1556.

pumps placed one above the other, all of them set in motion by the crank of a water wheel, a tier of three pumps yielding a combined lift of about seventy feet. In the glossary annexed to the De Re Metallica Agricola rendered sipho septimus, the seventh kind of suction pump (fig. 1) as the new Ehrenfriedersdorf wheel pump, "die neue Erenfridistorfische Radpompe"[8]. It would be rash to suppose from the fact of its being named after a Saxon mining town that it had been invented there, for, as has been shown, there was considerable variability in the matter of nomenclature as far as this machine was concerned. Its importance, however, for the future development of deep mining is not in doubt. Just as the rag and chain pump had consigned the chain of pots machine (but not perhaps its German name) to oblivion, so the new pumping engine was, in the course of an extremely rapid development, to confine this, and all other types of pumping equipment, to similar marginal situations. It was to become and remain for the best part of three centuries one of the most versatile and elaborately developed machines in the history of engineering before the modern period. I shall show below that Agricola's seventh suction pump was in fact the very earliest form of rod-engine or ur-Stangenkunst, for it is with the elucidation of the origins as well as with the development of this machine that I am here concerned. It would be, in addition, of some interest to show not only that the generally accepted view that Agricola had somehow failed to notice the Stangenkunst is without foundation but to demonstrate at the same time that one may use his engraving of it as a point of departure to explore the machine's pre-history as well as its subsequent development*. It might well be objected that Agricola neglected not once but twice to call the machine a Stangenkunst, and certainly that fact has seemed to some historians a sufficient reason for supposing that "die neue Ehrenfrisdorf Radpompe" could not have been a Stangenkunst, whatever else it was. The balance of evidence is, in my view, heavily weighted against this idea once one has accepted that the Stangenkunst, when it first appeared, was able to work only when it was placed over or in the pumping shaft. What emerges very clearly from all this is that the Agricolan period, far from signalling the onset of some time of classic stasis, was rather one on the verge of transformation: this the testimony of writers of the next generation makes clear. Even as Agricola's work came off Froben's presses at Basel the world of machines it described was on the point of disappearing[9]. Seen in this light Agricola had, after all, perhaps preserved a classic moment in the history of mining before it entered the 'modern' period.

In the light of the previous discussion of Stangenkunst nomenclature it will be granted, perhaps, that the problem as to what actually constituted a Stangenkunst is a subject much bedevilled by confusion and contradiction. It is true, as it may be most times, that much of the confusion need never have arisen, given a reasonable degree

* A chronology of the Stangenkunst is placed at the end of this chapter.

of care among historians when they came to consult the source materials. Apart from this, however, there does also exist a genuine difficulty. No one, as far as I know, has attempted to sketch the evolution of the machine from its first appearance, and until the stages of such an evolution are at least outlined, no real measure of understanding of the problems involved can be expected, nor can the source materials themselves be properly scrutinized and made to yield all that they contain. Indeed, it is unmistakeably one of those not uncommon circular situations in which it is almost a question of some source materials becoming such according to the nature of one's initial definitions. Other materials, again, take on significance only in the presence of an organizing axiom of a certain sort, shining as it were, with a sort of reflected light. These are, no doubt, common enough experiences, and are perhaps better discussed piecemeal in the unfolding of the argument.

The first problem then is to isolate the gestalt forms, the elements of the synthesis from which the machine took its rise. The second task is to attempt to determine the critical points in its subsequent development and to erect a chronological framework within which some of the major increments and refinements can be fitted which were to make the Stangenkunst a machine of unique resource for three centuries. For it was only in the 1730s and 1740s of the 18th century that its competitors began to find some few special situations where they might be preferred.

One of these competitors was obviously the atmospheric steam engine, and the history of its adoption in Europe in the early 18th century will be examined in a later chapter of this study. All that need be said here is that where such engines were built in some numbers it was either because the possibility of water power was virtually non-existent or because the product mined was coal.

There were two areas in Europe of rich mineral deposits that were also 'deserts' hydraulically speaking, and in both regions - Hainaut and central Slovakia - a precocious domestication of English technology along with a building up of a skilled local work force was well under way by the 1730s long before the rest of the continent turned over to 'palaeotechnology'[*10]. The other competitor was the water pressure engine, taking advantage, in a nicely antithetical way, of that other hydraulic extreme, where conventional wheels could utilize only a fraction of the high heads that were, in exceptional cases, available. Again such activity was slow to develop even if one chose to begin the account with Joseph Höll's Wassersaulen machine, column of water engine, of 1749 (the so-called Hollischemachine) rather than with those of his precursors[11].

I have called the Ehrenfriedersdorf Radpompe of c.1540 the ur-Stangenkunst and it is to the task of establishing what the antecedents of this machine were that I first wish to turn. It is a matter of great good fortune that Agricola's engraving of the machine was commissioned

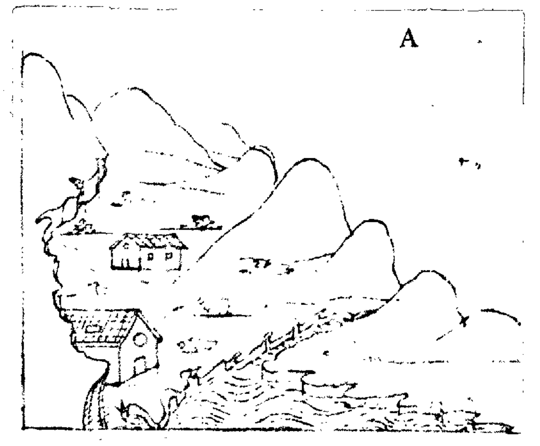
*That is, a technology based essentially on the use of mineral fuel. I take the word from Lewis Mumford.

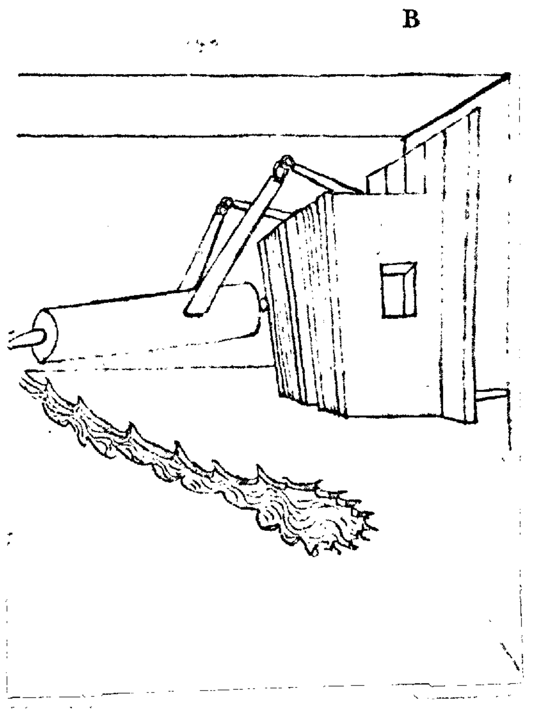
at a time when, fresh from its unknown inventor's hands, it still retained the primitive features of its original form. These features were to disappear quite rapidly, as I shall show below, but here it must be said that they are entirely characteristic of a situation in which a saltation, or sudden breakthrough into a new mechanical conception has taken place. The rocker arms and rollers (or half bell-cranks) for instance with which the machine was equipped and to which each of the pumps was separately attached in order to receive the motion of the wheel, were seen to be redundant as soon as the process of critical revision began. What is much more significant here, however, is that they figure in the design of the original machine and by their presence indicate very clearly the nature of the gestalt within the perceptual framework of which the machine as a whole had first been conceived. The carrying across of skeuomorphic, that is redundant, features from one form to another in such saltations, is such a well known and characteristic signature of the process of invention that it scarcely needs to be insisted on although it is true that recognition of the phenomenon and its fruitful exploitation has been more often in evidence in the work of those studying the arts and crafts of primitive peoples than in those investigating the evolution of the technical arts in more advanced societies[12]. It is therefore with the first appearance of the bell-crank (or rocking roller) in Europe that the search for the origins of the sipho septimus must begin.

The potentialities of the crank, which as late as 1400 according to one authority was still a dormant element in the technology of the west, were nevertheless sized upon in no small way in Europe during the next half century[13]. It was, moreover, the successful conclusion of such overtures which permitted a period of increasingly sophisticated machine design to begin. Among the manuscripts which furnish the record of this progress occur a handful of sketches important as the progenitors of the Ehrenfriedersdorf machine of 1540. In these drawings the crank does not occur alone but in association with the bell-crank. The latter, a simple roller with one or more rocker arms, set in motion by a connecting rod, permitted circular motion to be converted into reciprocating motion. Such a combination works equally well, of course, in the opposite sense, and if indeed the sequence of development indicated by the surviving drawings may be relied upon it was almost certainly first put to work in this way, as for instance when the prime mover is a man using his arms or his legs. The elbow (or knee) is then to all intents and purposes functioning as a bell-crank. The Hussite engineer's sketch of c.1430 showing a treadle device with connecting rods and double compound crank driving a flour mill may be taken as marking this stage[14]. But it is the passage from the manual phase to the use of water wheels to set such assemblies in motion that marks the decisive step towards a mechanization of a totally new character. What may be the earliest evidence of a

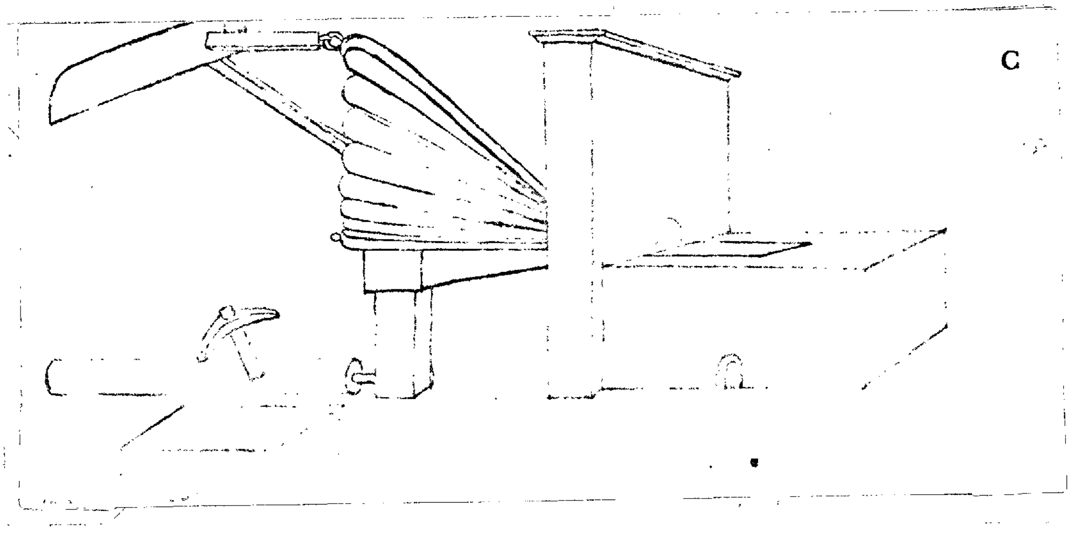
Fig. 2.

(A) Prospect of Ferriere



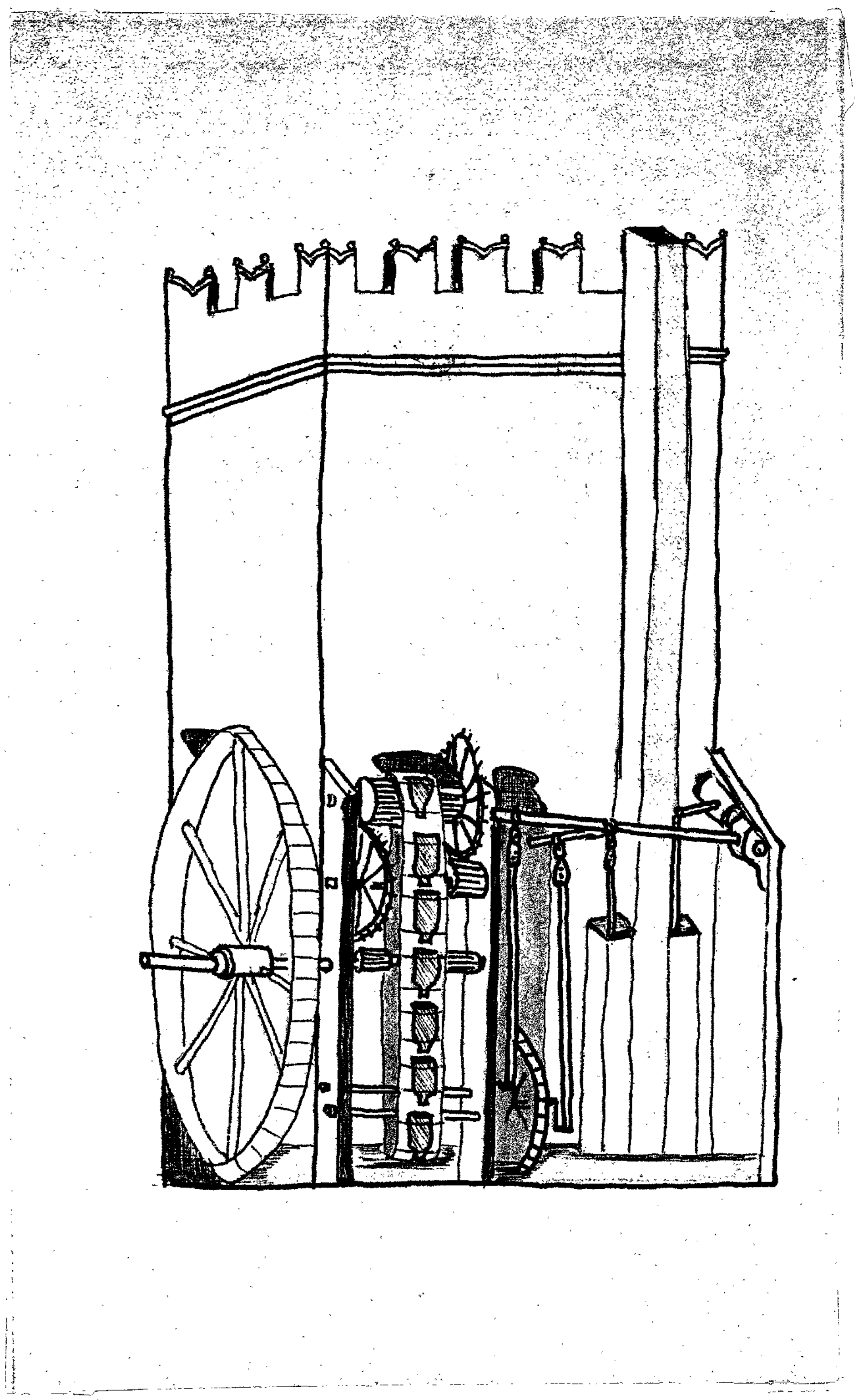


(B) and (C) Two varieties of bellows worked through bell-cranks.
Source: A. Filarete
Trattato di architettura
c.1465, f.127r.



mechanically powered machine of this kind is to be found in a treatise on architecture written by Antonio di Piero Averlino, known as Filarete, for Francesco Sforza in 1461-65 (fig. 2). Fearing to tire his patron with long unbroken descriptions of the planning of the ideal city "Sforzinda", Filarete broke up his work with a number of divertimenti. One of these, a description of a visit to a blast furnace, can be connected with an actual journey made by the architect in March 1463. This was probably to the plant at Ferriere in the Apuan Alps. But Ferriere at that time, although it had mechanically operated bellows, possessed no hammer mill, and in order to complete his descriptions of a fully equipped smelter Filarete most likely drew upon what he had seen of such things at Grottaferrata near Rome years before (1433-1447) when he was working in that city. Filarete's artistic powers were, despite his complacency, unfortunately unequal to what he wished to show, and the cryptic nature of the sketches which accompany his text have generated no little discussion as to what may have been the precise nature and mode of action of the machines at Ferriere. The balance of probability is that the bellows and possibly also the hammer were set in motion by bell-cranks and push rods, but some doubt must inevitably remain[15]. Although there is then some insecurity in attempting to ascribe origins in this matter to the 1430s or 1440s chez Filarete, one can certainly find a time well before the completion of his treatise in 1465 for which important elements of

Fig. 3.

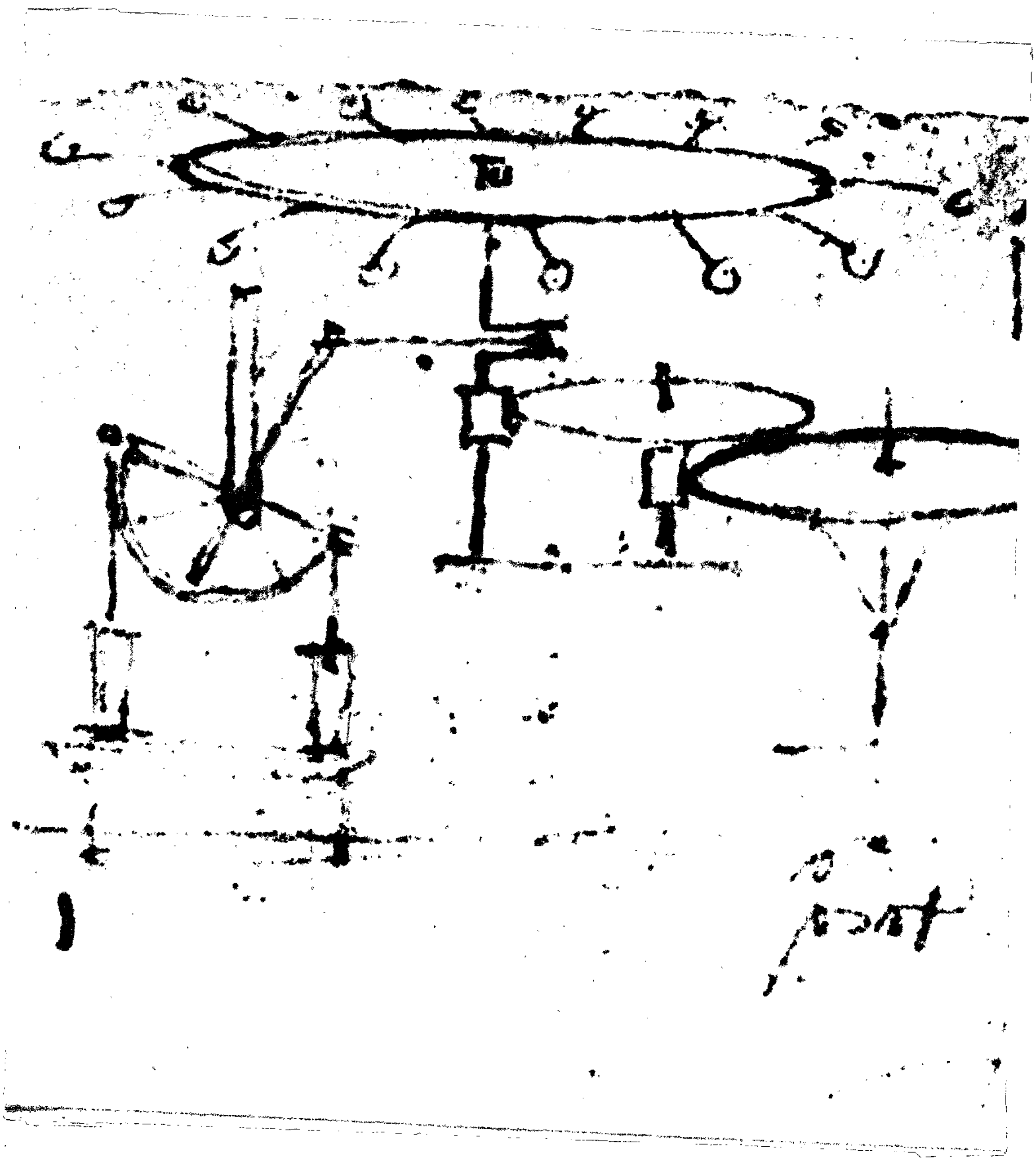


Water wheel driven chain of pots supplies water to a wheel working two force pumps by means of connecting rods and rocker arms.
Source: A. Pisanello, drawing with title macchina idraulica, c.1450.

the combination can be securely attested. Among Antonio Pisanello's drawings is a carefully executed sketch of c.1450 of two water raising machines (fig. 3). One is of slight interest (actually a waterwheel driven chain of pots) but the other beside it is of some moment. An overshot waterwheel with a crank handle on either end of its axle sets in motion a pair of force pumps flanking a central rising pipe, for the machine was evidently designed to provide a high head of water for domestic or town supply purposes. The drive is not delivered to the pumps directly, however, since the connecting rods drive up and down the free ends of two horizontally disposed levers (the rocker arms of two rollers) placed above them, each of which describes an arc of about 90° as it moves with the throw of the crank. The piston rods are secured to the mid-points of these rocker arms[16]. Such an ensemble, kinematically uncouth though it may appear, had an extraordinarily long life before it, and even a century later, at the time when <u>sipho septimus</u> appeared, was till in its lusty youth. Francesco di Giorgio Martini sketched a version of it in c.1478; Leonardo in 1488-9 turned the arrangement round through 180° so that now the connecting rod, for his machine had only one, hung down from the crank, a modification of no little significance as will shortly appear.

In the next century Vavrinec Kricka, about 1560, was working with very similar force pumps in Prague: his sketch book shows a three throw crank working upwards

Fig. 4.

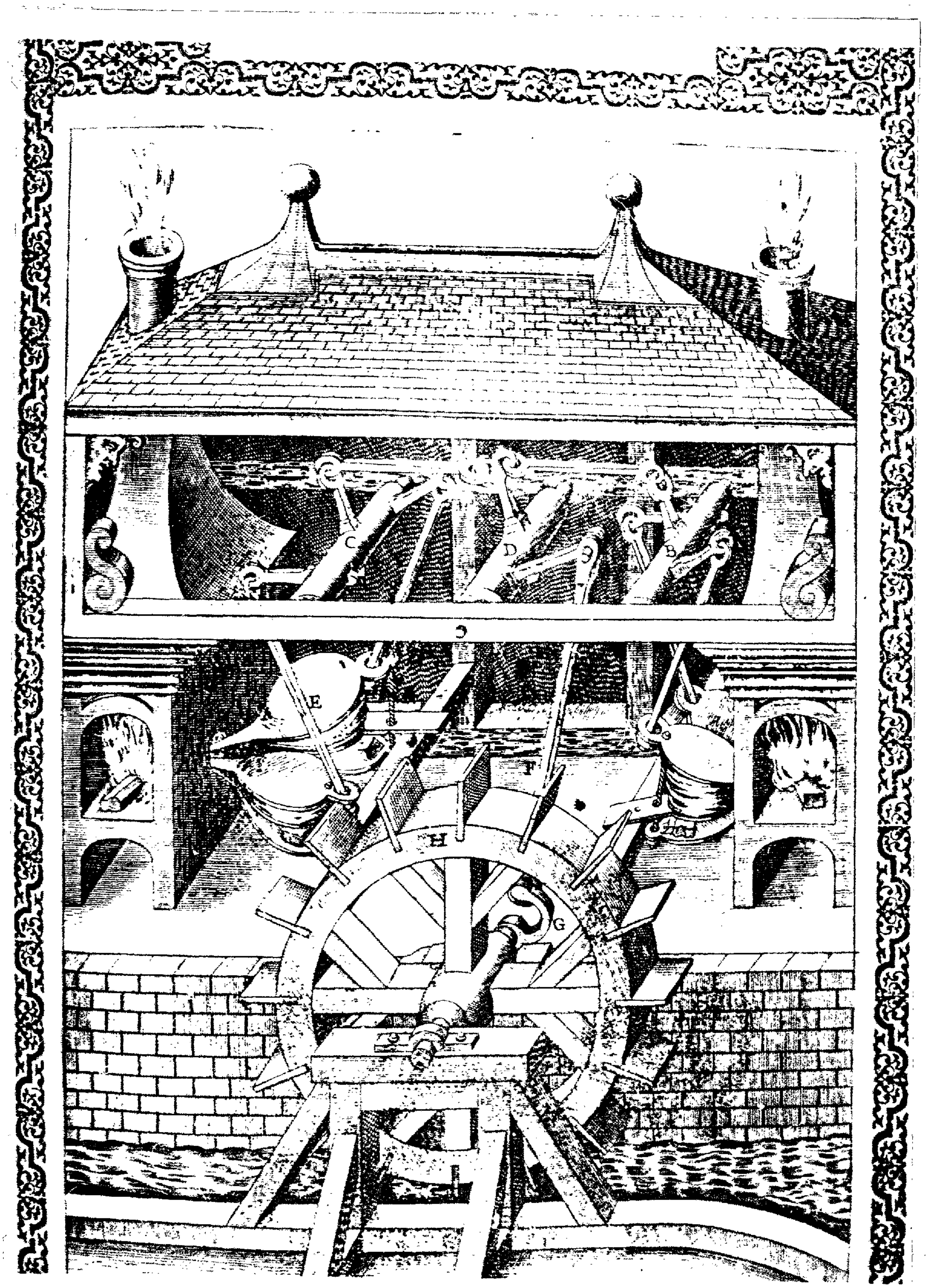


Bell crank with sector working two lift pumps.
Source: L. da Vinci, <u>Codex Forster III</u> (1493-94) f.45r.

through connecting rods. However, by joining these rods to the mid-points of the horizontal levers and bringing these into the same plane of motion as the crank shaft, he was able to leave the free ends of the levers available for the piston-rods and in this way maximized the length of their strokes. According to John Bate's engraving the fire-squirts in use in London in 1635 were still based on the Pisanellian model. It might well be incautious, in view of all this, to assume that the combination was making its positively final appearance when William Hedley made use of it in the transmission system of his locomotive "Puffing Billy" in 1813[17]. One might remark also before leaving Pisanello that whatever linked culture trait may once have connected the bell-crank device with blast production in metallurgical work - the nexus in which it seems agreed that transmission to Europe took place - now no longer held.

The combination of crank, connecting rod and bell-crank occurs again in what is in some ways an even more significant arrangement in Leonardo's sketch in Codex Forster, III, f.45r of c.1493-94 (fig.4). If one leaves aside the staggering aggregation of reduction gears, fly-ball governors and so forth, which together constitute the prime mover, one is left with something like an anticipation of mechanical ideas - the Geschleppe and the Kunst-Kreuz - which were to appear much later on in the development of the Stangenkunst[18]. The horizontal connecting rod of Leonardo's machine pushes and pulls a

Fig. 5.



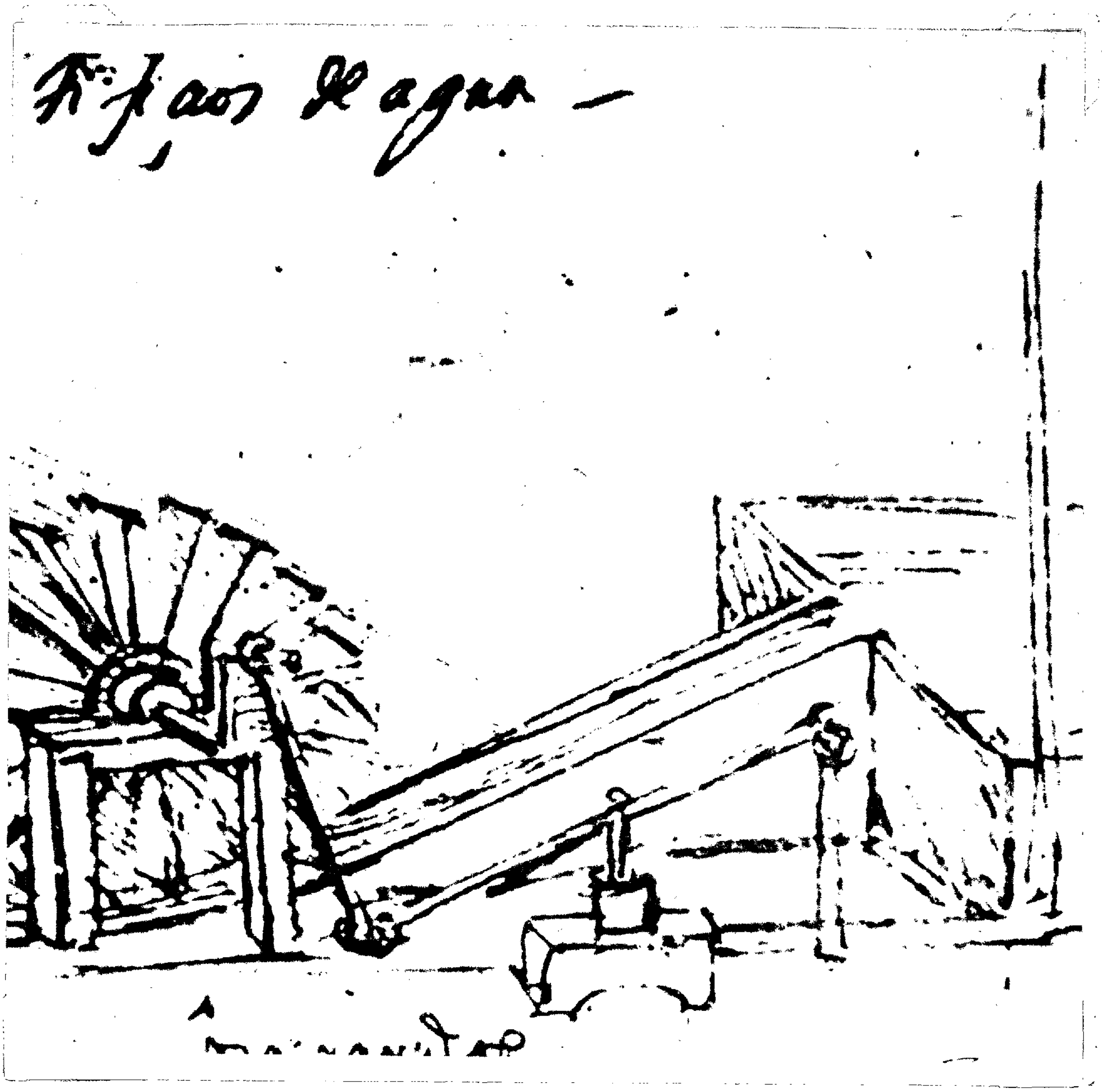
A water wheel driving two bell cranks (C,B) through a central principal bell crank (D).
Source: A. Ramelli, Le Diverse et artificiose machine, Paris 1588, plate CXXXVII.

bell-crank the end of which is equipped with a half circle. The ropes attached to either side of the half circle alternately lift the piston rods to which they are attached and like all sector and rope devices provide a solution to the problem of how to reconcile the two kinds of motion - straight line and circular - present in all pumping machines of the beam engine type[19]. It will be seen later how Oberkunstmeister Mathias Höll was to use something remarkably similar to this arrangement in order to reduce friction in the field rod engines he constructed at Windschacht in 1711.

There were then a number of gestalts available as early as the 15th century and all in vigorous existence in the next century[20]. Although Biringuccio's description of the machine working many sets of bellows which he had set up about 1510 at Boccheggiano is tantalisingly vague, it is clear that it would have involved a principal bell-crank (moved directly by the connecting rod of the water wheel) and two others set in motion by its push rods[21]. Cardano's description, in his <u>De Subtilitate</u> of 1550, of such an assembly shows clearly enough that it was then no uncommon practice to work more than one bell-crank off the crank of a water wheel in order to set numbers of bellows in motion, and some difficulty of terrain somewhere had only to require these to be positioned, as almost certainly they had been at Boccheggiano*, in series instead of in parallel (as one sees (fig. 5) in Ramelli's plate cxxxvii of 1588) for a miniature field rod system to come into existence unwilled[22].

*See note 21 where I attempt a construction based on Biringuccio's description.

Fig. 6.



Water wheel working a force pump through a connecting rod and rocker arm.
Source: L. da Vinci, MS.B. (1488-89), f.53v.

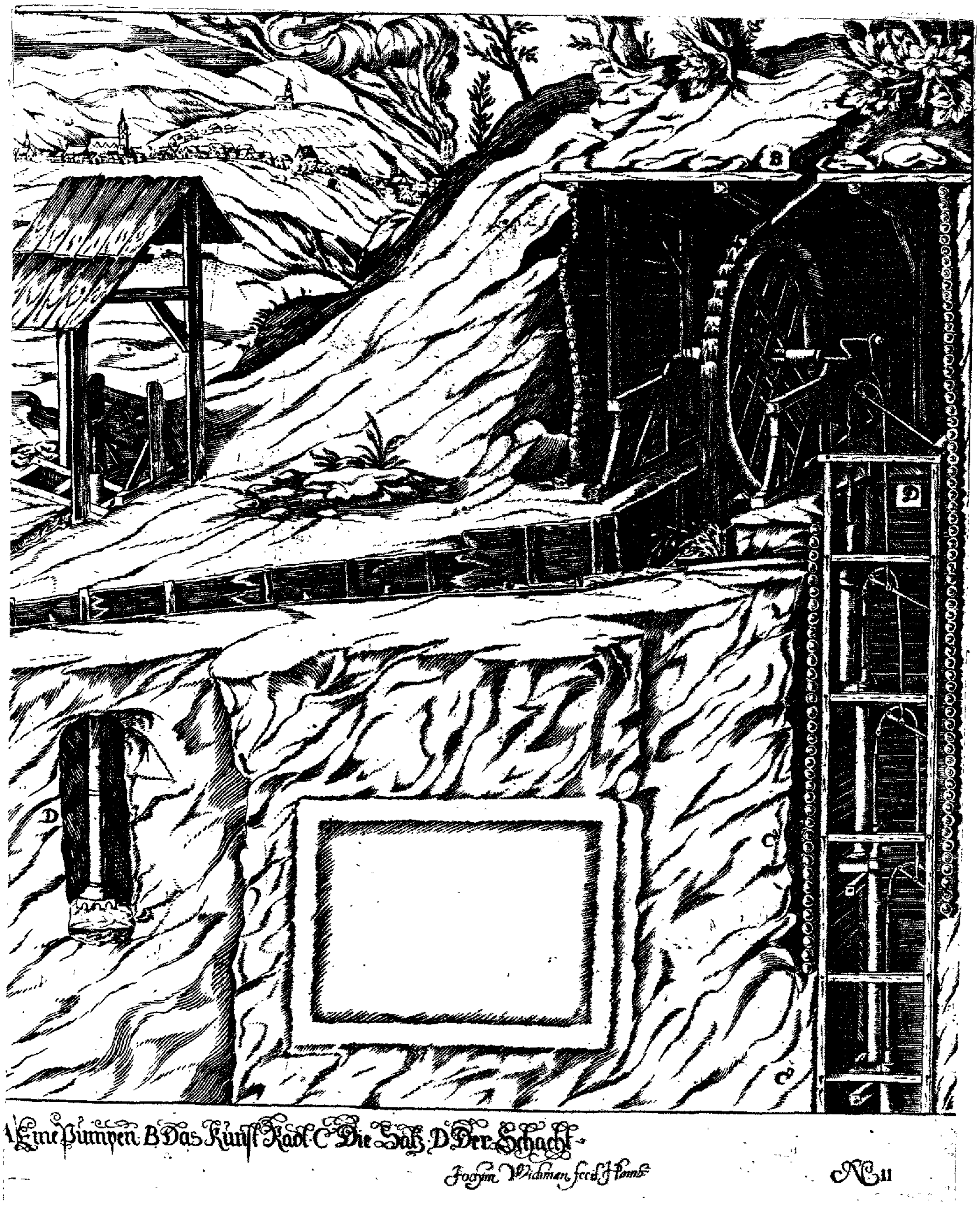
Such a system would work equally well in a vertical as in a horizontal sense although it would be to little purpose to use it to set a series of bellows one above the other. It is to a machine of the type of Pisanello's pumping engine as well as to these others working bellows that one must turn therefore if one is to seek the antecedents of the Stangenkunst. Imagine, for instance, Pisanello's machine turned about through 180°- in exactly the way the single crank version is handled in Leonardo's sketch in MS.B. f53v (fig. 6) - so that the connecting rods hang directly down from the handles of the cranks. All that is now necessary is for the analogy with a machine like Biringuccio's, or Cardano's, to flash across the mind of some engineer for him to see that the pumps, instead of being set side by side, might be placed one below the other. If, historically, it was the case that some modification of this sort was actually made to a machine of the form Pisanello had sketched, it would go far to explain, even perhaps it might be thought explain completely, the 'rationale' of the curious, not to say cumbrous, arrangement of rocker arms and rollers, pumps and piston rods which constitute sipho septimus, the Ehrenfriedersdorf machine (and which the gestalt would have imposed upon it). The marvel here lies not, of course, in the mechanical replication of those elements, skeuomorphic as they were, but in the splendid conception that pumps were not, as it were, by divine decree, immutably fixed in pairs positioned beside one another (like bellows) but might rather be arranged in tiers. It is tempting to think in all this that had deep mining work been as significant an activity south of the Alps as it was to the north of them, the exploitation of the suction pump in the manner of the Ehrenfriedersdorf machine might well have been grasped rather earlier. As it was, the problems of town water supply and the supplying of mechanically powered blast in metallurgical operations, although handled at an early stage with some sophistication in Italy, were not challenges of a kind remotely likely to produce such a response[23].

Now that the discussion has returned again to Agricola's sipho septimus it is time to take up the second object of this study, that is, the development of the machine after its invention about 1540. It was not, of course, the only device then in use in mines which worked pumps by means of a crank handle, for Agricola described two others, also newly invented, that were so arranged. The two water wheels of his pump number eight each worked a single pump in this way, while the wheel of his number nine set two columns of pumps in motion although it did so indirectly through a reducing gear with double cranks. These machines are defined in the Index Secundus of 1556 as the second and third new wheel pumps and had evidently appeared soon after sipho septimus (by implication the first wheel pump). Agricola indeed describes them in a manner which seems to suggest that both were conscious responses to the new situation created by the first.

Machine number eight was, for instance, to be built where the flow of water was insufficient to power sipho septimus, and number nine where it was great enough to drive more than a single tier of pumps[24]. When one considers the long history of crank driven pumps in Italy it is perhaps surprising to find them making so late an appearance in the mines of central Europe. Yet even leaving aside Agricola's evidence that this was so, it is clear that even in the 1550s and 1560s such machines were still uncommon. It has been mentioned elsewhere that Matthesius preaching to his congregation of miners felt it necessary to tell them (in 1559) that the crank handle of such a machine was shaped like a grind-stone handle, and that in the Harz in 1565 the author of a report on its introduction to Rammelsberg evidently felt that he had sufficiently identified it by saying that it was a water wheel with a crank handle, "Wasserkunst mit den krummen Zapffen"[25].

As for the mechanical arrangements of sipho septimus it is clear that at Joachimsthal in 1559 these were still unchanged. Matthesius' description of the machine working at the Elias mine at that time, just such a pumping engine as the Ehrenfriedersdorf wheel pump as he himself says, shows that it retained the rocker arms and rollers of the prototype: thus the rocker arm lifts the piston-rod and the piston sucks the water up..., "also heben das Hebearm das Gestenge, und der Kolben zeucht das Wasser auss..."[26]. Now despite the fact that Agricola went out of his way to stress the cheapness, usefulness and durability

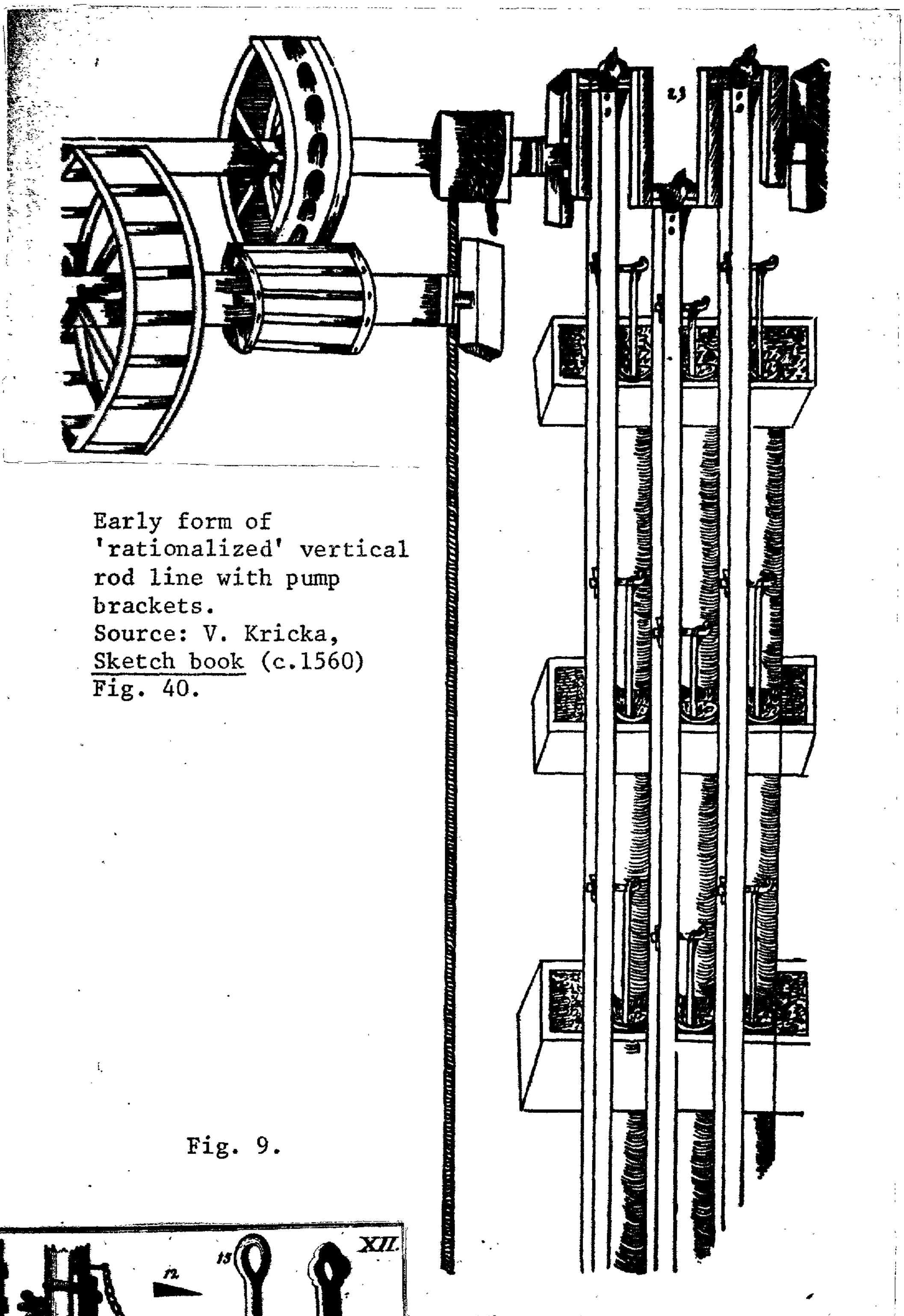
Fig. 7.



Stangenkunst of Agricolan type working through a tier of four pumps.
Source: G. von Lohneyss, Bericht vom Bergwerck..., Zellerfeld 1617, plate 11.

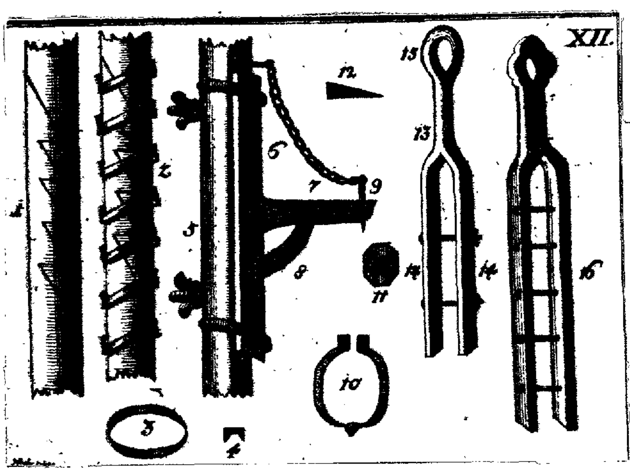
of this machine it is evident that its arrangements left something to be desired mechanically. Johann Lempe in 1799 in his commentary on the Ehrenfriedersdorf Radpompe went straight to the point when he invited readers familiar with the rod engines then in use in the Saxon mines to contemplate the shortcomings of the prototype from which they had been developed. No one, he says, would wish to reproach the ancient engineer who had first devised it, for once the basic idea of the machine had been conceived it was a comparatively easy task, calling only for common alertness, for those who followed him to observe its weaknesses of design and devise remedies for them. Nevertheless, when one considered the multiplicity of moving parts in the original machine and the penalty that had to be paid by reason of the sum of their frictions, it was little wonder that a water wheel could work only a modest tier of three pumps[27]. This was to take Agricola's drawing rather too literally for in fact the sipho septimus was extended to work four or perhaps even five pumps. This much is clear from the engraving (fig. 7) of such a machine in 1617[28]. All the same, as the machine was 'stretched' by the addition of each new pumping unit (pump rod plus rocker arm and roller plus piston pump) so one would guess that without some rationalization of the arrangements the total of frictions - and of breakdowns - would tend to become unacceptably large. In the developed form of the machine shaft or principal rods (Hauptstangen as they were sometimes called to distinguish them from piston rods)

Fig. 8.



Early form of 'rationalized' vertical rod line with pump brackets.
Source: V. Kricka, Sketch book (c.1560) Fig. 40.

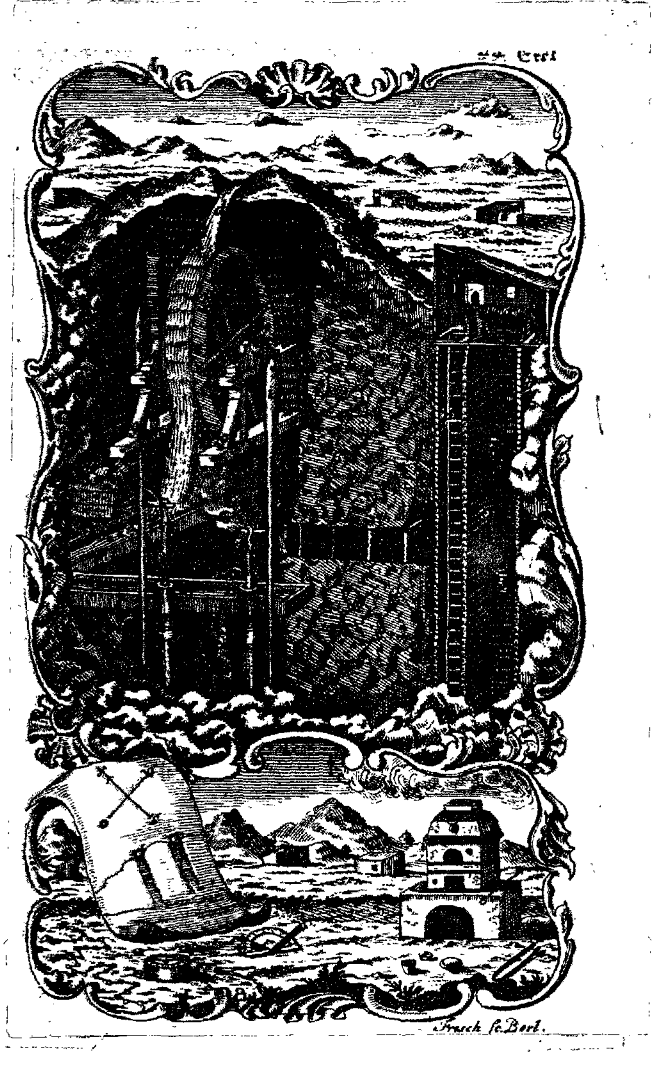
Fig. 9.



Mature form of shaft rod pump bracket (Krumpus).
Source: N. Poda, Kurzgefasste Beschreibung..., Prague 1771, Fig. XII.

many hundreds of feet long hung from the cranks of the machine. These were lengthened downwards as the engine shaft was deepened until the weight of the water column that had to be lifted became too much for the wheel. This was then said to have lost its heave (den Hub verloren)[29]. At regular intervals horizontal brackets were fixed to these rods to which in turn were attached the piston rods of the column of pumps they served. Although Matthesius' language seems to preclude the possibility that anything like this was yet to be seen in Joachimsthal in 1559 it is quite certain that in central Bohemia the substitution of Hauptstangen for Agricolan rocker arms had already taken place by that time. In the elaborate manual compiled about 1560 by the Czech engineer Vavrinec Kricka occur a number of careful drawings of Stangenkünste (fig. 8) all of which display the 'new' rod and bracket arrangement[30]. Kricka is known to have died probably by 1570 but in any case before 1576, so that his work is not far from being contemporary in time and place with that of Matthesius. But the changeover, one would guess, had not long taken place for by comparison with the standardized arrangements of later times Kricka's engines look decidedly flimsy. For the sake of heightening the contrast I would like to suggest a comparison of their constructional details with those of the Schemnitz engines (fig. 9) as they were described by Nicholas Poda in 1771[31]. This is not meant, of course, to be fair to Kricka but rather to reveal as starkly as possible the still experi-

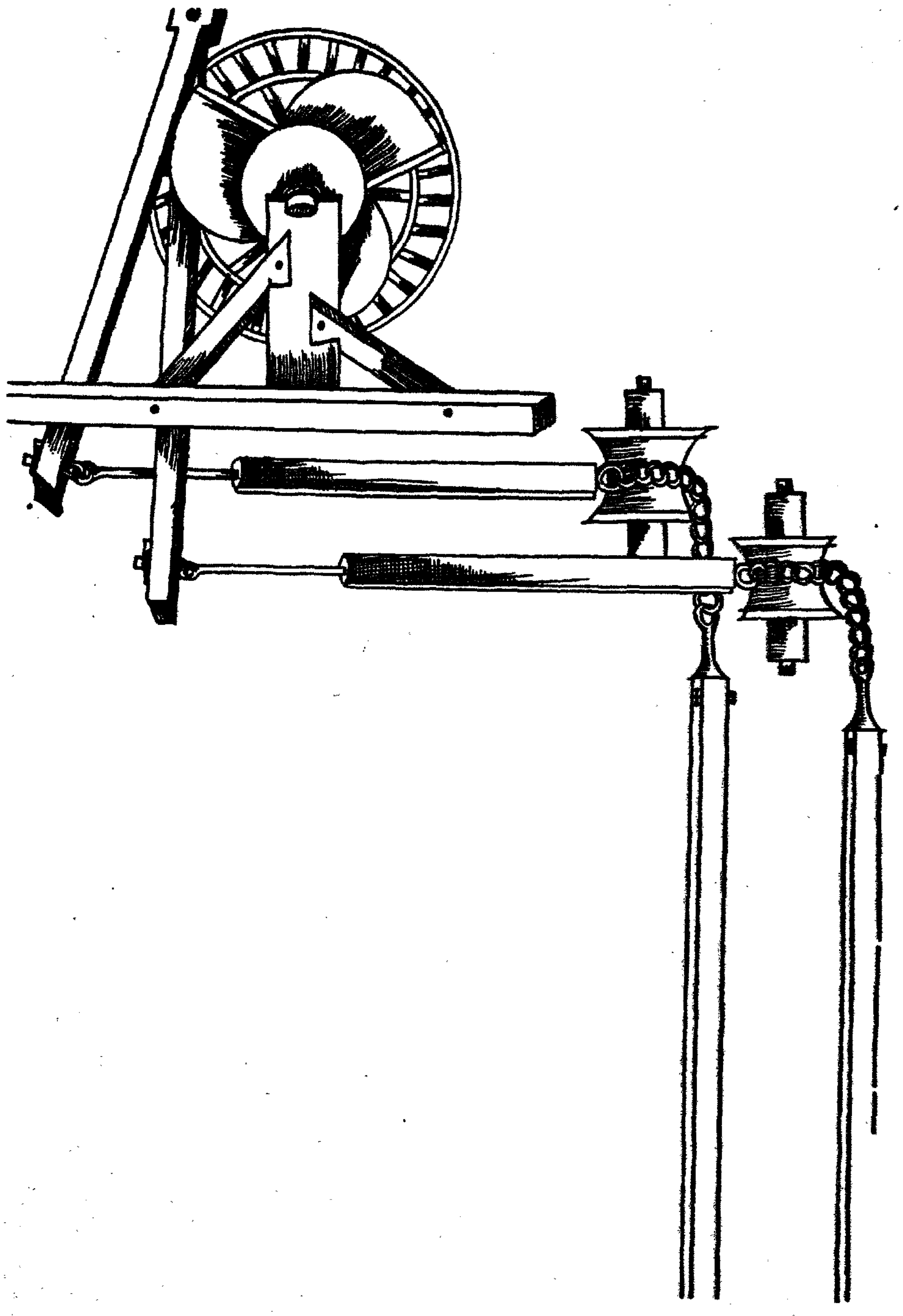
Fig. 10.



Standard over-the-shaft Stangenkunst with shaft rods attached to crank handles on either side of the wheel.
Source: J.C. Lehmann, Kurtze Einleitung ...der Bergwercks Wissenschaft, Berlin 1751.

mental nature of Stangenkunst design at the time when he made his drawings. It is clear, for instance, that only modest lifts were being attempted. This appears from the form of the bracket which he most often shows in use. It seems to be shown as consisting of little more than an iron peg driven through the shaft rod and secured at its further end with a cotter pin, whereas the manner of securing the integrity of the bracket (Krumpus) in Poda's description has obviously been the subject of careful thought[32]. Again, if one looks at the way in which the shaft rods are secured to the crank shafts in Kricka's drawings the simplicity of the arrangements is evidence enough of the early stage of the art. The shaft rods are attached to the crank shafts with what appear to be leather belts and buckles whereas later the most elaborately scarfed joints (Schlosser), iron-banded, ensure the durability of the clasp-work placed round the crank handle itself. A further instance of immaturity can be found in Kricka's schemes. It was standard practice later (fig. 10) to hang the shaft rods directly from the two cranks, one on either side, of the drive wheel axle itself and also always to separate the duties of pumping and winding, for the water wheels of winding engines (Kehrräder) had to be double-bladed so as to be able to reverse. All of Kricka's machines working suction pumps are driven indirectly through gearing or through toothed racks while two of them work not only three tiers of pumps but are also equipped in addition with bucket hoist gear[33]. But is Kricka really

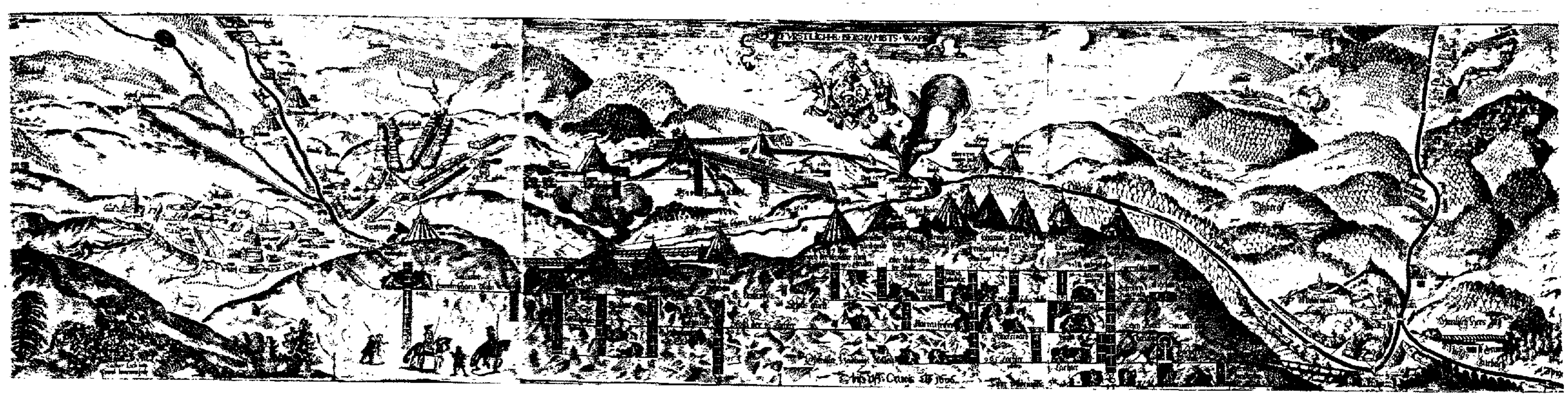
Fig. 11.



Proto-Geschleppe driven by cam action with anti-friction rollers.
Source: V. Kricka, Sketch book (c.1560), fig.44.

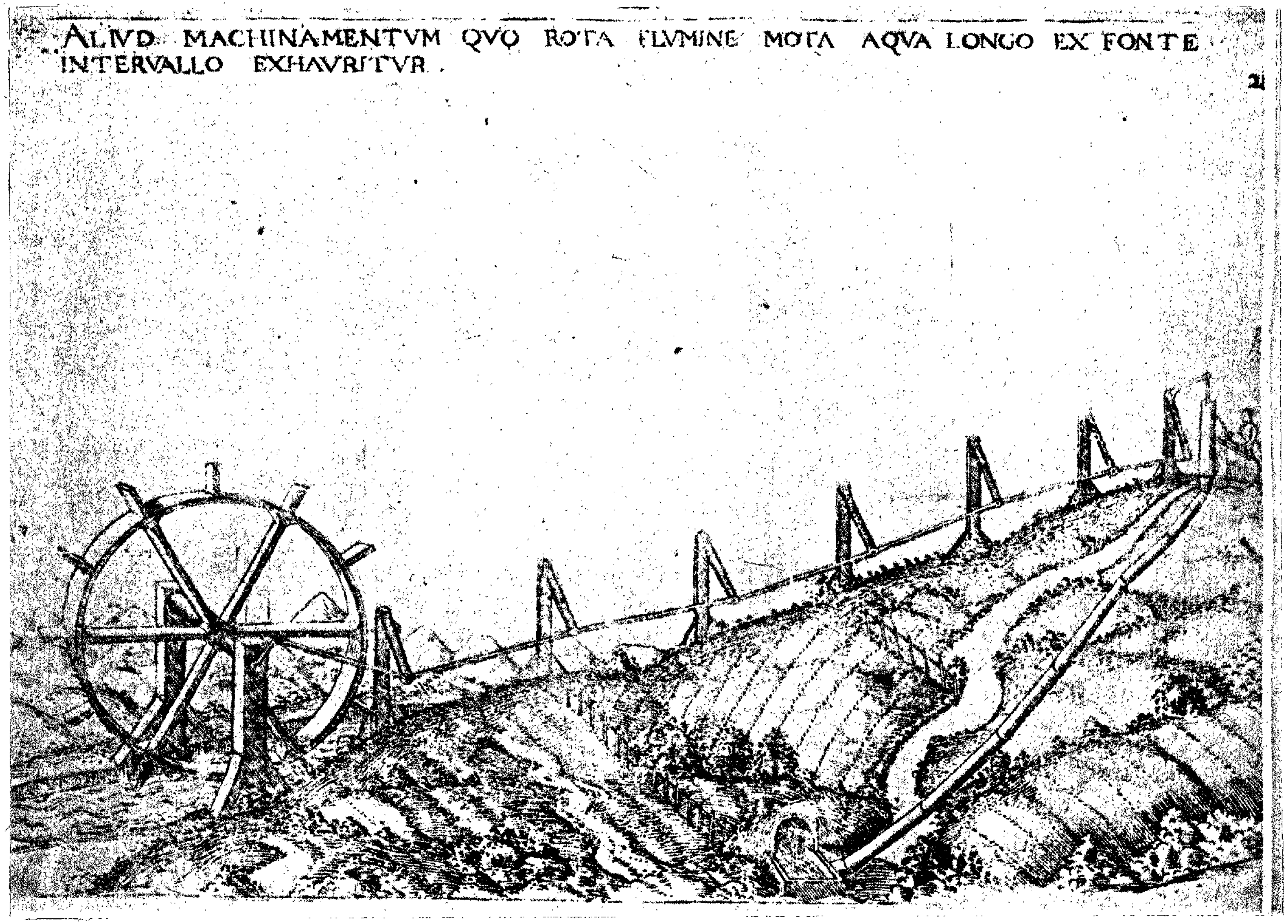
in the van of progress as I have assumed here or not? While it would be obviously unwise to place too much emphasis on his work in isolation, especially in view of the paucity of visual materials before one comes to the 18th century, one can say, with benefit of hindsight, that it does mark an intermediate stage both in the chronological and evolutionary senses of the word, between Agricola's drawing of the Ehrenfriedersdorf Radpompe of 1540 and the literary evidence presented by Berward in 1673 and Meltzer in 1684[34]. If in Meltzer's time the Stangenkunst had shaft rods a thousand feet long one can take it that their constructional arrangements were already like those later to be described by Poda. It is difficult to say more at this stage without anticipating what is to follow but Kricka's position in the mainstream of development can perhaps be even better illustrated by reference to another of his drawings. The machine in question (fig. 11) cannot on the criteria adopted here be called a Stangenkunst,but the substitution of a crank in place of the cams which drive it would immediately turn it into one (one assumes the series of pumps in the shaft as no doubt Kricka did). As it is, the cams on the axle of the motor wheel push back two rocker arms secured at their tops to horizontally positioned pin joints. The horizontal rods attached to the bottoms of the rocker arms are incipient if not actual field rods and under the action of the cams alternately raise the shaft rods to which they are attached. The whole ensemble in either case

Fig. 12.



Panorama of the mines at Clausthal and Zellerfeld in the Upper Harz showing nineteen runs of field rods.
Source: D. Lindemeier, engraving, 1606.

Fig. 13.



Single rod line suspended from supporting legs (Stage 1).
Source: J. Errard, Le premier livre des instruments mathematiques mechaniques, Bar-le-Duc, 1584, fig. 21.

is moved back to its resting position by the weight of the pump rods, shaft rods and water column. What I would suggest here is that just as Agricola's machine of 1540, given shaft rods, would (dropping the ur) become a Stangenkunst, so Kricka's machine of c.1560, given a crank connection, would become a Geschleppe or rather a proto-Geschleppe[35]. A Geschleppe (tugger) it should be noted here, is that most elementary form of Stangenkunst in which the motor wheel, at some distance from the shaft, acts through a single rod and thus sets in motion the column of pumps to which it is connected. Now it is certain that double rods (fig. 12) admittedly of rude design, were in existence soon after 1600[36]. Before that one has Jean Errard's engraving of improved single rods of 1584 (fig. 13) to provide a link between Kricka's adumbration and the latter event[37]. Leaving aside for the moment the question of where the idea of horizontal rods may have come from, enough has been said already to make it clear that the period 1560-1600 was a highly important one in the history of the Stangenkunst. By the latter date what one might call the machine's 'domain' had beyond question been established; what follows afterwards is essentially a lengthy period of critical revision. At the beginning of this period field rods did not exist, but by the end of it they had extended the usefulness of the machine in a most remarkable way. In 1617 Löhneyss could speak of transmission lines over a mile and a quarter long (800 to 1,000 Lachter) and show in his illustration

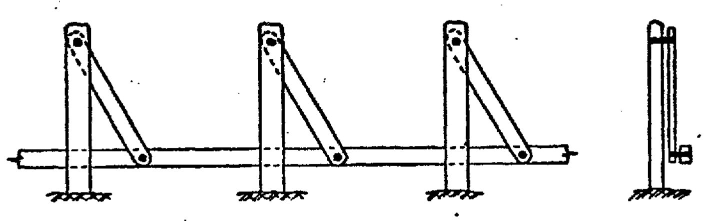
Fig. 14.

Double rod line with swing arms pivotting between double legs (Stage 2).
Source: G. von Lohneyss, Bericht vom Bergwerck..., Zellerfeld 1617, fig. 10.

of Stangenkünste equipped with field rods (fig. 14) that such machines were able to follow the contours of the ground which lay in their path. Just as the rod engine's vertical arrangements were being revolutionized in the 16th century so were the horizontal. Nomenclature was disturbed also and as one has seen, Löhneyss was tempted to confine the name Stangenkunst to the developed form of the machine equipped with field rods[38].

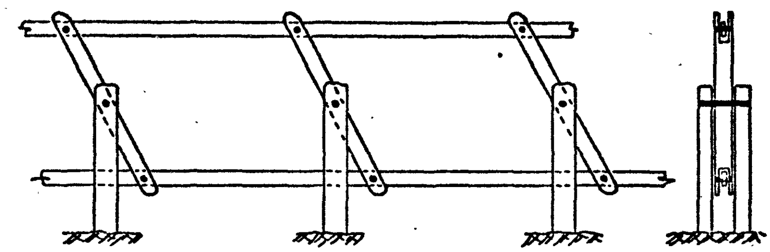
But where and in what period had field rods been developed? When Calvör came to discuss this question in 1763 he had only Löhneyss' work as evidence before him. However, when he compared the field rod construction of his own day with the details of the rods shown by Löhneyss in his engraving he was much struck by the latter's rudimentary nature and felt able, in the light of this, to conclude that field rods could not then have been long in existence. But there is little reason for thinking that the Harz was ahead of other areas of Germany at this time, and certainly Daniel Lindemeier's panoramic view (fig.12) of the mines at Clausthal and Zellerfeld in 1606 showing no less than nineteen runs of such field rods of really quite formidable sizes and extension forbids any easy belief that one is very near the beginning in 1606. It would in fact be easier to suppose that he was celebrating the <u>conclusion</u> of a lengthy building programme[39]. All that Calvör could report was that it was the locally held belief that the first field rods had been set up at Clausthal by George Illing about the beginning of the

17th century[40]. But nobody, and certainly not Calvör, claimed that he had invented them. A beginning must nevertheless be sought. If one were to assume that the single rod (Geschleppe) type was the earlier of the two machines it would then become possible to demonstrate in a formal way the steps in a sequence of changes which led to the standardized field rod construction technique of the second half of the 17th century, a method in fact so satisfactory that it had not changed even a century later when in 1763 Calvör took up the problem of its origin. The very first step may be shown by making a simple comparison between Jean Errard's machine of 1584 and Kricka's drawing of c.1560 of a device which I have called a proto-Geschleppe. The horizontal rods of this second machine are supported by anti-friction rollers. If such a rod system were lengthened and further rollers supplied to support the weight of the rods then a simple form of machine working through flat rods would result. The loss of energy caused by friction in such systems was, as a number of later writers stress, very great. Was it possible therefore to lessen such losses somewhat by suspending the rods in some way or other?[41]. Jean Errard's engraving of 1584 of a water wheel acting by means of a single suspended rod is clearly to be understood as an attempt to answer such a question[42]. But one need not suppose that it was Errard's own answer, for despite his claim that it, like everything else, "sort premier de ma boutique", one would probably not be far wrong in thinking that his little book was largely, if not wholly, a reflection of the schemes real and projected that were then in the air. I shall suggest below that field rod systems of one sort or another, far from being simply in the air, were already known and practised in several parts of Europe at the time Errard was writing. What I wish to draw attention to here is that the system shown in his engraving, that is, a single rod suspended by arms hanging from the pin joints of a row of vertical posts, forms a logical intermediate step between simple flat rods moving on rollers and the double rod system in use already by 1606 but first clearly shown in Georg Löhneyss' engraving of 1617[43]. One should first consider Errard's sytem when seen in profile:



This I shall call stage I.

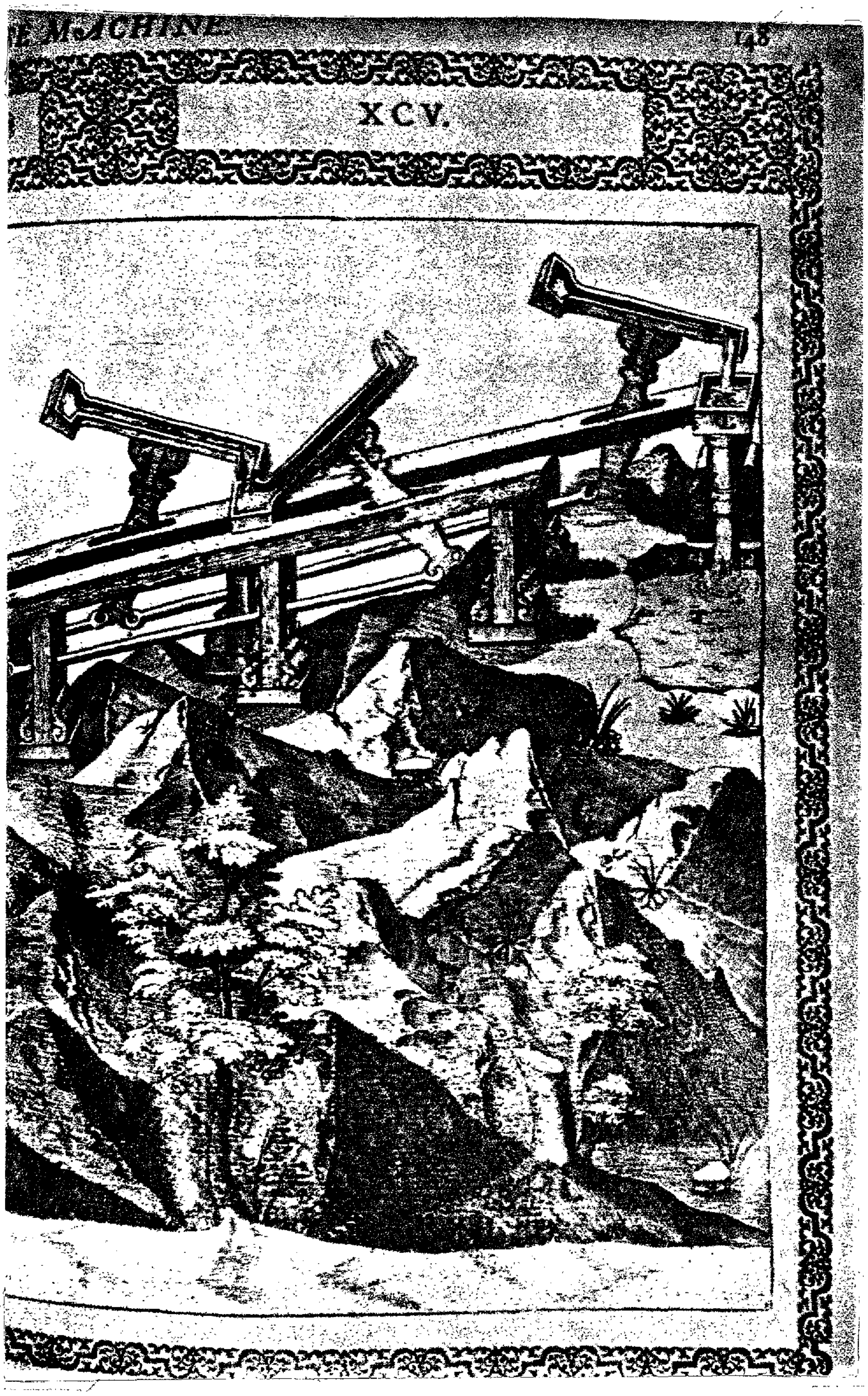
The profile of stage I may now be compared with the one obtained in a similar fashion from the field rod design shown in Löhneyss:



This I shall call stage II.

What emerges is clear enough: Errard's system has been doubled with an astonishing completeness and symmetry. The gain in mechanical advantage that resulted from this modification was considerable. The problem with a single rod line was how to keep it in simple tension on the gravity return stroke. Doubling the rods ensured that whichever of the lines was being pulled back by the water wheel would automatically push forward the other through the motion of the swing arms. In addition such a system permitted two columns of pumps to be worked simultaneously by a single wheel. It would be to run ahead unduly to pass immediately to a consideration of stages III and IV, but one may say in advance that the sequence can be shown to continue with an equal limpidity of conception. The significance of Errard's engraving lies, as I have suggested, in the fact that it reflects the significant advances that were being made (rather before 1584) in the long distance transmission of power. Only a little later Ramelli in plate XCV of his <u>Diverse</u>

Fig. 15.



Single rod line with swing arms centrally positioned in the horizontal bracing timbers.
Source: A. Ramelli, Le diverse et artificiose machine, Paris 1588, plate XCV.

<u>et artificiose machine</u> of 1588 (fig. 15) affords a further instance of a machine acting through single rods which are, like Errard's, suspended from swing arms. Although the constructional details of the other parts of Ramelli's machine are not of direct relevance at this precise stage of the discussion it will be useful as a hint of what is to follow to notice the robust character of the timber work with which he supports his rod lines. The horizontal beams which rest on the tops of the supporting legs might well seem to be fruit of experience gained from working with unbraced free-standing legs of the Errard type. Any such line of legs would tend, it may be suspected, to work loose by reason of the constant pulling to which the rod line would subject them. This source of weakness would certainly be greatly diminished if they were held rigidly in position by means of horizontal bracing timbers placed on top of them. It is interesting in this connection to note also that the swing or rocker arms, no longer pinned to the legs themselves, are now suspended at the mid-point of the horizontal beams. But should one subject plates drawn from the machine books to this kind of analysis? Are they not being taken very much more seriously than they deserve? It might be, however, an even more grievous error to under-estimate them by supposing that they are merely entertaining technical fantasies remote from reality. The themes of such works, if not the variations played upon them, have much to tell us, in my view, about contemporary technical actuality. They may

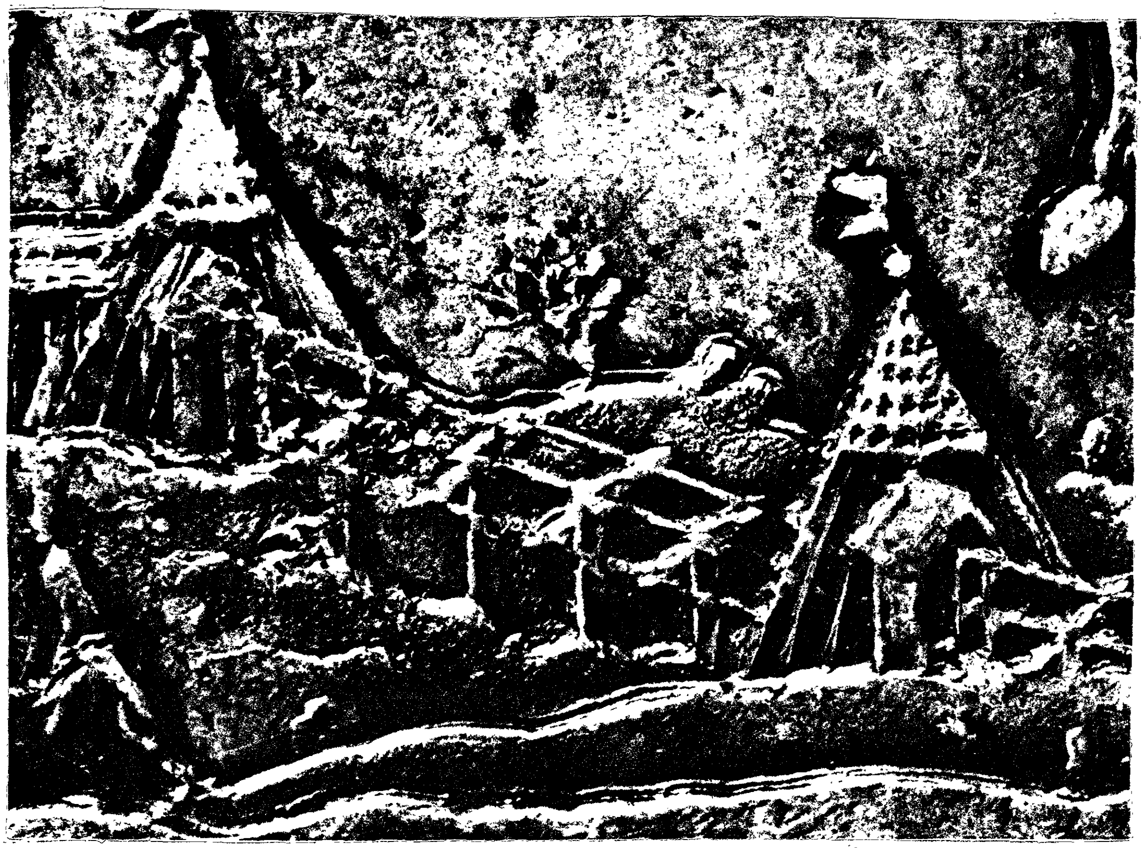
serve, in short, in default of workshop manuals such as Kricka's, as highly significant indicators within the limits of their authors' locale and interests, of new and developing technology.

Ladislao Reti's painstaking work in establishing the nature of Juanelo Turriano's achievement at Toledo in 1569 lends enormous support to such a view especially insofar as it bears on this particular case[44]. What Reti has demonstrated beyond all doubt is that by 23rd February 1569 Turriano had constructed some sort of field rod system in order to set in motion the six sets of oscillating troughs of his celebrated Artificio. This machine lifted water to a height of one hundred metres from the river Tagus to the Alcazar, the highest point in the city. By 1581, he had set up a second such machine beside the first. It is hardly necessary to insist here on any of the detailed argument by which Reti seeks to complete his account of Turriano's work except that part of it devoted to the field rods, the central feature of the machine. The length of the line from the river Tagus to the foot of the north east tower of the Alcazar is approximately 300 metres, a distance which corresponds closely, according to Reti, to the figure of 1,000 Castilian feet stated by Lizalgarate in 1613 to be the length of the machine. The rod line had clearly to accommodate itself to the broken ground leading to the Alcazar and had in addition to turn a corner as well in order to get past the convent of El Carmen which lay in the path of the direct line. Since one of the prime features of the ur-Stangenkunst was the rocker arm and roller, one may presume that such devices, disposed both vertically and horizontally, permitted Turriano to deal successfully with changes of direction in two planes. But how much of all this was original with Turriano? Some twenty-five or more years before he arrived in Toledo German engineers had brought together most of the elements he was to use and more particularly had demonstrated the idea of transmitting power through what were really enormously extended connecting rods even if the pumps they set in motion were arranged vertically rather than horizontally. One might indeed look even further back still to Biringuccio's experimental work with small scale assemblies of horizontal bell-cranks and rocker arms in 1510 at Boccheggiano to see an altogether more familiar cognate form, widely diffused enough I have no doubt, to afford hints to engineers on either side of the Alps[45]. However, in default of evidence to the contrary it seems reasonable to take Turriano's machine as a terminus a quo as far as field rods and direction changing devices are concerned[46]. Nevertheless one knows that the future lay with double rods for it seems clear that although short runs of single rods worked well enough, longer runs were apt to give trouble. It is a very noticeable feature of the later technical literature having to do with the subject that although the Geschleppe is regularly mentioned, it is as regularly condemned: it was over-delicate and liable to breakdown; it demanded extra care in fabrication and so on. It must, however, despite this, still have been the case that before double rods became available longer runs were from time to time attempted. A water-driven machine, prone to breakdown and requiring considerable attention, was still a more attractive proposition than employing much more costly means such as men and horses, even if economies on the scale Martin Planer had achieved at Freiberg in 1557-1570 with conventional Stangenkünste were not to be hoped for*. All one can say is that between 1569 and 1605 - and more likely in the 1580s than later - someone at last saw a way of curing the Geschleppe's congenital weakness. This weakness arose, of course, from the difficulty of ensuring that a long rod was always in a state of simple tension. While the throw of the crank was drawing back the rods and lifting the column of water in the pumps all would be well assuming that the line did not part somewhere under the strain. On the return stroke, however, the water wheel would tend to accelerate as its load was taken over by the descending weight of the water column. It was here that precision in construction was important for were there any slack in the line there was a distinct danger that the pull of the water column on the field rod might be outpaced by the speed with which the wheel was pushing the rod forward. If this happened the line would first buckle and then most likely be wrenched apart. However, the fact is that such single lines continued to be built long after double rod systems became

* See note 73 below for details of Planer's achievement.

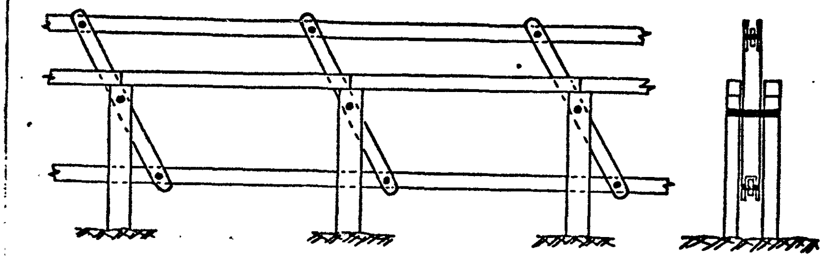
available, from which one must presume that such problems were overcome and that carefully built Geschleppen gave satisfaction[47]. At this point one may take up again the evolution of the double rod system from stage II. For convenience of reference I shall call the stage II rods of 1606 and 1617 <u>primitive</u> double rods. This primitive form consisted of a vertical swing arm (Schwinge) turning on its axis between the two upright posts (Bocke) which supported it. The upper and lower field rods were, of course, joined to the two ends of the swing arm. One can imagine,however, that the movement of swing arms and rods led to a good deal of line maintenance work as first one pair of supporting legs and then another began to work loose with the backward and forward pulls of the field rods. The move to stage III, or intermediate type field rods, was taken, one would guess, in order to avoid, or at least minimize, just suchleg-shaking caused by hundreds of yards of shoving and heaving timberwork. What was now added to the system was long horizontal timbers, arr-anged as a double row. Although one cannot be certain it seems highly likely that these were bolted down on the tops of the legs so as to brace them against shock. The tops of the legs were by now having to accommodate rather a large quantity of ironwork - the horizontal timber bolts and the axis of the swing arm - and were probably consid-erably weakened as a result.

Fig. 16.



Detail: double rod line with horizontal bracing timbers (Stage 3).

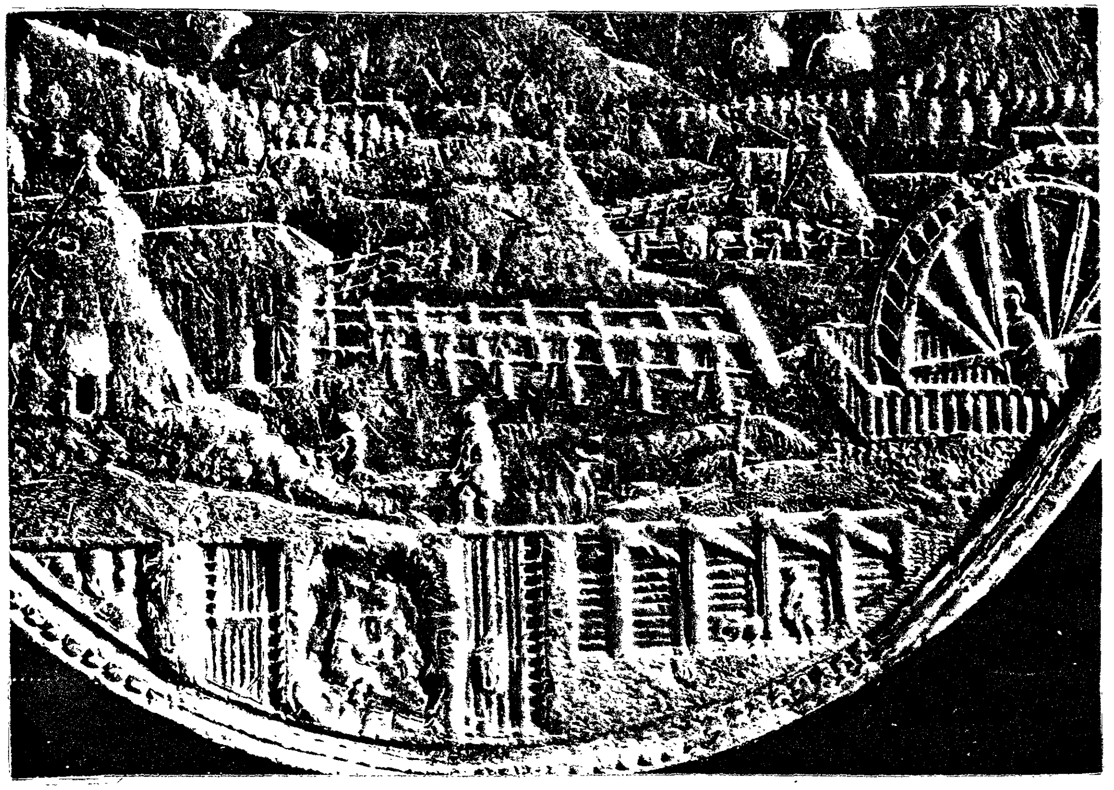
Whole face of coin: the wheel house at lower right and rod lines serving two shafts.
Source: L. Weber, Clausthal thaler of 1657.



Stage III.

Later on one learns some of the names for these members: Stege (catwalks) 1673, 1700, 1704, 1710, 1712; Strecklingen (stretchers) 1773; and most expressive of all, at least in German, Strosse or Strassbaüme (way timbers) 1693, 1710, 1773; but the visual evidence for such things is here available rather earlier than that provided by literary sources. On the reverse side of a series of multiple thalers (Lösers) engraved in 1657 by Lippold Weber at the Clausthal Mint in the Harz for Christian Ludwig, duke of Brunswick-Lüneberg (1648-1665), the 'new' system is clearly visible (fig. 16). I place 'new' in inverted commas since the fashion for showing Gopel, Feld-Gestänge and Wasserkünste had not then long been in vogue and 1657 is as a consequence a more than usually arbitrary date[48]. The intermediate system no doubt yielded more satisfaction than its predecessor but perhaps the desire to build longer runs of rods, perhaps a purely internal process of refinement prompted by its imperfections, yielded the realization that now it was no longer necessary to place the strain at just that place (between the legs) where it was most likely to cause trouble. Once a line was fitted with Strassbaüme the possibility arose, even if it was not immediately perceived, of shifting the swing arm away from the legs to the mid-point of the parallel horizontal beams lying above them. Such a move, and the placing of a strengthening cross-piece on the legs for the Strassbaüme to rest on, is the final step to standard field rod construction. This time the literary evidence is earlier than the visual in establishing a *terminus ad quem* for this event. It is provided by Christian Berward's technical dictionary of mining and metallurgy, a work commissioned by the Brunswick Board of Mines[49]. Berward was first Berggegenschreiber (mine clerk) and then Bergschreiber (mine secretary) at the Grubenhagen mine in the Oberharz and died in that office in 1676. Three years before this his dictionary had been printed for the first time (in 1673) as an appendix to Lazarus Ercker's *Beschreibung Allerfürnemsten Mineralischen Ertzt und Berckwercksarten*. The two works were printed together again in 1684, 1702 and 1736. The familiar terms are, of course, to be found there, but a new word has joined them: Holm. The entries in question are worth quoting in full: "Bocke an der Feldkunst sind lange Holtzer/so in die Erde bevestiget/und den *Holm* und das Steg tragen": "field rod supports are long timbers sunk in the earth which sustain the horizontal trestle cross-piece (Holm)

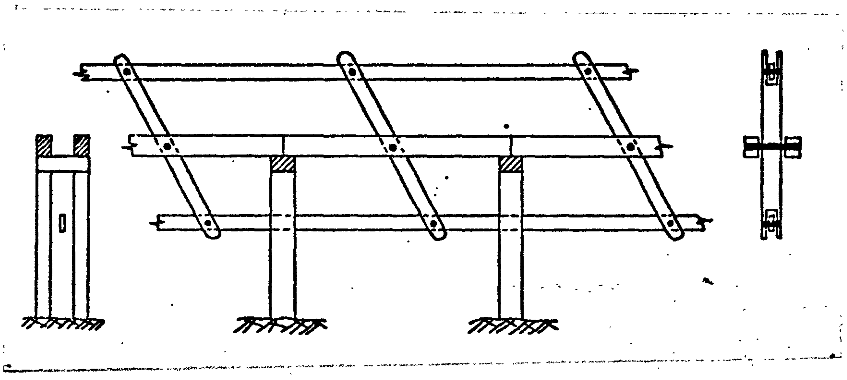
Fig. 17.



Detail: double rod line of standard design (Stage 4).

Whole face of coin: the wheel at lower right working rod lines to three shafts.
Source: H. Bonhorst, Clausthal thaler of 1677.

and the horizontal bracing timbers". As for the Stege themselves they are: "Holtzer/so die in lange liegen/ zwischen welchen die Feldkunst schiebet": "timbers lying lengthwise between which the field rods reciprocate"[50]. Stage IV (standard) rods appear thus:



One would hesitate, of course, to be as dogmatic as this in the matter were it not for the fact that the design appears soon afterwards on a commemorative medal and a series of multiple thalers struck at the Clausthal mint in 1677. These pieces appear to be the first artistic work (fig. 17) done at Clausthal by Heinrich Bonhorst who had been sworn in as Münzmeister to Duke Johann Friedrich (1665-1679) on 24th February 1675 in succession to Lippold Weber. One would expect him to cut new dies, of course, but was he simply more observant than old Weber who was still showing stage III rods on one of his thalers as late as 1672? Whatever the answer, the pieces Bonhorst issued in 1677 were not only up-to-date in the technical detail they recorded but are in a totally superior class to Weber's in point of execution[51].

It will perhaps have been apparent for some time in this history that an unduly large proportion of the evidence relating to the Stangenkunst's development comes from the Harz region[52]. Important as this area was, it would be idle to pretend that Saxony and Slovakia did not far outstrip it and yet for some reason the Harz attracted more artistic and scholarly attention than the first and incomparably more than the second. The point is worth taking up because it might seem, conceivably, that what one has seen unfolding here is some purely regional development rather than a region responding, probably with some delay, to innovations generated elsewhere. Given the paucity of materials generally, most acute of all in the case of Slovakia, the region ironically in which it is fairly certain from the general history of central European mining that the bulk of the developments in mining technology took place, it is not easy to assuage such doubts. Two things can be said, however. The first is that when Montesquieu visited the mine towns of Slovakia in 1728 he was evidently carrying in his luggage a copy of Georg Löhneyss' Bericht vom Bergwerck of 1617. He noted that "ce livre est considérable parce qu'on y voit comment on a travaillé anciennement aux mines du Hartz comme Agricola a été dans les mines de Saxe". This was a well observed remark for he was referring specifically to Löhneyss' figure 11 which shows a tier of four pumps worked not by a master rod but by a series of rocker arms: "chaque pompe avoit une machine particulière; ce qui faisoit beaucoup de frottement et

Fig. 18.

Standard field rods (Stage 4) of c.1680-85 at Marly.
Source:
J. Desaguliers, A Course of experimental philosophy, London 1744, Vol. 2, plate XXX after B.F. de Belidor, Architecture hydraulique, Paris 1739, Vol. 2, Ch.4, Plate 18.

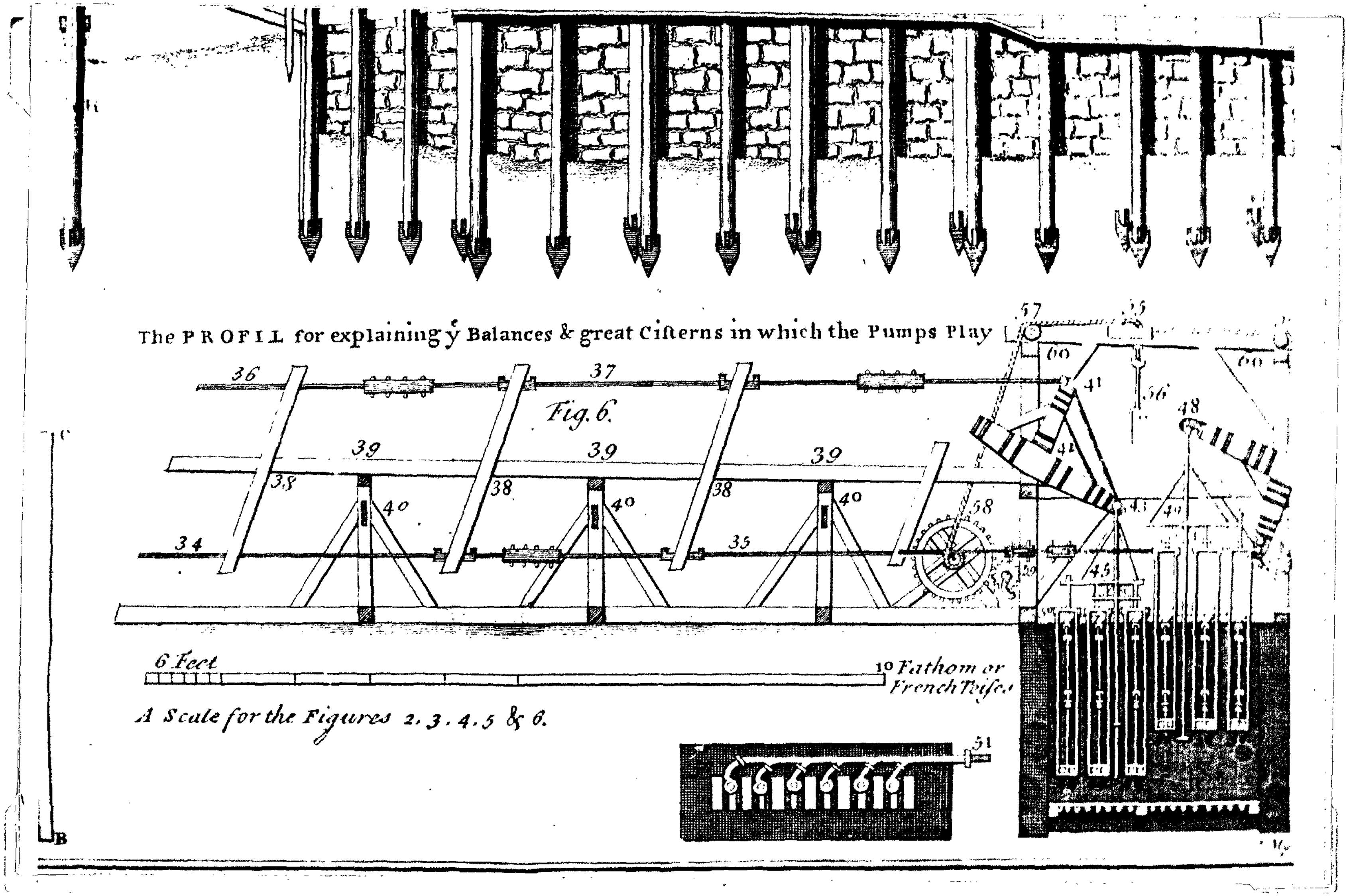
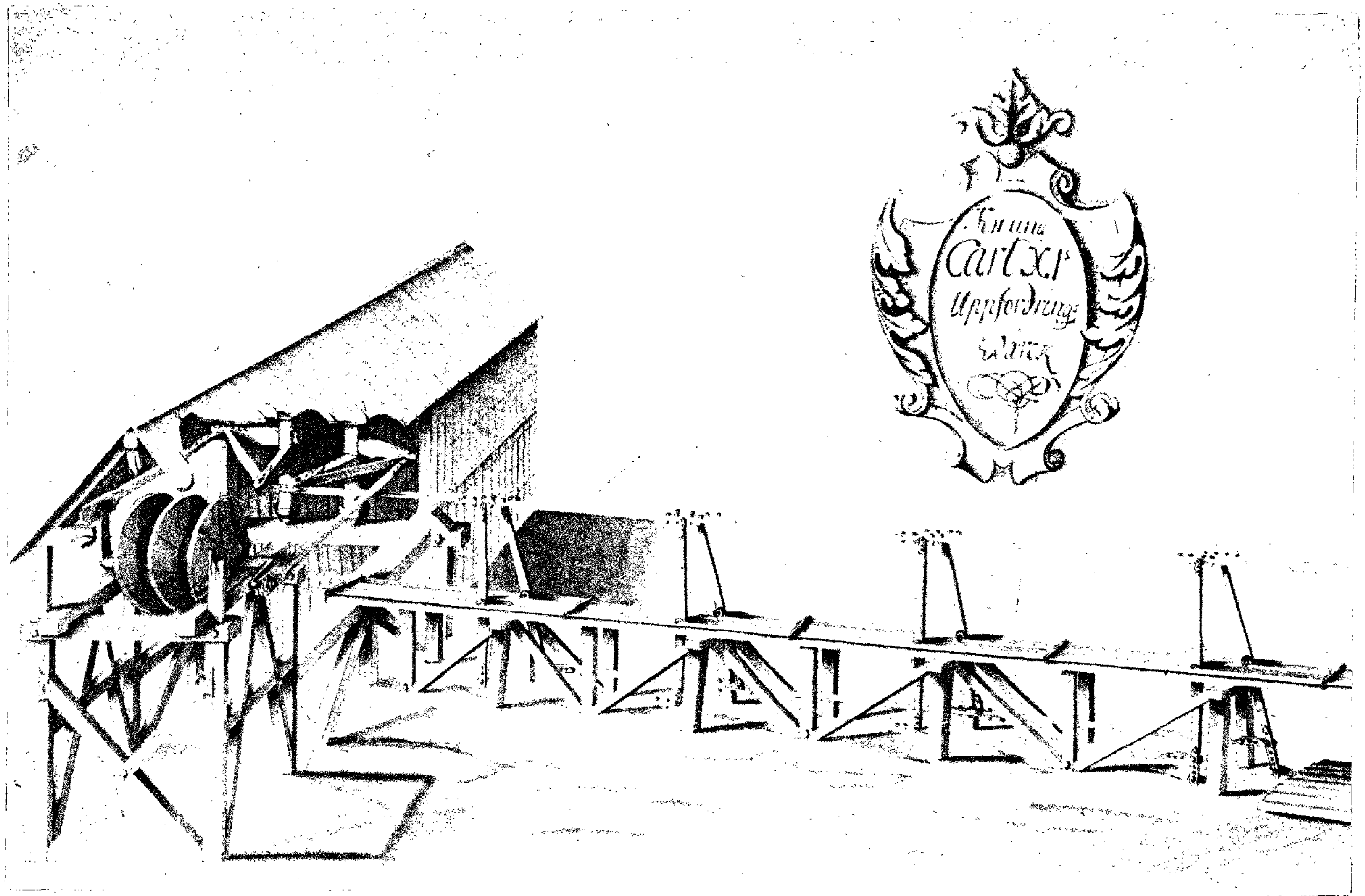


Fig. 19.

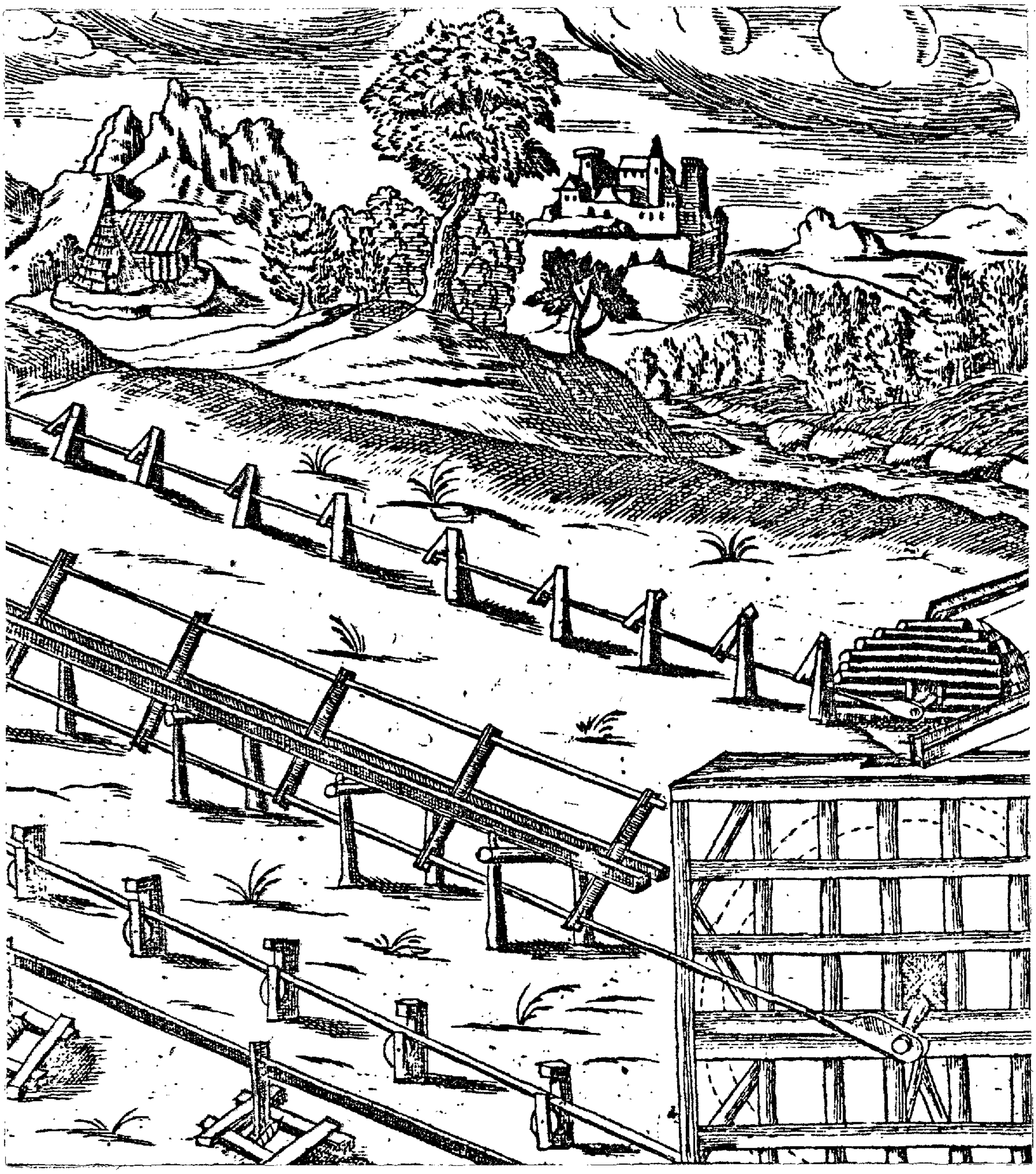
C. Polhem's rod driven hoist at Karl XI shaft, Falun, built in 1697-98.
Source: S. Sohlberg, <u>colour washed drawing</u>, 1731.



beaucoup de pesanteur à vaincre". He concluded that "autrefois dans chaque mine, chacun faisoit ses travaux sans guère profiter des inventions des autres"[53]. This certainly seems to have been true of the Harz in 1617 for elsewhere, as has been noted, rocker arms had been dispensed with some fifty or sixty years earlier. Nor is it possible to suppose that Löhneyss was not familiar with the machinery used for pumping. At the time his book was published (on his own private press at Remlingen) he was director of the Zellerfeld mines and had himself etched many of the plates that were to illustrate his text. On this showing the Harz was something of a backwater and the surmise that forms in the mind is that possibly Löhneyss' field rods were as antiquated as his rocker arms. And what of the improved systems of 1657 and 1673 in such a case? The existence of stage IV rods disclosed by Berward's glossary of 1673 leads to the second point.

When the field rods at Marly were set up in the early 1680s their design (fig. 18) was thoroughly modern (i.e. standard stage IV) and Rennequin Sualem's affiliations were, of course, not with Brunswick but with the Liége-Meuse coalfields, a region into which field rod technology had first been introduced about 1600. The field rods of the machine which drove the drums of the hoist at the Karl XI shaft, at Falun in Sweden, a machine designed by Polhem and virtually complete at the end of 1697, were of standard design (fig. 19). Again when Rössler illustrated in his 'Brightly Polished Mirror of Mining' the

Fig. 20.



Three types of single rod lines and standard (Stage 4) field rods. Source: B. Rossler, <u>Speculum metallurgica politissimum</u>, Dresden 1700, fig. 13.

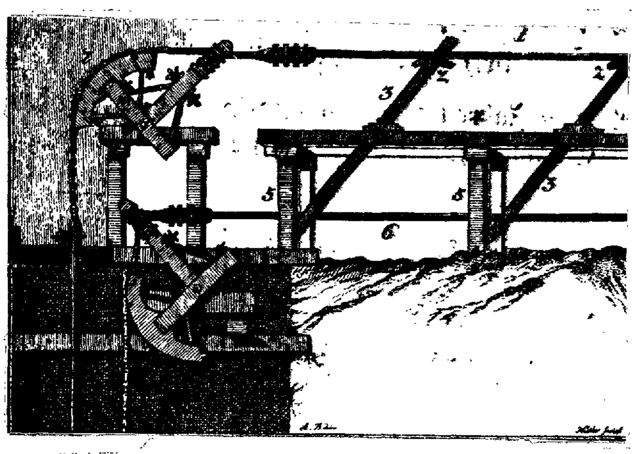


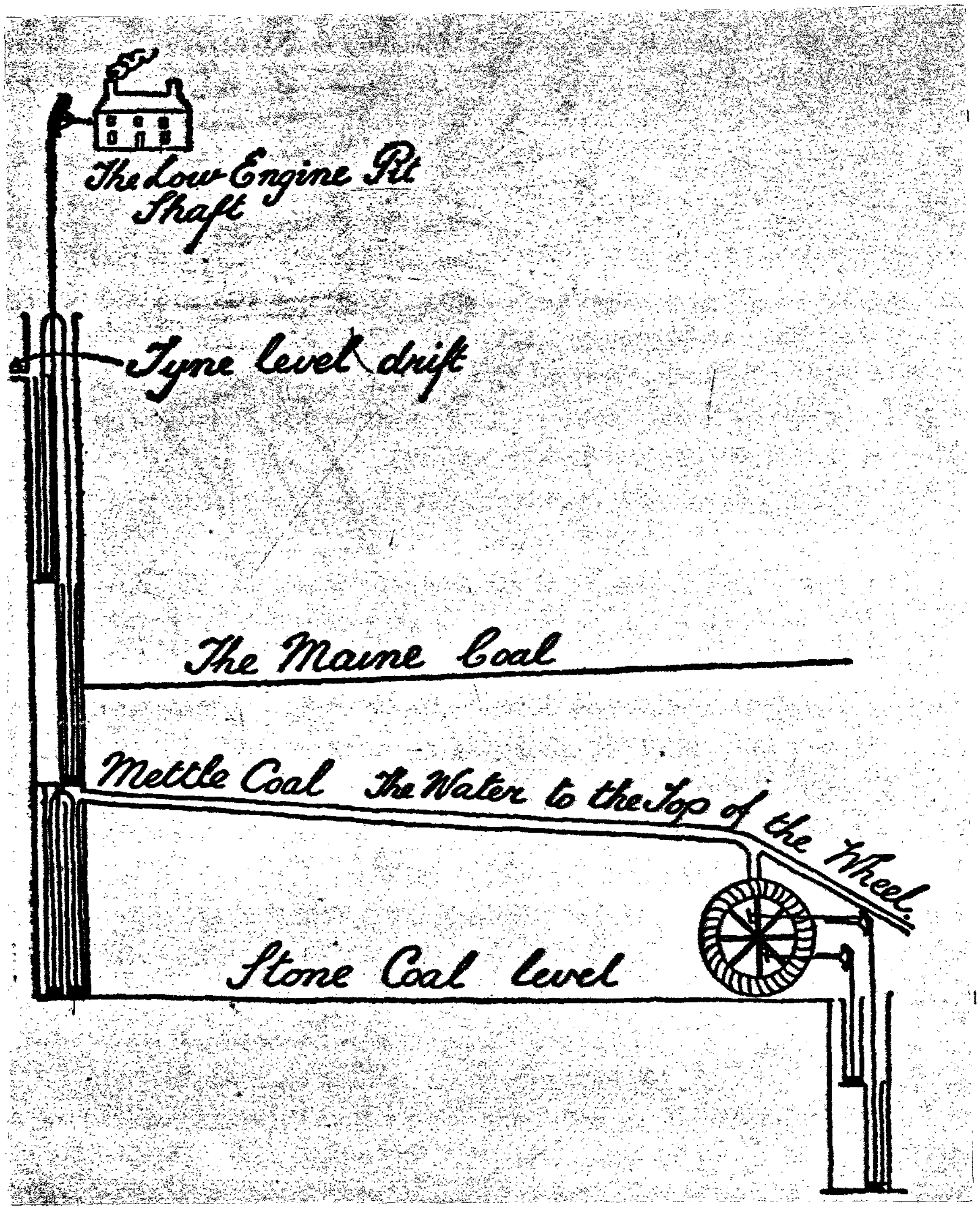
Fig.21.

Standard (Stage 4) field rods with T.bob (sector and chain) attachments built in 1711 by M.C. Holl at Windschacht. Source: N. Poda, <u>Kurzgefasste Beschreibung...</u>, Prague 1771, fig. XVI.

the types of field rods in use in Saxony in 1700 the only double type shown is the standard one (fig.20). The same was true also of Windschacht in Slovakia (fig.21) where indeed in 1711 a solution was at last found to a longstanding problem (not yet mentioned) which the very invention of double rods had created over a century before. On balance, therefore, I would very much incline to the second of the two possibilities mentioned above, that what one is seeing in the Harz is a regional response to innovations begun elsewhere. The question of quality of evidence is one to which in any case I shall return later in discussing more specifically the manner of the diffusion and geographical extension of the Stangenkunst. By the end of the 17th century the Stangenkunst had really reached maturity in the sense that not much remained to be added to it. I shall not attempt in this study to go into the question of its diversification into ore and spoil winding, yet by the 1670s at latest the possibility of supplementing the over-the-shaft Kehrrad (Bremsmaschine) winding engine, or rather remedying the want of such a machine by powering the winding drum by rods driven from a distant motor wheel was very definitely attracting the attention of hydraulic engineers. If evidence for the early history of the echt Stangenkunst is exiguous the situation might be described as desperate for the rod driven hoist. Yet Becher, as has been remarked, had claimed the idea as his own in 1682[54], and Papin refers obliquely not to possibilities but to actual practice in a paper of 1688 and again in the Recueil of of 1695[55]. Then again the substitution of reciprocating rods for winding drum and ropes, a feature of Polhem's machina nova of 1694 at Falun, Dalekarlia, presupposes some background, a few years at least, of conventional practice[56]. Polhem's idea seems to have been copied, at least as far afield as Brunswick, for Gabriel Jars' description of a hoist in operation at Treseburg in the Oberharz (north east of Nordhausen) leaves very little room for doubt that rods and hooks were involved[57]. Certainly it is more difficult to believe that the so-called man-engines (Fahrkünste) of the 19th century sprang fully armed from some Harz mine engineer's brain than that they represented some scarcely sustained continuous experience of Polhem's technique[58]. Such big leaps, after all, excite equally large questions.

All these interesting matters deserve separate consideration and I mention them now only by way of indicating how a more comprehensive description of the Stangenkunst than the present one would have to be developed from the 1670s. However, the field-rod machine pure and simple had still some modifications to be made to it in the 18th century, the most notable of which was the work carried out at Schemnitz in 1711 by Oberkunstmeister Mathias Corvinus Höll, a man grievously put in the shade by his son Joseph Karl. Höll senior was, however, a fine engineer and is described by von Wurzbach as "ein geschichter und grundlicher Mathematiker"[59]. To understand the problem he solved one must go back to the time when double

Fig. 22.



Water wheel fed by an atmospheric engine working two pumps in echelon through T.bobs.
Source: A. Barnes, View Book, 1733.

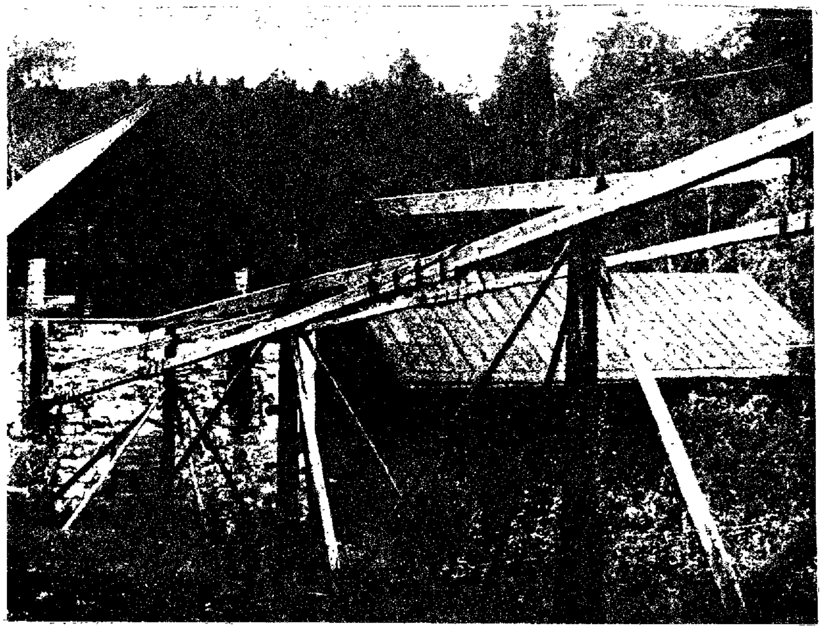
rod engines began to oust the single rod types. Where the two rods of a double field rod reached over the shaft they were connected to two arms of a cross (Kreuz, Winkelarm) to whose other two arms the shaft rods were joined (fig.14). The friction of the pistons against the sides of the pump barrels (especially the upper ones of the tier) resulting from the failure to reconcile the two sorts of motions, circular and straight line, brought together in the Kreuz was the price that had to be paid for keeping the field rods in simple tension. It is unfortunately not clear how the change in the direction of motion was handled in the Geschleppe for during a period of nearly two hundred years, between Kricka's proto-Geschleppe of c.1560 (fig.11) and a sketch of a tug-rod engine at Heaton colliery made by Amos Barnes in his View Book in 1733 (fig. 22) there is a total absence of evidence[60]. If one had to guess, however, about the way development had proceeded it would be that the way things were managed at Heaton in 1733 had long been established practice, and not only in England. Barnes' sketch shows two quarter circles (sectors), or T bobs as they were then called, each of which would be drawn back in turn by the throw of the double crank water wheel. The whole ensemble is referred to in the sketch as the "Bob Ginn". Twenty years earlier two engines, one called "Little Bob" and another called "the great Bob engine" were among the machines entered in an inventory drawn up at Griff colliery, Warwickshire, on 1st May 1711[61]. Were they like Barnes' Bob? One would hesitate to affirm so much perhaps except that by 1711 the spread of the sector and chain into a multiplicity of employments (with evidence coming from Holland, France, Germany and Austria) was already an accomplished fact*. Probably tug-engines had been so equipped for many years. If this were to prove to be the case it would diminish the degree of conceptual leap in M.C. Höll's achievement but would at least provide it with a context, for the fact of the matter is that what he did was really to treat each of the rods of the double type at its extremity over the shaft as if it were a Geschleppe rod (fig. 21). The cross was abolished and in its place were put two Halbkreuzer (half-crosses or T bobs) each with its Krummling (sector) and Uhrkette (clock-chain or pitch-chain). The first machine so equipped was one whose rods ran for sixty-seven Lachter (rather over 450 feet) from the motor wheel to the Magdalena shaft at Windschacht[62]. It would appear from Gabriel Jars' report of 1758 that by then all the machines in the district had been modified in this way. He was impressed and went out of his way to draw attention to the advantage..."tous les varlets ou croix des machines forment du côté où sont fixés les tirans, auxquels sont attachés les pistons des pompes, des quarts de cercle, sur lesquels s'enveloppe une petite chaine qui tient aux mêmes tirans de manière qu'ils sont toujours également éloignées du centre du mouvement du varlet qu'ils conservent la perpendiculaire et ne forment point

* See chapter six passim.

d'angle dans la pompe, ce qui évite un frottement considerable"[63]. Delius, in 1773, in the official textbook prepared for the use of the students at the Imperial Academy of Mines at Schemnitz, made the same point: if one wished to avoid obliquities then the best way of securing the shaft rods was to hang them from a small so-called "Zirkelwagbaum" (T bob with sector) which at Windschacht was indeed the means invariably used[64].

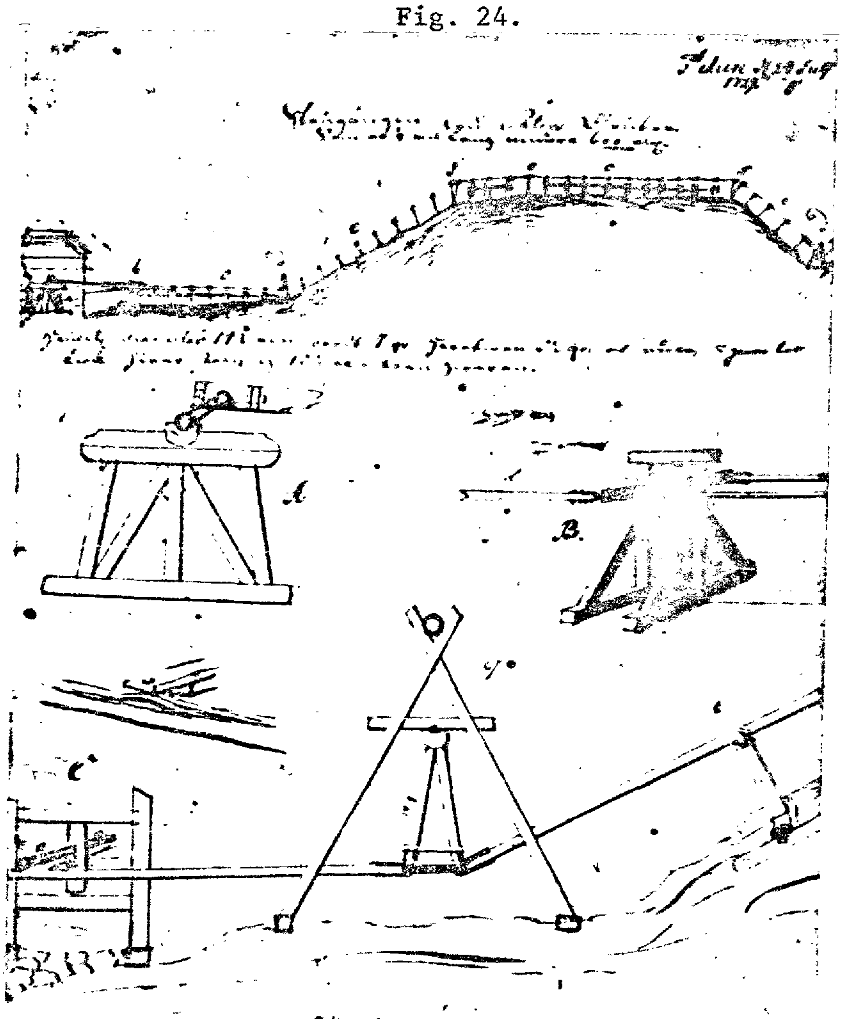
Jars was an acute critic, as quick to point out shortcomings - his remarks on Smeaton's bellows at Carron are a case in point - as he was to draw attention to superior practice. What seems surprising, in view of the rapid generalization that, as has been shown, characterized the earlier stages in Stangenkunst development, is that nearly fifty years after Höll's improvement Jars should have come across it only at Windschacht itself. It had evidently failed to travel: Calvör, for instance, evidently knew nothing of it in 1763. If this were an isolated case one might well think no more of the matter but Jars in Sweden in 1767 reported yet another example, this time in field rod design itself, which, no less than the Windschacht sectors, seemed to him to be a decided improvement over conventional practice and yet had not disturbed that practice outside its place of origin. At Falun he noted, "une autre construction, plus simple que nous avons vu executés, dans plusieurs endroits de la Suède, est celle-ci: au lieu de mettre les balanciers (the swing arms) verticalement comme dans presque toutes les machines

Fig. 23.



View of the horizontally mounted rod line at Bispberg in 1920.
Source: S. Lindroth, Christopher Polhem och Stora Kopparberget, Uppsala 1951, fig. 30.

Fig. 24.



C. Polhem's rod line at Falun in 1729 showing (B) and (D) horizontally mounted swing arms.
Source: A. Ehrensvard, Les machines de Mons. Polhem, 1729, f61r.

de celle espèce (i.e. double rod machines), ils sont ici dans une position horizontale et fixent à chacune de leurs extremités un rang de tirans (fig.23). Dans leur milieu est un pivot qui repose dans une grenouille (a recessed bearing block) assujettie à un poteau planté en terre; par celle construction, la machine a beaucoup moins d'effort à faire, et agit avec plus d'egalité que s'il n'y avoit qu'un seul rang de balanciers verticaux; elle dépense aussi bien moins en bois et par consequent est plus légère; cette espèce est certainement préférable lorsque les trains de tirans peuvent être placés en plaine"[65]. Quite when this type came into existence I do not know. The idea may, however, have come from Polhem although he does not seem to have actually built rod lines of precisely this kind whether at Falun or elsewhere. His schemes are generally well documented in the sketch books of his assistants, men such as Johann Cronstedt and Augustin Ehrensvard and by artists and engravers such as Samuel Buschenfelt and Samuel Sohlberg. Among these only a single sketch (fig.24) in Ehrensvard's collection reveals something like the arrangement described by Jars[66]. They may, therefore, have been a relatively recent improvement in 1767[67]. But whether they were or not, the contrast with the rapid and general development of the 16th and 17th centuries is quite marked. It suggests that large scale innovation creates so thorough a state of flux until its main stages have been passed through that for the short while this is happening the dead weight of routine, the

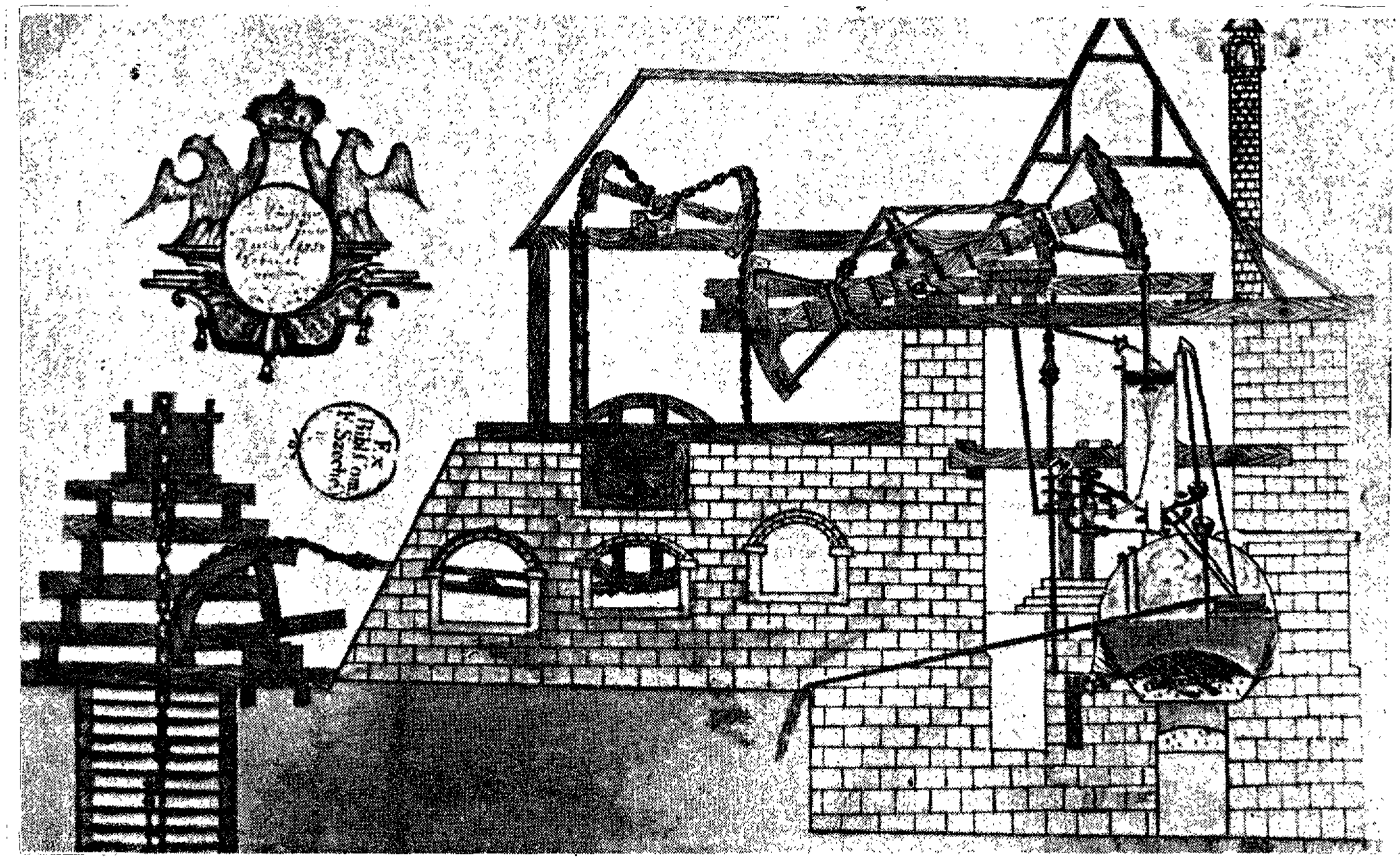
the cake of custom, is broken up. It then quickly reasserts itself in the wake of change. If this is so then the earlier stages of development may well have been passed through very much more rapidly than the dates of 1584-1673, which are in any case the outside limits, suggest.

There is very little more to add to this account of development except to note firstly a further use to which field rod machines were being put in the 1770s. This is revealed in a casual remark of Johann Beckmann's in the third volume of his Beyträge zur Geschichte der Erfindungen (History of Inventions) published in 1782. He remarked that ancient smelting sites were often totally without water and the bellows used must therefore necessarily have been manually operated because the idea of driving them through field rods was a new one[68]. Secondly, it should be noted that even the atmospheric steam engine was brought into use as a prime mover in rod engine work.

This might appear a thoroughly ridiculous thing to do, given a prime mover whose fundamental virtue was its ready adaptability to any site, but difficulties of terrain sometimes prevented the selection of an over-the shaft position. Sometimes too it seems as if the need for economy dictated matters, for if two shafts lay conveniently close and if the power of one engine were sufficient to drain both, then one or other of the shafts had obviously to be served with flat rods. What after all

Fig. 25.

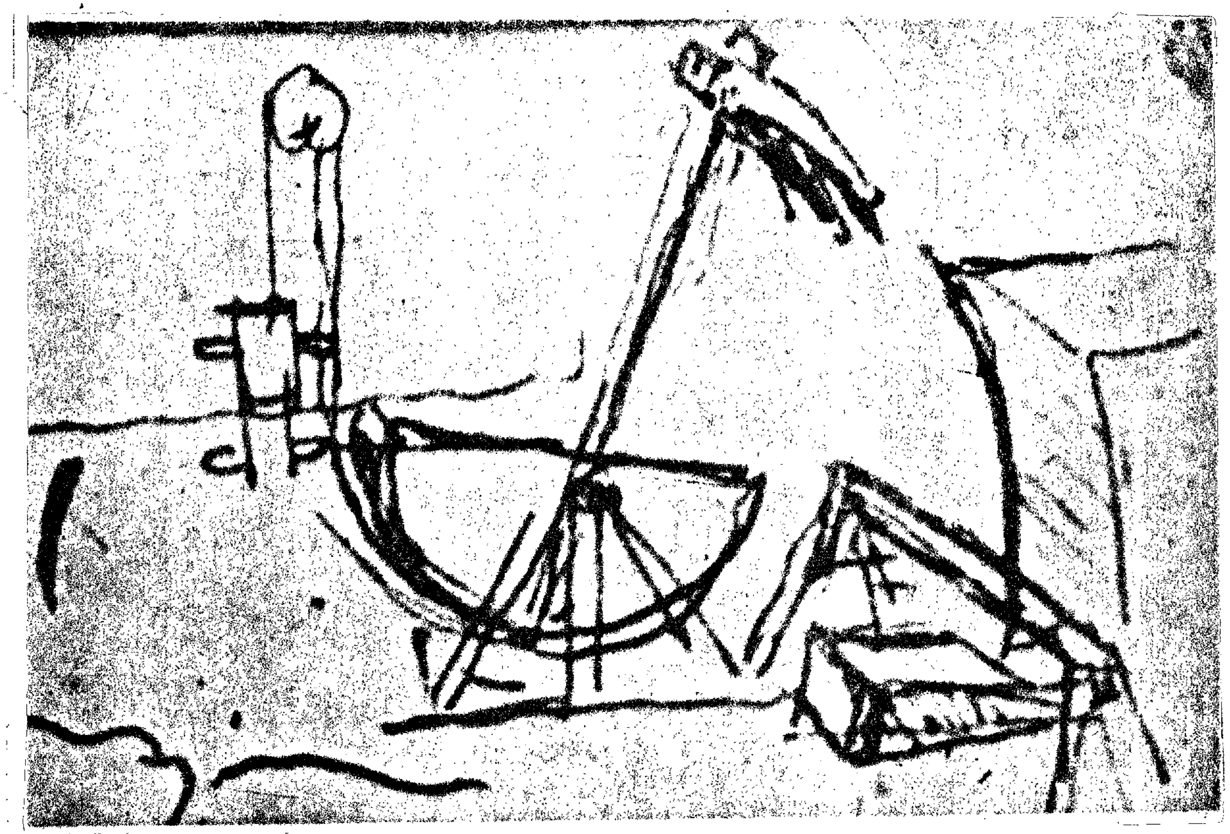
J.C. Holl's atmospheric engine of 1758 working the pumps at the Konigsegger shaft by means of a flat rod. Source: C. Holl, colour washed drawing, c.1770.



was a little friction beside the prime cost of an entire engine? It appears that the first European engineer to adapt the atmospheric engine to such work was Joseph Carl Höll who followed his father Mathias as Oberkunstmeister (chief engineer) at Schemnitz*. He had begun his career in 1734 with the construction of his Wasserhebemaschine and by 1749 had set to work the first (successful)Wassersaulenmaschine (column of water engine) erected anywhere. In 1758 he designed the sixth and last atmospheric engine at Schemnitz; this was to pump in the Königsegger shaft. Because of the configuration of the ground Höll was forced to build the engine at a distance of about one hundred and forty feet from the shaft and was consequently led to use field rods to transmit the pull from the engine beam over this distance. A drawing of this machine, copied probably by his daughter Constance from Höll's original sketch, is preserved in the archives of the Sechenyi Library in Budapest. It would appear from this drawing (fig. 25) that the transmission was managed in the following way: the power stroke on the cylinder end of the machine raised the 'pump' end of the beam in the normal fashion. But Höll evidently felt that without some extra tensioning and counter-balancing device the unaided pull of the beam chain on the inverted sector and its attachments, or equally indeed the unresisted tug of the weight of the field rods on their return travel when the vacuum was destroyed in the cylinder, might in either case prove a source of weakness. This seems the more

*The earliest example of such flat rod work in England appears to be the Mill Close engine of 1748 in Derbyshire.

Fig. 26.



Excavating device with self-righting cutter. Source: L. da Vinci, MSL (c.1502), f.76v.

likely since the shaft rods were separately equipped with a balance bob. The 'pump' end of the engine beam was accordingly attached both to the sector of the counter-balance beam above it, and, by its own chain, to a large winding wheel (the inverted sector) below it. As the 'pump' end of the beam rose, so it pulled upon and revolved the wheel while at the same time the weight of the flat rods was balanced by the overtipping of the counter-weight beam. As the rods were drawn towards the wheel, so the sector over the shaft was drawn back raising the pumps. The return stroke was performed under gravity in the usual way[69]. One might, before leaving this machine, remark the extent to which it repeated (except for the sector and field rods) the kinematics of Leonardo's mechanical excavator (fig. 26) in MS L f.76v[70]. There, however, the inverted sector not only reversed the direction of motion but acted as its own counterweight as well. The third instance of atmospheric engine flat rod work comes from England. One learns from William Pryce in 1778 that the firm of Boulton and Watt had "lately set to work" (actually in 1777) a thirty inch engine at Huel Bussy (Wheal Busy-Chacewater) and equipped it to pump in two shafts "by flat rods with great friction, three hundred feet distant from each other". Unfortunately, Pryce says nothing about the mechanical arrangements apart from mentioning the (by then) customary semi-circular wheel over the shaft[71].

But perhaps the palm for boldness ought to go to the engine builder who about 1793-4 transmitted power from a shore-based engine across some two hundred yards of open sea to the timber tower surrounding the shaft of Thomas Curtis' Wherry Mine, near Penzance. By 1791 the shaft had reached a depth of 26 feet, and despite the fact that water poured in at such a rate that virtually only a small fraction of time was spent in actual mining of ore, nevertheless £600 worth of tin stone was dug during that 'season'. The next year, according to Davies Gilbert writing in September 1792, £3,000 had been raised and got ashore in boats. This money evidently paid for the engine set up in 1793 and also for the trestle bridge to convey the hanging rods from shore to tower[72].

It might seem almost otiose to consider the source of rod engine technology in view of Agricola's statement, in boox six of De Re Metallica, that the machine had been invented ten years earlier (presumably in 1540), and his glossing of the term sipho septimus in the Index Secundus as the "neue Ehrenfriedersdorf Radpompe". This is the only firm evidence of a near contemporary nature that one has relating to the time and place of the invention of the machine, and one is correspondingly reluctant to disturb it. This is not because it is a rare thing to find the first appearance of an invention stated categorically to have been at a certain place at a certain time, for such claims are unfortunately as plentiful as they are unreliable, but because Agricola's statement has never been subjected either in his own day or since to the least challenge. Despite this, however, the nature of the pattern of the machine's diffusion, as far as it can be recovered, taken together with certain other considerations, tends to make the idea of a beginning at Ehrenfriedersdorf in 1540 look rather less convincing than might at first appear. If one were to begin by looking carefully at what Agricola actually says, it is at once clear that it is only by implication that one is drawn into associating 1540, the year of invention, with Ehrenfriedersdorf, the name of the machine. Nowhere is the connection made explicit. It is possible, therefore, to understand Agricola's comments in a variety of ways: the machine might have been invented anywhere at all: the generic term Radpompe used by Agricola for the three kinds of crank-driven pumps is non-specific: Ehrenfriedersdorf was where he knew such a machine to have been in use. Agricola had no great problems of nomenclature to face in composing his Latin description of pumping machinery. He was not writing a history of the machines in use but was concerned simply to describe current practice. He was free, therefore, to impose an arbitrary number order on the various categories of engines. The problem could not be avoided, however, in the Latin-German glossary of technical terms which he supplied as an appendix to his treatise. When he came to sipho septimus he was uncharacteristically specific. Yet when one reads his pages devoted to crank-driven pumps he can only be understood as indicating that all three of the new machines were already in wide use.

The varieties of situations to which each was most suited are carefully described. The date of 1540 for the beginning of these developments is not, of course, Agricola's but is adduced from the fact that he had 'completed' the writing of De Re Metallica by December 1550 although he did not send his manuscript to Froben in Basle until 1553. 1540 might therefore not be 1540 at all. If one assumes, however, that this was the year he intended his readers to understand, it seems reasonable to suppose that for three machines to be developed and pass into general use would take some few years, at least. From 1546, however, Agricola was continuously engaged in political and diplomatic activity, and it seems possible to suppose that if it was after 1546 that he learned of these machines, it was more likely to have been by way of information received than from personal investigation in the field. In no other case does he attempt to say anything at all about the history of the machines he describes. Finely spun conjectures of this kind, however unsubstantiated they may appear in isolation, acquire somewhat more solidity when one considers the historical circumstances relating to the construction of the earliest rod engines. The mining town of Schneeberg in Saxony lies less than twelve English miles from Ehrenfriedersdorf, yet when Bernard Wiedemann put forward a proposal to build a rod engine there in 1554 his suggestion was treated with the utmost reserve: he was to build it at his own expense and absorb the costs if he failed. If the machine was known to be useful, cheap and easy to maintain as Agricola says it was, then the events at Schneeberg become difficult to understand. Again according to Meltzer, the historian of Schneeberg, it was only after Wiedemann's success that the Stangenkunst, or Pompenkunst - for he uses the terms synonymously - began to be adopted generally in Saxony. Freiberg, for instance, had none until Martin Planer began replacing the expensive bag-hoists with such machines in the last quarter of 1557[73]. At Rammelsberg in the Harz the machine was such a complete novelty that the anonymous reporter who described how Mathias Eschenbach set up the first rod engine there in 1565 did not even know what to call it but was reduced to saying merely that it was a water wheel with a crank, "Wasser-kunst mit den krummen Zapffen". Löhneyss' engraving of 1617 shows that a machine of this type was exactly like sipho septimus.

There is, in other words, something of a discrepancy between the historical evidence such as it is and what Agricola has to say. The failure of any writer after Agricola to name the rod engine after Ehrenfriedersdorf, except Johann Matthesius who had evidently read his old friend's work and copied the name from him, is again something of a curiosity. But if some doubt begins to gather round Agricola's reliability in giving the machine a Saxon parentage (if that was what he intended to do) an even greater difficulty arises, for if the machine had merely been introduced into Saxony following its invention somewhere else, where could it have come from? The locations and dates of the earliest known Stangenkünste: 1551 Joachimsthal, 1554 Schneeberg, 1557 Freiberg, 1565 Rammelsberg, 1596 Ydria, clearly suggest diffusion west and south from an easterly direction. There was at that time only one great centre of mining activity east of Bohemia and Saxony, that which lay in what is now central Slovakia but was then called Lower Hungary. Here were to be found the famous mining towns, the "niederungarische Bergstädte", among them Cremnitz, Schemnitz (Windschacht) and Neusohl, producing quantities of gold, silver and copper on a scale unequalled anywhere else in Europe. Here then is a probable source of rod engine technology. However, it is by a process of elimination only that one is drawn towards such an idea since there is no direct evidence on the matter at all; that is, unless one is prepared to presume Joachim Becher's statement of 1682 - that the machine was invented in Hungary - to have been based on some already old and reliable central European tradition. The reason for such a complete absence of information is not far to seek. Whereas the Harz mines, a minor area, are comparatively well documented and have furnished the bulk of the evidence used in this study, and Saxony, a much more significant region, a good deal of the rest, the most important mining region in all Europe attracted virtually no scholarly attention at all until the 18th century. Even then writers such as Jars and Poda and Delius and Ferber, who concerned themselves with Slovakia, were not primarily historians, and the fact that one seizes so eagerly on the few historical facts they let fall merely underlines again the chronic paucity of information. In 1673 Edwarde Browne noted both the gap in the literary record and the pity of it: "It would be tedious to describe all the works of these mines which do well deserve as accurate descriptions as those of Misnia and other parts of which Agricola hath written so largely...certainly there are few places in the world to be compared with this (Windschacht-Schemnitz), where art and nature strive to show their utmost force and riches"[74]. Browne's account, brief though it was, remained virtually the sole source of information on the Hungarian mines available to Western Europeans before the middle 18th century[75]. What is perhaps significant, despite the lack of regular documentation, is to find so many inventions and innovations ascribed to Hungary, and more generally a Europe-wide recognition of the debt owed to that region's technical virtuosity. Meltzer in 1684 stated that the Bulgenkunst (Kehrrad) had been brought into Saxony from Slovakia, "...die aus denen Ungerischen Bergk-Städten hieher gebracht worden"[76]. Browne himself mentions the recently made invention, by Mathias Dollinger (at Cremnitz) of a new stamping technique. The introduction of gunpowder blasting in place of fire-setting is generally ascribed to Caspar Weindl at Schemnitz in 1627. Even the name of the universal ore carrying truck - the Hund - is thought to derive from a Slovak verb, honit, to drive[77]. One could not, of course, conclude even from an inventory many times longer than this more than that Slovakia was a highly developed and progressive region and therefore a more than likely source of new technology. Unfortunately, one cannot go further than this except to repeat that the pattern of diffusion of the Stangenkunst, so far as it can be reconstructed, and the inferences which may be drawn from the pattern, indicate very strongly the machine's Hungarian origins.

By 1565 the Stangenkunst had reached the mines of the Harz. Thereafter the advancing frontier of the new technology in the West began to pass the limits of German speech[78]. At about this time the coalfields of Liége, sunk to depths of about five hundred feet, began to experience great difficulty because the adits which had for centuries served to drain the mines were no longer able to serve as the workings began to be driven below their outfalls. One by one they were drowned out, for no sufficient means of pumping them clear of water was available. Some idea of the gravity of the crisis may be gained from the fact that the government of the territory was prepared to override all existing rights in such lost pits and guarantee their future unhindered exploitation to anyone able to recover them. The articles of the ordinance setting out the exact legal nature of these provisions was drafted and received the approval of prince-bishop Ernst (1581-1612) on 22nd December 1581. On 20th January

1582 it was promulgated to the sound of a trumpet at the Peron of Liége, so becoming law[79]. This document came to be known as the Édit de Conquête. In it the prince-bishop set forth the provisions mentioned above: that within the city and in several places outside there were "...beaucoup de hoüilles et charbons noyez et perdus, à cause des eaux qui forgagnent lesdittes hoüilles". Such coal works might be unwatered "recuperer et reconquester...s'il y avoit bonne ordonnance" guaranteeing those who would do it security of tenure. It was accordingly decreed that those "...soit par oeuvres de bras...où autrement" who should put "les hoüilles et charbons d'aucuns fosse on ouvrage...qui sont et estoient neiez et perdus..." and who should "les conqueste et gaigne les veines...par leur industrie, fraix et despens auront ainsi conquesté et dechargé lesdittes eaux" should enjoy them quietly without hindrance and so "contenuer et en faire leur profit.."[80]. Thus matters stood until in August 1585 Georg-Johann, comte de Velden, approached the burgermasters with a scheme to improve navigation in the principality. When the parties met, the city fathers represented to him the desperate situation in which the greater part of the coal mines lay. The count replied by saying that there were machines unknown in Liége that he had used on his estates in Westphalia and that these were capable of draining the coal mines. He declared himself ready to set one up provided that he was allowed to use the river to work it. The offer was accepted and he was given every assistance.

He would be sold the necessary land, he would be helped to obtain timber for construction and would be freed from any restrictions on using local craftsmen. On 18th July 1586 Leonard Redouté (master carpenter) and Jean Deschamps, both of Liége, and Johann Godschalk, a German, informed the burgermasters that they had agreed terms with the count and had begun the work. The site of the machine, a common ground called Leuze next to the Meuse, lay a little to the east of the city. Across it a canal was dug to lead both river and adit water to the machine. Above it the land rose steeply to the Thier de Liége. What the count planned to do was set up a field rod engine which would act along the line of an adit to where it intersected the shaft. At the shaft the motion of the rod line would be redirected downwards to set pumps in motion. He had thought to move from mine to mine laying all dry in turn. Despite his confidence it seems certain that his project failed. The registers of the city council contain no further references to the matter, and it is clear that for some years longer the pits were to remain flooded and silent[81]. By 1601, however, the technique had been successfully mastered and used to recover a lead mine at Prayon which had lain abandoned for over fifty years. On 27th February 1601 David Remacle of Limbourg was granted a privilege which declared that "par son art et industries à ses grands travaulx et despend", he had made "certains instrumens et mollen tirant pompes et grand nombre choese nouvelle et inusitée en notre pays de Liége, à effet de tirer les eaues hors des fosses et ouvraiges de la montaigne de plombterie de Prailhon"[82]. Thereafter, although there is no record of it, rod engines were applied to the coal pits themselves. Edward Browne noted them in use in 1673 as he journeyed westwards from Germany. "Their pumps and engines to draw out the water are very considerable at these mines; in some places moved by wheels at above a furlong's distance to which they are continued by strong woodwork..."[83]. A little later, of course, Rennequin Sualem was to apply the skills he had acquired in such work at Liége to set up the great machine at Marly-le-Roi. In 1662 with his brother Paulus he had already helped to set up a rod engine at Vedrin near Namur. I have no information on St. Marie-aux-Mines, or Markirch in Leberthal to give it its German name,but it would be surprising if it had failed to keep pace with the rest of Germany. Also in Alsace but further south it is virtually certain that by the early years of the 17th century the Phenning-thurn (treasure tower) mine near Giromagny was employing the new machines. Later the region became part of France. Guillot Duhamel, who pubished a lengthy study of the Giromagny mines in 1797-8, speaks of the old rulers of Alsace settling Saxon miners there and of the villages of Auxelle, Puits and Giromagny owing their existence to these people. He concluded that the workings of Phenning-thurn had been almost as extensive at the beginning of the 17th century as they were at the end of the 18th, although one doubts whether the haphazard working of the mines by the French after the original hydraulic engineering arrangements were destroyed in 1716 approached anything like the efficiency of the earlier period. In general, Duhamel's picture is one of fairly comprehensive incompetence[84].

During the first half of the 17th century the Stangenkunst was probably introduced into Russia (1634) and Sweden (1642). The reason for thinking that its entry into Russia may have taken place as early as 1634 is admittedly based on nothing more than a probability. In 1633 copper was discovered near Solikamsk on the western slopes of the Urals, and according to the compiler of the Theatrum Europaeum a number of miners and mining people were chosen to go from Saxony in 1634 to this first mine discovered in Siberia[85]. According to Danilevski the Stangenkunst was known in Russia in the early 18th century, and certainly in the second half of that century rod engines were widely employed. Peter Pallas reported numbers of them in the mines he visited in the Urals in 1770, while the large-scale plants erected by Kozma Frolov in the 1770s and 1780s, and indeed Frolov's very emergence as an outstanding engineer can only be understood in terms of his working within and extending a long established technology. The ore hoists and pumping machinery of the silver mine at Zmeinigorsk in the Altai mountains, built in 1787, were undoubtedly his greatest achievement in mechanical engineering[86].

For Sweden the introduction of the rod engine can be more precisely stated. The reporters of the Theatrum Europaeum record an event in 1642 which without any of the vagueness and uncertainty surrounding that of 1634 marks clearly enough the successful domestication of the new technology. That year (1642) was, according to the report, "an especially noteworthy one for the Queen of Sweden (Christina 1632-54) since the mines of her kingdom, especially those yielding silver, copper and iron, brought forth abundantly". But it was not so much new mines that had been discovered as that valueless drowned out old ones had now been successfully dewatered. The report concludes: "...in which business chief engineer (Obriste Bergmeister) Georg Griessbach's new invention for pumping water was of great value". Griessbach got a present of 20,000 thalers and in March 1642 was knighted (in Adelstand...auff dem Ritter-Saal erhoben) and enfeoffed. The new invention can only have been the Stangenkunst, and it is evident that Griessbach's ennoblement in March 1642 marked the successful completion of a comprehensive programme of machine building in the principal Swedish mines, including most likely those at Sahlberg and Falun (mines of silver and copper respectively)[87]. It is only in fact as the flowering of some such long established tradition of engineering that two of the finest works of hydraulic engineering in 17th century Sweden, that is the machine built by Olaf Trygg at Dannemora in 1679 and Christopher Polhem's well known machina nova at Falun in 1694, become at all understandable. After 1642 the next evidence of rod engine construction in Sweden is that concerning a wind driven machine set up in 1675 by Johann Peter at the Sahlberg silver mine, Vastermannland. It was able, according to Wollenius, to raise daily as much water as eight strong men were scarcely able to achieve, to a height of one hundred and twenty feet; "quantum vix potuerunt alias octo viri ad alt. 120. ped. quotidie extraxit" and was a great sight for travellers[88].

But so also was Olaf Trygg's enormous machine built in 1679 to drain the iron mines at Dannemora some twenty five miles north of Uppsala. M.H. Sunborg, who published a dissertation on the mine some years later, was evidently most impressed by what he had seen there. After describing how Olaf Trygg junior, Konstmastare at Falun, had in 1694 built a dam five hundred yards long to prevent the waters of Lake Gruffion flooding the pits called Koijor and Kabbyser, he goes on to describe the elder Trygg's machine: "The said waters (of Lake Harwikz) not only power the nearby (Osterby) iron smelters but move the famous machine...whose great wheel has a circumference of over one hundred feet. The torrent pouring on this wheel revolves it, a tremendous sight as it creaks in turning. Its axle of wrought iron, those made of cast iron break, weighs nine hundred pounds and was forged by the highly skilled craftsmen of the anchor workshops at Soderfors. To this axle is joined the first arm of the field rods which by a reciprocating motion transmits the power of the machine over a distance of nearly three miles to the very lip of the workings where the pumps, set in action by its motion, draw water from the cavernous pits and exhaust it into Lake Gruffion whence it comes. The machine was set up by Olaf Trygg, an engineer from Falun, in 1679. As for this kind of machine, the so-called Konsten, it is believed that they were first in use among the Germans and, seen there by our people, were later copied here". Before these became available, he concludes, one used animals to wind up buckets: "Praedictis autem aquis non officinae solum ferrariae vicinae juvantur; sed praecipue machina insignis et magna hydraulica, quae post aggeres utique proxime contemplanda venit, agitatur. Notula ※ aedificium est rotam tegens aquaticam maximam; nam ultra 50 ulnarum circumferentiam habet: collecta modica aqua suo torrente affusa, circumvolventem sese rotam et tremendo aspectu in gyrum ruentem agit; cuius axis, trium librarum nauticarum pondere e ferro, malleis manuariis majoribus Soederforsae, nobili illa anchorarum officina, confectus est: nam quos e ferro fuso habuere rumpebantur; huic axi primum brachium kurstången annectitur, quod per vices trahendo et pellendo, machinam movet, per 886¾ perticarum longitudinem, continuatio opere cohaerentem, ad margines usque et oras fodinarum praecipites, ubi emissis alis, antliarum embolos motu reciproco agitat, aquamque tali modo e cavernarum profundis in vicinium lacum Gruffion, derivandam extrahit. Exstructa haec et perfecta machina est, a mechanico Falunense, Olaf Trygg...Anno 1679...artem hanc, sic enim Konsten, appellant, apud Germanos primum visam nostris, postquam domum redierunt similiter institutam, credibile est"[89]. It is from Sunborg also that one learns of the wind driven Stangenkunst (spiralem machinam) also at Dannemora set up by the famous "architecto metropolitanae urbis Dr. Hansso Bucheggero anno 1692"[90]. Jars saw it working still in 1767: "nous avons vu en mouvement; l'arbre vertical repose sur une manivelle double qui repond à des tirants et balanciers, comme en ont les machines hydrauliques ordinaires"[91].

By the late 17th century a sort of salient of rod engine technology was developing west of Liége as coal works lying on the great northern coalfield began to pass from peasant ownership into the hands of well endowed syndicates able to afford to set up such machines. The Intendant of Hainaut (then a part of France) in a memoir composed in 1697 urged the government to encourage wealthy men to interest themselves in coal works since the peasants were too poor to install the machines necessary to achieve increased output. The model he had in mind was what had been done at Wasmes near Mons in 1695. A syndicate had been working without fear of water since they had installed "une machine pour le tirer continuellement faite à peu près en petit comme celle de Marly"[92]. Before this time rod engines had become more familiar to the French (as the memoir indicates) by reason of the exotic works involving rod lines for overland pumping put up at

Modave (c.1668) and at Marly (1685) by the liègeois, Rennequin Saulem. In general, however, France was extremely backward. This was not so much because it had few rich mines as that most were in the hands of men totally unable to develop them and lacking even the most elementary equipment. The growing shortage of wood and charcoal and the need of the state to increase coal production made it necessary to sweep away this class. At length the French government issued the arrêt of 1744 resuming the power to regulate and licence the mining of coal that it had allowed to lapse in 1601. According to Rouff, however, the trouble with the peasant miners was at bottom a psychological one and went deeper than lack of money: "ce ne fut pas seulement la manque de moyens financiers qui maintint les petites exploitations ...en état d'inferiorité; ce fut surtout l'esprit routinier et borné" while later he talks of "la mentalité etriquée de ces petits entrepreneurs"[93]. Once this class was dispossessed and the concessions made over to substatial entrepreneurs - men like de Solages and Tubeuf - rod engines began to be erected in some numbers: two at Carmaux, near Albi, in 1757 (the engineers from Namur), several in the 1770s in the Forez-Rive de Gier (St. Étienne-Lyon) region. By the 1770s at least six engines were at work in Baigorry near St. Jean Pied de Port (Pyrenees) although it is only in Baron Dietrich's description of 1786 that one learns something of them[94]. Earlier, however, simple ignorance of the Stangenkunst's very existence seems to have been general outside Hainaut, even in the case of full-blown capitalistic enterprises. The Pontpean lead mine near Rennes lacked adequate pumps before P.J. Laurent completed the installation of 'modern' machinery in November 1755. The works needed to bring the mine, flooded since 1740, back into operation cost 300,000 livres (£15,000)[95]. Laurent, interestingly enough, came from the extreme western end of the Wasmes-Mons salient already noted. The mines of Poullaouen and Huelgoat, which like those of Pontpean were also in Brittany, were modernized by engineers brought in from Saxony. Poullaouen was pumped for a time (1749-50) by an atmospheric steam engine but the cost of fuel proving ruinous it was sold off and Koenig, the director of the mine, constructed a rod engine to replace it. The old workings were abandoned in 1781 and new shafts were sunk further to the east. In 1806 two rod engines pumped water from a depth of over five hundred feet[96]. Huelgoat was re-opened by Koenig in 1760 and in 1806 was drained by what Daubuisson called "deux superbes machines hydrauliques" built by Brollmann, his successor. As more distant pits were opened the field rods of these machines were extended until they finally reached a length of some two and a quarter miles[97]. Inadequate no doubt though the idea of a technological frontier is, the events at Pontpean and Carmaux and at Poullaouen and Huelgoat coming so close together give the notion some slight sanction[98].

In all these events, of course, lies the clearest possible indication to the historian of technology that to neglect the social and economic institutions of a country (to say nothing of its climate and geology) is to show a total misunderstanding of the nature of technical change. Manifestly, certain pre-conditions have to be met: a capitalistic structure is necessary (whether state run or privately financed) and above all a supply of able civil servants or entrepreneurs (their motivation will obviously differ) as the case may be, to direct the flow of men, money and materials. But neither the one nor the other can proceed without the highly trained engineers (the living tradition) and behind them a work force divorced from the spasmodic and undisciplined work pattern of the fields. But is one talking of cause or effect? The dominating spirit in western Europe, the economic motivation of the most energetic classes, makes it both, and western European travellers going into regions where Europe effectively came to an end remarked the difference of temper. "Asia begins on the Landstrasse" Metternich is supposed to have remarked at the Congress of Vienna, and with that verdict neither Edwarde Browne nor Charles Patin would have quarrelled a century and a half earlier. But on a more concrete level consider the contrast offered by the different experiences of Liége and Charleroi, a mere fifty miles apart. The Liége mines, already highly developed by the beginning of the 16th century, early fell into the hands of large and well endowed enterprises. Although it is only in 1673 that one learns from Edwarde Browne of the large numbers of Stangenkünste at work there, it is clear that a corps of experienced hydraulic engineers who maintained them had been formed many years before: the fact that Liége was capable of producing a Sualem is proof enough of that. In the pays de Charleroi, on the other hand, capitalistic undertakings were so slow in developing by reason of the complexity of tolls and tariffs set up by competing jurisdictions which virtually shut off Charleroi from surrounding markets that the age of Stangenkunst construction, belonging to the 1720s and 1730s, became virtually telescoped with the age of atmospheric steam engine building: Gilly Colliery's first Stangenkunst was set up in 1725 but before 1750 it had a fire engine. For Charleroi the dates are 1731 and 1745.

As for expansion to the south, one is fortunate in having abundant evidence for the course of events at Ydria (Idrija) in Carinthia (Krain; Friuli). In 1860 Peter Hitzinger, priest at Ydria, published a history of the mercury mines based on materials in the mine archives of Obervellach to whose administration Ydria had long been subordinated. The mercury bearing lode (Silbeschiefer) was first struck on the 22nd June 1508 when the Achazi shaft bottomed on to it. But the running of the mine by private individuals left much to be desired, and by 1578 Franz Khisel, Bergrichter (mine administrator) of Obervellach, was sent to Ydria to put things on a workmanlike basis. The old Achazi shaft was by degrees abandoned and by 1596 a new shaft, the St. Barbara some six hundred feet deep, equipped with a Kehrrad and a Stangenkunst working two tiers of twenty-six pumps, was in operation. The machines were fed by a leat (Fluder, Rinnwerk) nearly three miles long. A later, deeper shaft sunk in 1738-48 was similarly equipped. Khisel also engineered the system of float-flumes (Holztrift) and sluices (Klausen) needed to float in the vast quantities of timber fuel required by the drive for increased output. In 1612 production of mercury amounted to about 150 tons (3,000 Centner)[99]. One is equally fortunate in having for the mercury mines of Almaden in Spain the careful work, controlled by archival material, of J.M. Hoppensack, a work which he was moved to write, he said, after reading Klipstein's garbled account of 1780. Hoppensack was called to Almaden in 1775 by a French company desperate for technical expertise. Earlier Laurent had been called in and had built a horse-driven Stangenkunst (Rosskunst). Hoppensack describes what he found: they had before Laurent's time no rod engines but had raised the water in leather sacks in a series of sixty foot lifts. The picture generally was one of complete hopelessness; canals and wheels had been set up for which scarcely enough feed water ran even in winter. As for the removal of ore from the workings, the mind boggles: one might still be living in the days of Pliny. "At my coming in as director" says Hoppensack, "I found the so-called Trecheo still in use...

Men stood at eight foot intervals and passed light baskets (soleras) full of ore from hand to hand until the ore was brought to grass"[100].

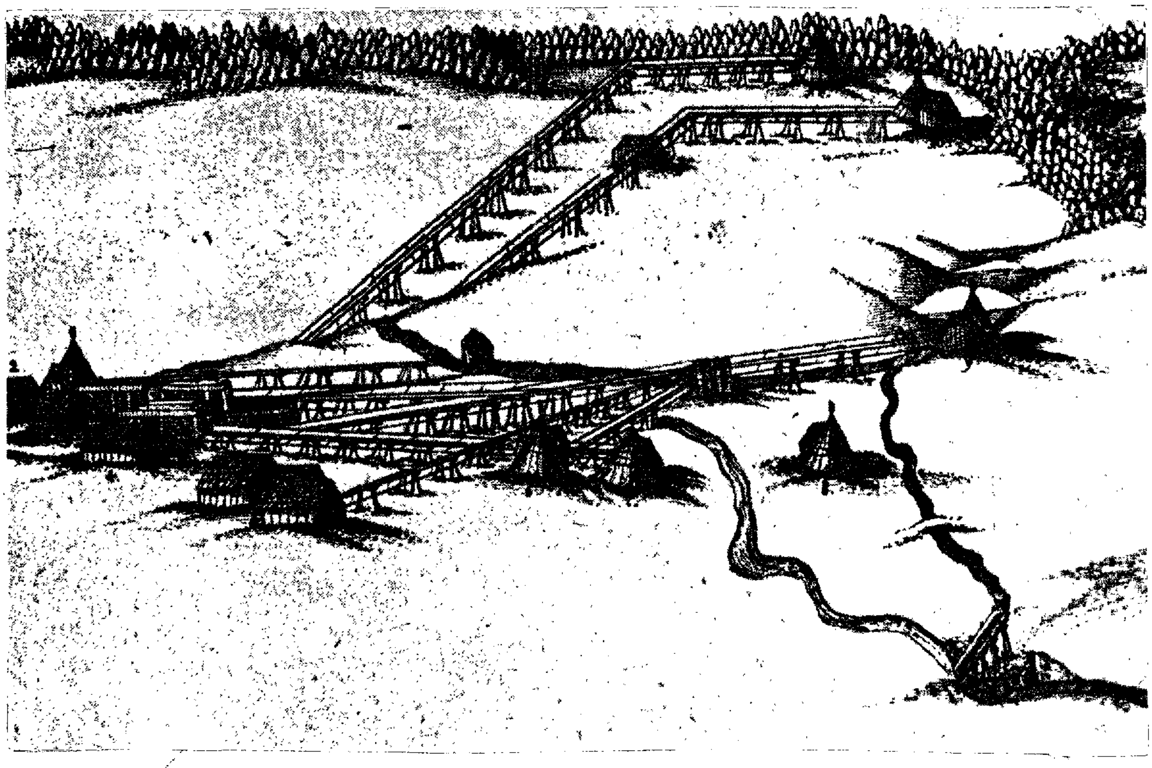
As for the regions south of Slovakia, nothing stirred: everything went to rack with the Turks. Browne's feeling about Serbia, that "...if it were in the Christians hands of the temper of those in the western parts of Europe it might make a very flourishing country"[101] is expressed even more strongly by Charles Patin about the Ottoman lands generally. He describes Hungary as an admirable country abounding in riches and he is led to regret "la perte que la Chretienté a fait d'une partie de ce beau pais. Tout périt chez les Turcs, mesme ce qui concerne la guerre...de sorte que par paresse ou par ignorance, ils laissent inutiles beaucoup de minières qui avoient déjàésté ouverte vers Bude et Belgrade"[102]. Nowhere in fact was the frontier, in every sense of the word, more sharply drawn. The truce of Vasvar (1664) had brought the Turkish power virtually into the mining zone. At Schemnitz a loaded culverin was kept ready on the tower of the upper castle of the town to give warning should the watch discover the approach of a Turkish army while before Cremnitz an earthwork had been thrown up to hinder any Turkish force advancing up the valley of the river Gran (Hron). A force of cavalry was permanently assigned to frontier patrol duties. It was in these desperate circumstances that the guerilla war, in which Pater Josua played such a destructive part, broke out.

It was during the course of one of his razzias on Austrian territory in 1679 that the installations at Windschacht were burnt to the ground[103]. Among the works which must then have perished were the great field rod engines which according to Joachim Becher, writing in c.1681, had once drained the mines there. They had not been rebuilt in 1692, however, for the anonymous author of the Neu ausgefertigen Probier-Büchlein published in that year in describing the machines then in use at Windschacht mentions only horse-driven engines. There were seven horse-driven Stangenkünste, "Kunst-Gopeln", employing four hundred and sixty-eight horses, and eight horse driven ore raising whims, "Berg-Gopeln", requiring a further one hundred and eighty. The total of six hundred and forty-eight horses cost annually something between £14,000 and £15,000 to maintain[104]. This enormous financial burden and the need to reduce it led to Oberkunstmeister Mathias Höll's programme of catchment reservoir construction and the building of seven field rod engines completed by 1711, and later still to the construction of five atmospheric steam engines in 1732-38[105].

It was the stark contrast between the energy and skill displayed here and elsewhere in Europe, and the amelioration in the lot of men generally that accompanied it, and the abysmal spectacle of human degradation obtaining beyond the frontier of Europe in the Turkish lands, and more particularly in the Turkish mines, that led Montesquieu to observe in L'Esprit des Loix that before slavery was abolished in Europe, "on regardoit les travaux des mines comme si penibles qu'on croyait qu'ils ne pouvoient être faits que par des esclaves ou criminels. Mais on sçait que aujourd'hui les hommes qui y sont employés vivent heureux. On a par de petits privilèges encouragé cette profession...où est parvenu à leur faire aimer leur condition plus que toute autre qu'ils eussent pû prendre"[106]. The immediate cause which had permitted this improvement in the human condition to take place were machines: "on peut par la commodité des machines que l'art invente ou applique, suppleer au travail forcé que d'ailleurs on fait faire aux esclaves. Les mines des Turcs, dans la Bannat de Temeswar étoient plus riches que celles de Hongrie et elles ne produisaient pas tant, parce qu'ils imaginent jamais que les bras de leurs esclaves. Je ne sçai si c'est l'esprit ou le coeur qui me dicte cet article ci". But the ultimate reason for the Turkish failure was a failure of mind to rise to an understanding of how men are shaped for good or ill by the institutions of the society in which they have their being: "Parce que les loix étoient mauvais, on a trouvé des hommes paresseux; parce que les hommes étoient paresseux on les a mis dans l'ensclavage"[107].

The European achievement in engineering was impressive not only in what it represented morally but concretely in the vehicles through which such values were made manifest. At the peak of the Stangenkunst's develop-

Fig. 27.



Panorama of the wheel houses and field rods at
Clausthal in the Upper Harz.
Source: F.E. Bruckmann, Magnalia Dei in locis
subterraneis..., Vol. 1, Brunswick 1727.

ment, for example, a number of large areas of Europe - one is thinking of tracts of land many square miles in extent - must have presented an astonishing sight to the eyes of travellers unfamiliar with mining regions. Moving forests of transmission lines standing twenty or more feet high on their supporting trestles, commonly up to a mile long and often sending out branch lines along their length, were indeed potent symbols of European mechanical ingenuity (fig. 27). Charles Ourthier describing in 1744 the scene at the Stora Kopparberg mine at Falun was much struck (metaphorically: he was no Huskisson) by "la forêt mouvante qui forment toutes les différentes machines et bascules"[108]. Joachim Sprengel in his description of the Harz mines of 1753 drew attention to the spectacular machines employed in the Spiegelthal: "Diejenige Wasserkünste sind ebenfalls vor andern gar Merkwürdig, welche man im Spiegeltahl antrift. Die Radstuben sind zum Teil an der Hang eines Berges angeleget, und die Feldgestänge schieben in das Tahl herunter, und von da vermittelst grosser gebrochener Schwingen zum gegenseitigen Berge hinauf. Überhaupt bemerket man hier solche Anstalten, welche durch ihre Verscheidenheit und Kunst die Aufmerksamkeit der Reisenden vorzüglich an sich ziehen können"[109]. "Those hydraulic machines are remarkable above all others which one encounters in the Spiegel valley. The wheel houses are situated on one side of the mountains forming the valley wall and the field rods lead from them down into the valley beneath and from there by means of enormous direction changing gear climb the opposite mountainside. It is here above all that one notices installations which by reason of their singularity and ingenuity compel the attention of travellers". Such scenes must have presented as stark and alien - and impressive - an element in the environment of the past as the looping lines of cables and pylons setting out from the power stations are in today's. Spectacular though such sights may have been, however, it was the work which many hundreds of such machines performed more obscurely deep in the earth itself which constituted the real wonder in laying dry workings which had in many cases been driven well over one thousand feet deep. All this was achieved a century before English engineers found their own solution to such problems. Nor was the power exerted by these hydraulic machines inferior to what steam engines commonly provided. A census of machines in use in the Prussian mines compiled by Severin in 1825 reveals an astonishing state of equipose between steam and water power even in a situation where the state had put its whole effort into domesticating the new English technology. Seventy-seven steam engines (a mixture of Newcomen and Watt types) yielded 1440 H.P., seventy-six hydraulic engines (nearly all Stangenkünste) produced 1430.5 H.P.[118]. Not only were rod engines powerful: they were also extraordinarily cheap when set beside the high prime cost of steam engines, while in addition the power they provided was free. This was why before locomotive traction and railway networks were established in Europe steam engines could not compete and were only ever able to be worked successfully in coal mines, that is, where their fuel was also free. Daubuisson in his study of the Saxon mines published in 1802 shows clearly enough how modest an outlay was required in order to set up a typical Stangenkunst wheel. A wheel of thirty-six feet diameter with cast iron cranks cost only 1,281 livres (£64), which with the rest of the apparatus, which would include the wheel house, pumps and shaft rods, required a total outlay of 4,000 to 5,000 livres (£200-£250). The life of a wheel was about fifteen years during which time it would require practically no attention. Where such a machine worked field rods exposed to the weather, the latter would ordinarily last ten years[111].

But mining supplies, as Mumford has remarked, a peculiarly precarious basis for men to build upon and raise any such monuments of calculation and dexterity. The veins diminish and the active societies which they once sustained fail with them. Brückmann's picture of Hohe Forst, once so bustling with activity at the time of the Hussite Ways, where one could still find, after three hundred years, old dumps and waste things, may stand for them all: "Die darin noch befindlichen alte Halden, Schachte und wuste Dingen...anziegen wie stark man ehemals dieses Werck allhier getrieben und gebauet..."[112].

The Chronology of the Stangenkunst

c.1540 - 1833 .

(1) Gestalts

c. 1440	Antonio Filárete	horizontal bell-cranks working bellows
c.1450	Antonio Pisanello	horizontal rocker arms working force pumps
1463	Antonio Filarete	horizontal bell-cranks working bellows
1488	Leonardo da Vinci	horizontal bell-crank working a force pump
c.1493	Leonardo da Vinci	horizontal bell-crank working suction pumps

(2) Contemporary cognate forms of sipho septimus

c.1510	Vannocchio Biringuccio	horizontal bell-cranks working bellows
1550	Girolamo Cardano	horizontal bell-cranks working bellows

(3) The Stangenkunst

c.1540	Georgius Agricola	Sipho septimus (the Ehrenfriedersdorf Radpompe) the 'ur-Stangenkunst'.
1551	Michael Mittelbach, erector	first Stangenkunst at Joachimsthal
1554	Bernard Wiedemann, erector	first Stangenkunst at Schneeberg
1557	Martin Planer, erector	first Stangenkunst at Freiberg
1559	Johann Matthesius' 12th sermon	"water must be led to the shaft"
c.1560	Vavrinec Kricka	'rationalized' shaft rods
c.1560	Vavrinec Kricka	'proto-Geschleppe' employing flat rods
1565	Mathias Eschenbach, erector	first Stangenkunst at Rammelsberg (Goslar)
1568	Daniel Hochstetter, erector	? first Stangenkunst at Goldscope, Cumberland

1569	Juanello Turriano	completion of artificio No. 1 at Toledo
1570	Martin Planer	report on the Freiberg mines. 38 Stangenkünste set up in period 1557-70
1581	Juanello Turriano	completion of artificio No. 2 at Toledo
1584	Jean Errard	single rod transmission line (Stage I)
1585-6	Comte de Velden	proposal to build Stangenkunst at Liége
1588	Agostino Ramelli	single rod transmission line
1596	Franz Khisel, erector	first Stangenkunst at Idria (Friuli)
1601	David Remacle, erector	first Stangenkunst at Prayon (Liége)
1606	Daniel Lindemeier	earliest picture of primitive double rods (Stage II)
1617	Georg Löhneyss	detailed view of Stage II rods. Earliest picture of Kunstkreuz and of contouring
1618-19	Johann Reifenstuhl, erector	Seven water and horse driven Stangenkünste built on Bad Reichenhall-Traunstein pipe-line
1642	Georg Griessbach	programme of Stangenkunst construction completed in Sweden
1657	Lippold Weber	intermediate double rod design (Stage III)
1659	R. D'Acres	description of hanging rod experiment and other transmission devices
1673	Christian Berward	earliest use of technical terms denoting standard double rods (Stage IV)
1675	Johann Peter, erector	earliest evidence of windmill-driven Stangenkunst at Sahlberg
1677	Heinrich Bonhorst	first visual evidence of Stage IV rods. Split drive first shown
1679	Olaf Trygg	rods of 2¾ miles' length driving three sets of pumps at Dannemora

1682	Joachim Becher	claims invention of rotary drive through rods and double cranks
1685	Rennequin Sualem, erector	La Machine at Marly-le-Roi
1685	Denis Papin	proposal to use vacuum tubes in place of rod lines
1692	Hans Buchegger, erector	Windmill-driven Stangenkunst at Dannemora
1694	Christopher Polhem, erector	first rod hoist - Machina Nova (Blanksstotspel), Falun
1698	Christopher Polhem, erector	Humbo-Norrbarke machine: rod drive to combined pump and hoist engine
1700	Balthasar Rössler	earliest visual evidence of single rod (Geschleppe) designs
1711	Mathia Höll	sectors and chains in place of Kunstkreuz, Windschacht
1729	Augustin Ehrensvard	Polhem's design for horizontal field rods at Falun
1733	Amos Barnes	Geschleppe with sectors and chains, Heaton Colliery, Newcastle
1758	Joseph Höll, erector	atmospheric engine driving flat rods, Windschacht
1767	Gabriel Jars	report on horizontally positioned double rods, Falun
c.1775	J.G. Beckmann	reports in 1782 the recent invention of field rod drive to bellows
1777	James Watt, erector	single acting Watt engine drives flat rods serving two shafts at Huel Bussy mine, Chacewater, Cornwall
c.1795	Thomas Curtis' Wherry Mine, Penzance, Cornwall	first marine field rods
1833	H. Doerell	first Fahrkunst (man engine) set up at Zellerfeld

NOTES

1. F.M. Ress, 'Die Oberpfalzische Eisenindustrie im Mittelalter und in der beginnenden Neuzeit', <u>Archiv für das Eisenhüttwesen</u>, Vol. 21 (1950), pp 205-215, states that the reference to Schmiedmühlen occurs in a charter of that year relating to the monastery of St. Emmeran. By 1170 the name of Ernst de Smidimulne, scion of a knightly family (adeliges Geschlect) is attested.

2. R.H. Schubert, <u>History of the British Iron & Steel Industry</u>, London 1957, pp 139-141, estimates that a furnace in England, c.1350, working without water power could produce from 2½-3 tons of iron per annum; with water-powered bellows but with manual deslagging 25 tons; with both bellows and hammer mechanized 45 tons. Mechanization took place late in England but its effects on production are not likely to have been very different from those experienced earlier in Europe.

3. See the appendix (Wood transport on flumes and floatways) for a brief historical sketch of such systems. The vitally important role of forestry in the economic life of Europe has been almost entirely neglected in English historical writing except insofar as English needs for charcoal-iron and naval stores are concerned. No doubt the early conversion of English domestic hearths and English

industry to the use of coal has diverted attention from the question of how such problems of fuel supply were met in regions where coal was not available. What is badly needed is a work which would, by describing the European timber fuel economy, complement Nef's study of the English coal industry, thereby showing, as it were, the other side of the coin.

4. This sequence is, needless to say, ideal, and relates only to mining. Other pressures acting in other parts of the economy such as the growing demand for domestic fuel and the needs of other kinds of enterprises such as salt boiling were equally important. As far as the date 1400 is concerned, it has to be confessed that it lacks a certain rigour. Yet in 1583, when Hardan Hake, pastor of Wildemann in the Harz, noted in his Bergchronik that, "der alte Mann unter dem Stollen von der Hengebank bis auf die Sohle nicht tiefer als 11 Lachter gewesen...", "the old-timers could not go deeper than 11 Lachter (about 75 feet) below the headstock of the winding gear in the adit", it seems likely, despite the vagueness as to the time he was referring to, that he meant the period before the water-powered bag hoist and rag and chain pump began to come into use, that is to say,

before about 1400. It may be worth noting here that R. D'Acres in his Art of Water Drawing of 1659 talks at even so late a date of a lift of some seventy feet as being a great height, a statement which no doubt corresponded very well with the experience of English mine engineers unfamiliar with contemporary continental developments.

5. In 1553 Pierre Belon du Mans, then in Siderocapsa in Macedonia, mentioned that "les noms dont ilz usent pour jourdhuy...en exprimant les causes métallurgiques, ne sont pas Greca, ne Turcs; car des Alemans...ont enseigné aux habitants à nommer les choses...en Aleman; que les estrangers tant Bulgares que Turcs ont retenoz". Les Observations, Paris 1553, p.45. A writer reporting on the salt mines of Wieliczska in the Philosophical Transactions of 1671, No. 61, p.1099, noted that "The instruments...have almost all German names with Polish terminations".

6. J.B. Mispoulet, 'Le Régime des Mines à l'époque Romaine et au Moyen Âge', Nouvelle Revue Historique de Droit, Vol. XXXI, 1907, pp 345-391 and pp 491-537, is invaluable for an understanding of the period and makes clear the specifically German character of developments in mining law in the Middle Ages.

7. M. Koch, Geschichte und Entwicklung des Bergmänn-

ischen Schriftums, Goslar 1963, p.13ff for further details of this literature. Apart from this the general bibliography that Koch supplies, although far from complete, is of great value. It is interesting to observe that at this time also European political thinking undergoes considerable modification consequent upon the increasing complexity of economic life. In the work of Thomas Aquinas (1225-1274) the state is largely governed by the economic motive in contrast to Aristotelian theory which stressed the state's moral purposiveness.

8. A summary description of the modus operandi of sipho septimus is given on p.75 of chapter two of this study. The Index Secundus was printed as an appendix to the first edition of De Re Metallica, Basle 1556. Agricola might have added that its use dramatically reduced the cost of pumping. But see note 73 below.

9. The word "disappearing" I am conscious of using in a rather special way. Few machines, still less tools and techniques, seem actually ever to die out provided they are broadly established in the work pattern of the community (I leave aside refined techniques practised for connoisseurs which plainly do not satisfy this requirement). This or that machine may be superseded but it is most striking that out of 'front line' use though it

may now be, it does not cease thereby to have value in less exacting situations. In brief, the 'ecological' balance of technology favours diversity.

10. But it needed mines virtually perched on the tops of mountains - at Vedrin and at Windschacht - to provide the extreme conditions necessary to initiate such developments.

11. Denisart and De la Deuille in 1731 and Winterschmidt in 1748 were the pioneers but J.K. Höll's machines were the first to be practically successful - unless one is to award that distinction to the water pressure engine with floating piston described by Robert Fludd in 1617 in his <u>Natura simia seu technica macrocosmis historia</u>.

12. R.U. Sayce, <u>Primitive Arts and Crafts. An introduction to the Study of Material Culture</u>, Cambridge 1933, should be mentioned as a useful initiation into this mode of enquiry.

13. L. White, <u>Medieval Technology and Social Change,</u> Oxford 1962, pp 111-112.

14. Codex Latinus 197, f.21r, Staatsbibliothek, Munich. The MS is bound up with three MSS of Taccola. The sketch in question is reproduced in C. Singer and others, <u>The Oxford History of Technology</u>, Vol. 2, Oxford 1965, p.653, fig. 597. It is, perhaps, worth noting that Konrad Kyeser, a generation earlier, shows only small scale applications of

single cranks working cross-bows and a cochlea. However, his f.76r, a spanning device with a crank handle at either end of its axle, is something significantly new. The progression from hand to feet, to water wheel (Kyeser, Hussite engineer, Pisanello) is certainly instructive. Altogether these materials, scanty though they are, inspire confidence in their representativeness since in general the devices they figure conform to a logical as well as to a chronological line of development.

15. See J.R. Spencer, Filarete's treatise on Architecture, Vol. 2, New Haven and London 1965, f.127r. A collection of papers concerned with the elucidation of Filarete's machines as well as with the metallurgical techniques he discloses is to be found in Technology & Culture, Vol. 5, 1964, pp 386-407. After paper-making, iron technology now appears to be the best documented case of transmission of East Asian technology into Europe although the case rests as much on the machinery as on the foundry technique. The oliver, for which 14th century references exist, appears to be ancestral to the bell-crank proper.

16. Pisanello's drawing (No. 2286) is in the Louvre, Paris. The only reproduction of it appears to be that in B. Degenhart, Antonio Pisanello, Vienna 1942, plate 147. The dating of this

drawing to 1450 is entirely arbitrary. All that is known for certain is that Pisanello was spoken of as dead in 1455-56 but was still working, and at the height of his powers, in 1449-50: witness his beautiful portrait medals of John VII Palaeologus (in Florence 1439) and of Sigismondo (1445).

17. C. Maltese (ed.), Francesco di Giorgio Martini, Trattati di Architettura Ingegniare e Arte Militare, Milan 1967, f47v; Leonardo da Vinci, MS B.f53v; F. Pisek (ed.), V. Kricka, Mathesis Bohemica, Prague 1947, plate 40, but whose proto-Geschleppe, plate 44, is also a product of this gestalt; J. Bate, The Mysteries of Nature and Art, London 1635, p.71, fig.10; William Hedley's locomotive is preserved in the Science Museum, London. Foster and Raistrick's locomotive, the "Stourbridge Lion" of 1829, I have noticed subsequently, used the same system with some modifications. See E.L. Ahrons, The British Railway Locomotive 1825-1925, London 1927, p.10, fig.5.

18. The Geschleppe (or tugger) was a machine transmitting its power through a single horizontal field rod to a series of pumps placed in a shaft at some distance from the water wheel which set them in motion. The Kunst-Kreuz or engine cross was a device by means of which the reciprocating action of a double field rod was redirected

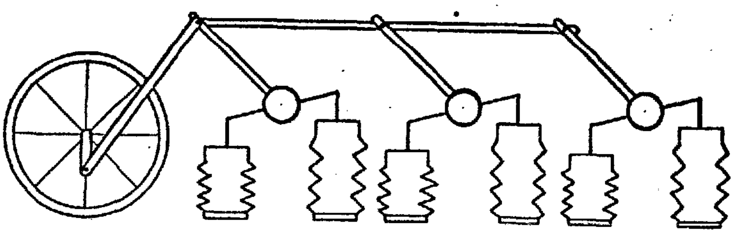
through 90^{o} to two vertical shaft rods each working a column of pumps.

19. The evolution and development of the sector and chain idea, a particularly elegant mechanical conception, is traced in chapter six of this study.

20. One cannot, however, be certain that Leonardo's ensemble in Codex Forster III, f.45r, was transmitted. Kricka knew nothing of it in 1560. However, Mathias Höll's use of this idea in 1711 with double field rods raises the possibility that single rod machines were already so equipped. Unfortunately, there appears to be no evidence to substantiate such an idea. B. Rössler, Speculum Metallurgica Politissimum oder wohl politiert Bergbau Spiegel, Dresden 1700, plate 13, shows three varieties of Geschleppe rods but unfortunately does not indicate how they were connected to the shaft rods they served. The technical dictionaries of 1673 (Christian Berward) and 1693 (Abraham von Schönberg) are equally reticent. All that one can say is that given the sector and chain's diffusion in the 17th century into a wide variety of employments, it would be surprising if it had not found its way into this particular situation.

21. The machine was, as Biringuccio confessed, too

difficult for him to draw: "Io questo non vi posso demostrare in disegno perche e cosa troppo difficile a me...". Despite this one can have a good deal of harmless pleasure in trying to sort out his verbal description (De La Pirotechnica, Venice 1540, p.111. See also C.S. Smith and M.T. Gnudi, The Pirotechnia of Vannoccio Biringuccio, New York 1959, p.306. Biringuccio speaks of horizontal shafts reaching above three pairs of bellows, of levers that push against these shafts and of arms that lift the bellows. The form of these levers and arms may be gleaned from the engraving (fig.53, p.305) of the device that immediately precedes the Boccheggiano machine. In this figure a lever morticed into the bell-crank hangs down from it so as to be within reach of the workman who, pushing on the lever handle, causes the bell-crank and its arms to nod to and fro. This movement is communicated to the bellows by rods attached to the bell-crank arms. The workman's arms are in effect the connecting rod. I have chosen, however, to show the levers of the Boccheggiano machine morticed in an upright position into the tops of the bell-cranks so as to have the rod-line passing overhead, à la Ramelli. To join a rod line to a series of downward hanging levers (as in figure 53) would be to have the whole apparatus reciprocating at waist height to the great and unnecessary embarrassment of the work force. Following these considerations it appears to me that the machine at Boccheggiano was of the following form (omitting the first of the four sets of bellows worked by cams on the wheel shaft itself):



If this reconstruction is turned through 90° and arrangements are made for attaching pumps to it instead of bellows, it becomes in effect Agricola's sipho septimus. T. Beck, Beiträge zur Geschichte des Maschinenbaues, Berlin 1900, p.120, fig. 134, however, goes further than Biringuccio's incomplete and rather confusing description permits in introducing into his sketch elements for which the latter's words give no licence. He is, in any case, certainly over-confident when he claims later (op. cit. p.165) that Biringuccio's machine is the same as Cardano's, a very questionable statement, as I make clear in the following note.

22. G. Cardano, De Subtilitate, Libri XXI, Nuremberg

1550, p.14. I take Cardano to mean that the first bell-crank may be supplemented by a second "quod fabri facere solent" but placed on the left "a sinistra jungere" of the first. If the second is so placed this might seem to mean that the axes of the cranks are to be thought of as being in line, that is end-on, rather than sideways on. It is unfortunate that Cardano's wretched sketch offers little guidance in the matter.

23. The slow pace of diffusion is especially well illustrated by the long interval that elapsed before such a device reached England. When Peter Morris set up his water pumping machine at London Bridge in 1582 it was (according to the terms of his patent) an art not previously known or practised in the kingdom. The chronology of town pumping engines in Germany is rather obscure but it is clear from what Johann Matthesius, writing in Joachimsthal in 1559, has to say, that the idea was by then a commonplace. From this it follows that such wheel pump machines were substantially earlier in use in Germany for forcing water upwards into cisterns than for lifting it from mine sumps. But if wheel pumps could serve for the first purpose, why not for the second? It is obvious where such a question was most likely to be asked.

24. G. Agricola, De Re Metallica (Hoover translation), London 1912, pp 187-8. The standard form of Stangenkunst, as it evolved, was to unite features present separately in Agricola's sipho 7 and sipho 9, that is, it was to have a single wheel but one with a crank arm at either end of its axis, each working a tier of pumps.

25.(i) J. Matthesius, Sarepta oder Bergpostilla, Nuremberg 1562, p.145b.

(ii) Vom Rammelsberge und dessen Bergwerk, ein kurzer Bericht durch einen wohlerfahrnen und versuchten desselbigen Bergwerks etlichen seinen guten Freunden und Liebhabern der Bergwerk zu Ehren und Nütz gestellet. Anno 1565. This report is printed as appendix II in H. Calvör, Acta Historico-Chronologico-Mechanica circa Metallurgiam in Hercynia Superiore oder Historisch-Chronologische Nachricht und theoretische und practische Beschreibung des Maschinenwesens ...auf dem Oberharze, Brunswick 1763.

26. J. Matthesius, op. cit., p.145b.

27. J.F. Lempe, 'Beschreibung der Förderungsmaschinen und Wasserhebezeuge der Alten: nach den Lateinischen des Agricola. Nebst Bemerkungen über selbige', Magazin für die Bergbaukunde, Dresden 1799, Vol. 13, pp 135-6. It is interesting to observe that Lempe was in no doubt about the essential identity of Agricola's sipho septimus

and the sophisticated pumping machines of the late 18th century which in his day had made Saxony famous all over Europe. I have called Agricola's machine the ur-Stangenkunst. Lempe called it the "erste sachsische Kunstegezeugé'. As I have shown in the previous chapter, Kunstgezeug and Stangenkunst were in the beginning, before the invention of field rods, synonymous terms, although by Lempe's time the first was usually reserved for a machine placed over the shaft, the latter for a machine working field rods.

28. See G.E. von Löhneyss, Bericht vom Bergwerk wie man dieselben bawen und in guten Wolstande bringen sol, Zellerfeld 1617, plate 11.

29. C. Meltzer von Wolckenstein, Bergklaufftige Beschreibung der Churfürstlichen Sachsischen Freyen...Bergk-Stadt Schneebergk, Schneeberg 1684, p.99, speaks of the rod-engine being able to lift water from two hundred Lachter (some 1,350 feet), "die Pompen oder Stangenkunst welche in 200 Lachter heben können".

30. Little is known of Kricka's career. His manuscript, written in Czech, is preserved in the library of the University of Prague. It was published in 1947 in Prague under the title Vavrince Kricky z Bitysky (Mathesis Bohemica). Kricka clearly belonged to the 'higher artisanate'. His

technical vocabulary is mostly German with Czech inflections. He treats of four subjects of which the section on pumps is the second. The other three deal with munitions and projectiles, with the casting of bells and cymbals, and with foundry work and the casting of ordnance. His drawing style is largely unaffected by the Florentine technique of drawing in perspective, which was by then of course becoming universal. He employs the medieval technique of a shifting plane of vision ultimately derived (as I believe) from Islam. His figure 44 is a good example of how explicitly this technique permitted the line of action of a machine to be shown: tug rods and rollers are turned through 90°, the rest is shown as it would appear from the side. The rod and bracket arrangement is shown in figs. 35, 36, 39, 41, 42 and 43. It was clearly standard practice by this time (c.1560).

31. N. Poda, Kurzegefasste Beschreibung der, bey dem Bergbau zu Schemnitz in Nieder-Hungarn errichteten, Maschinen, Prague 1771, p.36, Vignette XII. Poda taught mathematics at the Bergakademie, Schemnitz, for a number of years. His book, really only a manual, is nevertheless of great value. One is initiated down to the last wing-nut and wedge.

32. Ibid. Zubehor der Kunstsatze (the parts of the engine pump).

33. V. Kricka, op. cit., figs. 35 and 41. It might be noted also that Kricka's pumps are spaced out at regular intervals. By the 17th century things were handled differently. In the literature the distinction is always drawn between lower, "niedriger", and high pumps, "hohen Satzen". The lower pumps usually lifted only some twenty feet, the higher fifty. The precise nature of such arrangements varied from region to region.

34.(i) C. Berward, Interpres Phraseologiae Metallurgicae oder Erklärung der Fürnehmsten Terminorum und Redens-Arten, welche bei den Berglauten... gebrauchlich sind. (Printed as an appendix to L. Ercker, Beschreibung Allerfürnemsten Mineralischen Ertzt und Berckwercksarten, Frankfurt 1673).

(ii) C.Meltzer von Wolckenstein, op. cit.

35. V. Kricka, op. cit., fig.44. I call this machine an ur-Geschleppe since it lacked a sector and chain acting as a linkage between the horizontal and vertical rods at the shaft mouth. Kricka's arrangement, loose chains running on anti-friction rollers, would have given rise to excessive wear and friction and soon impelled

engineers to look for some better form of connection.

36. Daniel Lindemeier's engraving of 1606 showing a panorama of the Harz mines lying between Zellerfeld and Lautenthal as it was in the last quarter of that year provides the earliest visual evidence of double rods. Nineteen runs are visible, one of which is shown with a turning (direction changing) point, another with a split drive serving two shafts. The Bergbau Museum, Bochum, West Germany, possesses a copy of this engraving. F.E. Brückmann, Magnalia Dei in Locis Subterraneis oder Unterirdisches Schatzhammer, Wolfenbuttel 1730, Vol. 2, plate XIV, reproduces it in severely cropped fashion. U. Thieme and F. Becker, Allgemeiner Lexikon der Bildenden Kunstler, Leipzig 1929, Vol. 23, p.247, notice Lindemeier, goldsmith and engraver, briefly. His patron was Heinrich Julius, duke of Brunswick. The original drawing from which Lindemeier worked was by Zacharias Koch.

37. J. Errard, Le Premier Livre des instruments Mathématiques Méchaniques, Bar-le-Duc 1584, plate 21. Errard's single rod machine has a very feeble looking connection with the single pump it serves. Technically this single pump puts it out of court as a Geschleppe.

38. See chapter two pp. 87-88.

39. Daniel Lindemeier was evidently employed in the service of Duke Heinrich whose great passion was for mining. Two of Lindemeier's eight known engravings are portraits of the duke. It seems reasonable to suppose that he and Koch were specially commissioned to make a permanent record of the scene following the completion of so many large works.

40. H. Calvör, op.cit., (note 25), p.38.

41. R. D'Acres, The Art of Water Drawing, London 1659, pp 16-17, records that this was precisely the way things were going in England about 1640 when, very belatedly and apparently in complete ignorance of what had been achieved on the continent, a certain engineer had attempted to reduce the friction to which ordinary flat rods gave rise. The episode is discussed in chapter four of this study.

42. J. Errard, op. cit., fig.21.

43. G.E. von Löhneyss, op. cit., fig.10. It is possible in fact to make out the basic features of the primitive double-rod systems in one of the machines engraved by Lindemeier in 1606 although he was generally content to conventionalize such details.

44. L. Reti, El Artificio de Juanelo en Toledo: su historia y su tecnica, Toledo 1967.

45. V. Biringuccio, op. cit., p.111. Boccheggiàno

is situated in the Colline Metallifere of Liguria.

46. Even so developments subsequent to 1569 are difficult to trace. Split drives and direction changing appear to have been employed in the Harz in 1606 to judge from Lindemeier's engraving while by 1617 Löhneyss shows an even more complex broken drive in operation.

47. As for instance in the line built to serve the Königsegger shaft near Windschacht in 1758 by J.K. Höll. Doubtless the extreme care taken by engineers in counterweighting their devices greatly assisted in overcoming such difficulties. But see Daubuisson's comments on the matter in note 110 below.

48. Department of coins and medals, British Museum: SSB 57-127, 4 thalers 1657 L.W;, SSB 55-127, 3 thalers L.W; C.3584, 2 thalers 1657 L.W. All show a wheel house (Radstube) with field rods serving (or so it would appear) two shafts. All were struck from dies cut by mint master Lippold Weber (Münzmeister at Clausthal 1640-1674). It is an interesting fact that even in numismatics the move towards showing mining activity seems to be subject to the step by step progress one observes in technical development. A 4 thaler coin minted at Andreasberg (Harz) in 1624 has a quartered reverse showing four genre scenes:

hunting, fishing, farming and mining (men are shown working at the smelters and moving ore), and appears to be the first to break new ground in this way by dispensing with the armorial bearings which had hitherto appeared on the reverse of coins. The coin by Heinrich Pechstein is figured by E. Fiala, Münzen und Medaillen der Welfischen Lände, Prague 1904, Vol. 4, p.182 and plate 14, No. 3. The fashion was to continue. A 4 thaler Schaustuck of 1638 engraved by Henning Schlüter, mint master at Zellerfeld 1635-1672, for Georg, Fürst of Calenberg, shows two Gopel and other mine buildings. By 1647 at latest the fashion was taken up at Clausthal, the principal mint in the Harz. A 3 thaler piece of that year (No. 4044 Clarke Thornhill bequest, British Museum) struck for Frederick of Zelle (Duke of Lüneburg 1636-1648) by Lippold Weber shows reapers, shepherds, two miners embracing at the entrance to an adit, and a forest reduced to stumps. The next stage is the fullblown mining scene of 1657.

49. C.Berward, op. cit., (note 34).

50. Ibid, p.28 (for both Bocke and Steg).

51. See E. Fiala, Münzen und Medaillen der Welfischen Lände: Das Neue Haus Lüneburg (Celle) zu Hannover, Vol. 7, Prague 1912, plate 16 No. 5, and plate 17 No.3. Heinrich Bonhorst, previously in the

service of Brandenburg, presented his first accounts to the Brunswick commission of mines at the end of the Reminiscere (1st) Quarter, 1675. Not only does his work show up to date rods but his 2 thaler Löser of 1677 (plate 17 No. 3 above) shows one wheel serving three shafts. The detail shown in the figure accompanying this chapter is from a 2½ thaler in the possession of the Bergbau Museum, Bochum, West Germany. As for Weber's failing to keep pace with technical progress, it may be worth observing that his contemporary Henning Schlüter's field rods are of the same form so that the adoption of Stage IV (standard) field rods in the Harz may be genuinely late.

52. Viz. that provided by the Anonymous (1565), Hake (c.1583), Lindemeier (1606), Löhneyss (1617), Weber (1657), Berward (1673), Bonhorst (1677) and Calvör (1763). Slovakia by comparison gets only some brief reporting by Edward Browne (1673) who, <u>en passant</u>, laments the want of an Agricola to do the region justice. Apart from the anonymous <u>Neu-ausgefertigen Probier Büchlein</u> of 1692 it was not until the 18th century that it began to receive the careful examination it deserved. After Brückmann (1727) the record is unbroken: Montesquieu (1728), Jars (1758), von Born (1770),

Poda (1771), Delius (1773), Ferber (1780), Townson (1793), Bright (1815). This is to say nothing at all of the intense interest aroused in central Europe by the building of the atmospheric steam engine at Königsberg (Nova Bana), part of the Lower Hungarian mining district, in 1722, an event which spawned a minor literature on its own.

53. C. le Secondat, marquis de Montesquieu, Voyages (ed. A. de Montesquieu) Bordeaux 1896, Vol. 2. The quotations in the order in which they appear here are (i) pp 261-2, note 3; (ii) p.261; and (iii) p.262. The passage in (ii) continues, "à present, on se contente d'attacher...une seule piece le long de laquelle on attache toutes les pompes (this was the principal shaft rod or Hauptstange)...Rien n'est si léger et si commode que ce bois continu, qui va du haut de la mine en bas".

54. J.J. Becher, Närrische Weissheit und weise Narrheit, oder ein Hundert...Concepten und Propositionen, Frankfurt 1682, p.268, "...einer Bewegung welche ich inventirt", "a motion which I invented". Elsewhere he describes (p.115) how when he explained the idea to Prince Rupert at Windsor Castle the prince at once seized on it and used it as a drive mechanism for the invalid carriage (Sessel) with which he was then

experimenting. Becher's claim occurs in a passage (pp 265-270) forming part of an appendix to the main body of the work entitled Kurzer doch Grundlichen Bericht vom Wasserwercken und Wasserkunsten. Whether the two pieces were separately composed I do not know, but both contain material relating to Becher's experiences in England (1679-1682).

55. D. Papin, 'De usu tuborum praegrandium ad propagandam in longiquum vim motricem fluviorum', Acta Eruditorum, Leipzig 1688 (December), pp 644-6 and plate XIII. He also published the paper in French in the Nouvelles de la république des lettres, Amsterdam 1688, p.1308ff, subsequently reprinted as chapter three in his Recueil de diverses pièces touchant quelques nouvelles machines, Cassell 1695, pp 36-48. Papin is plainly thinking of providing a means of powering both pumps and hoists at a distance by means of vacuum tubes, "pour y tirer l'eau des mines et y faire d'autres ouvrages qui requierent beaucoup de peine et travail". He notes that such tubes may be buried in the ground and thus form no obstacle to traffic such as field rods offered and were in any case more easily able to accommodate themselves to broken ground. It needs to be remembered in the light of Papin's remarks that engineers always preferred

to face the cost of large scale flume construction rather than commit themselves to the even costlier business of maintaining long runs of rods. Such were a last, not a first, resort unless special factors were involved. At Kopparberg (Falun) in Sweden, for instance, Christopher Polhem's reform plan involved abolishing all leats running to the machines positioned on the rim of the excavation because of the danger of subsidence and the possibility that ruptured flumes might discharge uncontrollably into the workings. The great subsidence of 24th June 1687 was still remembered. His famous "machina nova" of 1694 was later put out of action by just such rock falls. Most writers stress the problems that field rods give rise to, a curious instance of which is afforded by H. Behrens, The Natural History of the Harz Forest, London 1730, p.149, "...when it freezes hard, if there is any iron (other than that from the forges at Gittelde) about the wooden bars that move to and fro it breaks like glass". The original German edition was published at Nordhausen in 1703.

56. S.H. Lindroth, Christopher Polhem och Stora Kopparberget, Uppsala 1951, Ch.2, Blankstöt-spellet (the Machina Nova), pp 18-37. Permission

to build the machine was given in 1692. It was completed in December 1693 and tested early in January 1694.

57. G. Jars, <u>Voyages Métallurgiques</u>, Vol. 3, Paris 1781, pp 80-81.

58. D.A. Tew, 'The continental origins of the man-engine and its development in Cornwall and the Isle of Man', <u>Transactions of the Newcomen Society</u>, Vol. XXX, 1955-57, pp 49-62. The first "Fahrkunst" (man-engine) was built at Zellerfeld in 1833 and thereafter the machine was rapidly adopted in western Europe. The first English man-engine was hung at Tresavean, Cornwall, in 1842. Tew fails to perceive that the machine was a late development of Polhem's idea of 1694 or that it was related to the Stangenkunst. But then neither the <u>Oxford History of Technology</u> nor <u>Technology & Culture</u> contains any reference to the Stangenkunst, a significant reflection of the insularity of English technological experience. R.P. Multhauf, 'Mine Pumping in Agricola's time and later', <u>Bulletin 218, Contributions from the Museum of History and Technology</u>, Washington 1959, alone supplies a glimpse of this important machine and its role in European mining. Nothing like it appears to have been known in China judging by the absence of any reference to the machine in Needham's many works.

Most surprising of all is that so shrewd a critic as Lewis Mumford should have failed to notice the machine.

59. C. von Wurzbach, Biographisches Lexikon des Kaiserthums Österreich, Vienna 1862, Vol. 8, p.261, sub Höll (Hell),Joseph Karl.

60. Barnes' MS is preserved in the archives of the North of England Institute of Mining and Mechanical Engineers, Newcastle. His sketch (the only one in the book) is reproduced by A. Raistrick, 'The Steam Engine on Tyneside 1715-1778), Transactions of the Newcomen Society, Vol. XVII, 1936-37. The T bobs in Barnes' sketch are essentially the same as those drawn by Leonardo in 1493.

61. M.B. Rowlands, 'Stonier Parrott and the Newcomen Engine', Transactions of the Newcomen Society, Vol. XLI, 1968-9, p.56. The document is among the Newdigate papers, Warwick County Record Office.

62. N. Poda, op. cit., Vignette XVI. The swing arms were ten feet long and sixteen feet apart. The motor wheel, forty-two feet in diameter, made five revolutions a minute. The machine pumped water over seven hundred feet from the fifth Sargozi level to the Pieber (Beaver) adit at the rate of forty-two gallons a minute.

63. G. Jars, _Voyages Métallurgiques_, Vol. 2, Paris 1780, p.151. The machines he described were at Windschacht, the wheels which drove them being spoken of as very far from the pit - over eight hundred yards - with the rods going up a mountain as they did at Marly.

64. C.T. Delius, _Anleitung zu der Bergbaukunst nach ihrer Theorie und Ausübung...von den Grundsatzen der Berg-Kammeral Wissenschaft_, Vienna 1773, p.351 and fig. XIV. The T bobs in the figure are said to be twelve feet long, the sectors six feet. This work was designed for the use of students at Schemnitz: it would in fact be difficult to find a better cicerone than Delius.

65. G. Jars, op. cit., Vol. 3, p.42. Towards the end of the 18th century, however, the sector and chain at least had come into use (instead of the Kunst-Kreuz) in Brittany and in Saxony.

66. A. Ehrensvard, _Les Machines de Monsr. Polhem, 1729_, f61r. The folio bears the date Falun 24th July 1729. The MS is preserved in the archives of the Tekniska Museet, Stockholm.

67. S. Lindroth, op. cit., p.67, fig.30, illustrates the rods (of the form Jars describes) at the Bispberg mine as they were in 1920. It is clear that the rods built there earlier by Polhem have nothing to do with these. According to Lindroth (p.57) parts of the machine built at

Humbo-Norrbårke by Polhem in 1698 are preserved in the Tekniska Museet, Stockholm. The building of this machine was said by Polhem to have been the most difficult job he had ever undertaken. The line was over one thousand metres long with ten changes of direction. At the iron mine the rods both pumped water and wound four-wheeled skips up an inclined plane. Very few Stangenkünste seem to have been preserved in situ although two are so preserved at Kosen and Kreuznach in East Germany. Both pumped brine at the Salinen (wiches).

68. J.G. Beckmann, Beyträge zur Geschichte der Erfindungen, Leipzig 1782, Vol. 3, p.321, "Bey den altesten Schmelzhütten sind die Balge von Menschen getrieben worden, deswegen findet man alte Bingen, Halden und Schlacken in Gegenden, wo man zu unzern Zeiten, wegen Mangel des Wassers, keine Hütten anlegen wurde, und die Gewalt eines oft weit entfernten wassers durch Feld-Gestänge anzuwenden, ist eine noch neuere Erfindung".

69. J. Voda, 'Ohnővé Stroje na Slovensku vo vivoji parných strojov pred Wattom v 18 storici', Z Dejín vied a technicky na Slovensku, Vol. 1, 1962, p.234 and fig. 20 for a description and illustration of this machine. The original drawing, probably the work of Holl's daughter,

Constance, is preserved in the Szechenyi archive, Budapest.

70. See chapter five of this study, p. for a description of this machine.

71. W. Pryce, Mineralogia Cornubiensis, London 1778, p.313.

72. J. Hawkins, 'On Submarine Mines', Transactions of the Royal Geological Society of Cornwall, Vol. 1, 1818, pp 136-141. The charming frontispiece to this volume shows the whole ensemble with St. Michael's Mount in the background. Hawkins' article had appeared earlier in the Neue Bergmännisches Journal, Vol. 4, pp 163ff, 1804, published in Freiberg.

73. Martin Planer whose Verzeichniss und Bericht (register and report) of the works he had carried out at the Freiberg mines from the Lucia quarter (Oct. to Dec.) 1557 to Lucia 1570 which was delivered on 26th November 1570 to Elector Augustus' commission of mines, is an extremely valuable document. He reports that he had erected thirty-eight Stangenkünste in the thirteen years of his directorship. In his summa summarum of the economies he had been able to effect as a result of this programme he states the yearly saving as 102,400 florins (probably something over £10,000), "Wenn es auf ein Jahr zusammengezogen wird, thut die Summe 102,400. Dieses

wird ein Jahr lang mit den Zeugen (i.e. Stangenkünste) espart". His figures for individual mines reveal what startling economies in water pumping could be achieved if one scrapped old plant (the water bag hoists, "Bulgenkünste") and re-equipped with rod engines. At mine after mine the cost of pumping was cut to ten per cent or less of what it had been. The report is printed in full by R. Wengler under the title, 'Bericht des Bergverwalters Martin Planer über den Stand des Freiberger Bergbaues im Jahre 1570', Mitteilungen des Freiberger Altertumsverein, 1898, Vol. 35, pp 57-83.

74. E. Browne, A Brief Account of Some Travels in Hungary, Austria Servia...Carniola and Friuli, London 1673, p.93.

75. Copious extracts lifted from Browne's work appear in the spate of histories of Hungary put out in the 1680s, all no doubt seeking to profit from the interest aroused in Europe generally by Count Imre Thököly's rebellion against the Austrian crown. Schemnitz, of course, provided Thököly with the sinews of war. Browne continued to be quoted even in the 18th century, notably by Brückmann.

76. C. Meltzer, op. cit., (note 29), p.99.

77. M.J.T. Lewis, Early Wooden Railways, London 1970,

pp 7-8.

78. In chapter four of this study I review the evidence for supposing that such machines had been introduced into Cumberland by Daniel Hochstetter in 1568. But perhaps what should be stressed here is rather the failure of the new technology to pass beyond the areas of German settlement in any significant way until very much later.

79. The peron du marché was a platform in the centre of the principal market place of Liege lying across the square from the grande fontaine fed by the water flowing from the adits of the coal mines.

80. M.G. de Louvrex, Recueil contenant les édits et règlements faits pour le païs de Liége et comté de Looz par les évêques et princes, Liége 1750, Vol. 2, pp 204-5, Mandement publié au Peron de Liége au son de trompette et mis en garde de Loix le 20 Janvier 1582..

81. T. Gobert, Liége a travers les âges, Liége 1928, Vol. 5, p.499. De Velden's canal was still open in Gobert's day and carried off water from the old adits.

82. Ibid., p.179. Prayon (Prailhon) lies on the river Vesdre some five miles south east of Liége.

83. E. Browne, An Account of Several Travels through a great part of Germany in four journeys, IV From Colen to London, London 1677, p.171. Field

rod engines seem mostly to have been employed in the area of Hervé (Erf) some nine miles east of Liége, and it was no doubt here that Brown noticed them. Six miles west of Aachen at Kalmis (La Calamine) near the castle of Einenberg he saw others by which he was greatly impressed.

84. G. Duhamel, 'Rapport sur les mines de Giromagny, département du Haut-Rhin', Journal des Mines, An VI, Vols. 39 and 40.

85. J.P. Abelin (ed.) Theatrum Europaeum, Frankfurt 1639, Vol. 3, p.234.

86.(i) M.P.S. Pallas, Voyages en différentes provinces de l'empire de Russie et dans l'Asie septentrionelle, Paris 1789, Vol. 2, pp 149, 159 and 188. At Sisertskoi an entrepreneur named Turskaninov had built up an impressive array of workshops including one in which "on execute des ouvrages d'ébénisterie, aussi beaux que ceux des Anglois" - the comparison would be with Thomas Chippendale and William Vile. The most important of all Siberian mines was, according to Pallas, that at Goumeschesskoi (p.202).

(ii) V.V. Danilevski, History of hydro-engineering in Russia before the 19th century, Jerusalem 1968. Frolov's work is discussed in chapter six of this work where fig. 39 is particularly worth noting. Zmeinogorsk, now in the Kazakh S.S.R., lies 300 miles south of Novosibirsk.

87. J.P. Abelin, op. cit., Frankfurt 1643, Vol. 4, p.897.

88. P.O. Wollenius, Argenti Fodinae ut et Urbis Salanae succincta Delineatio, Uppsala 1725, pp 18-19. This work is printed as an appendix to Vol. 2 of F.E. Brückmann, Magnalia Dei in Locis Subterraneis, Wolfenbuttel 1730.

89. M.H. Sunborg, Dissertatio Mineralogica de Metallo Dannemorensi, Uppsala 1716, section 2, pp 1-5. The enormous length of Trygg's machine is accounted for by the fact that it drove two sets of rods, one off each end of its axis. By the time these lines reached the mine they must have been at least half a mile apart. Nor was this all, for each of the principal rods had branch lines. The windmill stood beside the northern principal rod. Trygg junior followed his father as Konstmaståre at Falun. He died in November1699. Polhem, who had spent six years of wrangling with his superior, was appointed Konstmaståre in succession to Trygg on 29th March 1700.

90. Ibid., p.5.

91. G. Jars, op. cit., Vol. 1, Lyon 1774, p.123. The deepest pit at Dannemora was nearly 500 feet below the level of the lake.

92. Quoted by E. Grar, Histoire de la recherche... de la Houille dans le Hainaut Française, dans la

Flandre Française et dans l'Artois, Valenciennes 1847, part 2, p.10. The definitive loss of these valuable mining areas following the treaty of Utrecht (1713) led immediately to attempts to find coal on French territory. From this time one may date the beginning of Jacques Desandrouin's epic searches for the concealed field first at Fresnes and then at Anzin; the former was brought into production by August 1723, the latter by June 1734.

93. M. Rouff, Les Mines de Charbon en France au XVIIIme siècle 1744-1791, Paris 1929, p.335. But see Ch. 5 passim. A kind of guerilla war developed in many parts of France after 1744 between the dispossessed coal owners and the new, but in general coal production was greatly expanded.

94. P.F. de Dietrich, Description des Gîtes de Minerai, des forges et des salines de Pyrenées, Paris 1786, Vol. 1, p.470ff. No historical notices are attached to Dietrich's descriptions.

95. The history of Pontpean has been admirably researched recently by L. Thbaut, 'Machinisme et mentalité de profit aux mines de Pontpean vers 1760', Revue du Nord, Vol. LV, No. 219, 1973.

96. J.F. Daubuisson, 'Mine de plomb de Poullaouen en Bretagne et de son exploitation', Journal

des Mines, Paris 1806, Vol. 20, pp 347-377. Some idea of French backwardness may be gained from noticing that this mine, first opened in 1729, was abandoned on account of flooding in 1740 although the workings had barely reached a depth of thirty metres, only a trifle better than the 11 Lachter of Hake's old-timers of c.1400. It was this abandoned mine that Koenig, a Saxon, recovered in 1750. The Stangenkunst he set up permitted the work to be driven to a depth of seventy metres by 1756.

97.(i) J.F. Daubuisson, 'Description Succinte de la mine de plomb du Huelgoat en Bretagne', *Journal des Mines*, Paris 1807, Vol. 21, p.83.

(ii) J. Ogée, *Dictionnaire Historique et Geographique de la province de Bretagne*, Rennes 1843, Vol. 1, p.355. As the veins led away from the canals supplying the Stangenkünste it became necessary to extend their motion, "à plus de 3,500 metres de distance, à l'aide de pièces de bois et, outre que la puissance initiale se trouvait réduite de plus de moitié quand elle parvenait aux puisards, l'entretien devenait horriblement coûteux". They were eventually replaced by water pressure engines. Polhem, it may be noted, thought that rod lines up to one mile long (upp til en mils) were a practicable proposition. One old Swedish mile was equal to ten kilometres.

98. However, Bertrand Gille has come close to such a view, although using language more appropriate to the history of the decorative arts: "De même qu'on remarque pour les meubles...des styles regionaux, de même il existe des styles techniques parfaitement determinés". 'Découverte, invention et progrès technique'. _Sciences et l'enseignement des sciences_, No. 18, 1962, p.66.

99. P. Hitzinger, _Das Quecksilber-Bergwerk, Idria_, Laibach (Ljubljana) 1860, p.28. "Im 1580 geschah sodann die völlige Übergabe der privaten Theile der Gewerkshaften an die Erzherzogliche Kammer". This expropriation permitted Khisel to begin putting operations on a professional basis. Walter Pope who visited the mine and published his description in the _Philosophical Transactions_ in 1665 mentions that Khisel's Stangenkunst had 52 pumps in two sets of 26. J.J. Ferber, _Beschreibung des Quecksilber Bergwerks zu Idria in Mittel Crayn_, Berlin 1774, gives interesting performance figures for the same machine. The field rods were short (160 feet); The wheel (6 r.p.m.) was overshot, 16 inches broad and 36 feet in diameter. Each heave (the throw of the crank was 39 inches) exhausted 90 Vienna Seidel or about 52 gallons per minute from a depth of 770 feet. The best

engraving of Idrija is to be found in J.W. Valvasor, Die Ehre dess Herzogthums Crain, Laibach (Ljubljana) 1689, p.397. Khisel's rake-work (Rechen) across the river Idria is clearly visible. This served to catch the timber floated down from the Planina for the smelters.

100. J.M. Hoppensack, Über den Bergbau in Spanien überhaupt und den Queck-silber Bergbau zu Almaden insbesondere, Weimar 1796, Pt.II passim. Hoppensack reports that a fire engine was just then being put up. The 50 inch cylinder had come from England. He had found coal seams at Espiel some 11 miles from Almaden which would keep it supplied with fuel.

101. E. Browne, A Brief Account of some travels in Hungary, Austria, Servia...Carniola and Friuli, London 1673, p.40.

102. C. Patin, Relation Historique, Strasbourg 1670, p.45.

103. Contemporary reports of the plundering of Schemnitz and the reduction of the mine installations and houses there to ashes in 1679 make it the work of Father Josua (parson of Tallia near Tokay). See G. Krekwitz, Totius Regni Hungariae Superioris et Inferioris Accurata Descriptio, Frankfurt 1685, p.759, according to whom Josua's haul included 1,700 marks of

silver, all the Church treasure and 40,000 Reichthalers. See also Theatrum Europaeum, Vol. XII (vom Jahr 1679 bis 1687) Frankfurt 1691, pp 47-48, for a report of Josua's execution in the market square of Tallia in October 1679 at the hand of his former favourite, "der Junge Sprenz".

104. Anon. Neu-ausgefertigen Probier Büchlein, 1692, p.110ff. I have not been able to trace a copy of the original. A section from it, 'Von dem Schemnitzer Wind-Schacht oder Ober-Biber Stollen, is printed by both F.E. Brückmann, op. cit., (note 88), p.978ff and J.F. Lempe, 'Vom Nieder-Hungarischen Berg-und Schmelzwesen in Jahr 1692', Magazin für die Bergbaukunde, Dresden 1792, Vol. 9, pp 181-224. This outlay on horses may be put in some perspective by noting that about 1740 the annual value of the bullion produced at Windschacht amounted to some £250,000 according to A. Marczali, Hungary in the 18th century, Cambridge 1910, p.24. The cost of the horses agrees quite well with contemporary English evidence, which indicates something like £20 per horse per annum. L.F. de Marsigli, Danubius Panonico-Mysicus, Amsterdam 1726, Vol. 3, pl. X, reproduces an engraving of Windschacht which, he says, was copied exactly after one made in 1695. A number of large horse-driven

machines are shown at work.

105.(i) N. Poda, op. cit., p.43.

(ii) The history of these machines is discussed in chapter five of this study.

106. Op. cit. Geneva 1748, Vol. 1, p.393 (Inutilité de l'esclavage parmi nous). E. Browne, in his description of Turkey in Europe (1673) was moved to write "but that which moved me most was the pitifull spectacle of captives and slaves which are often met with in those countries".

107.(i) Ibid.

(ii) G.E. von Löhneyss, op. cit. (note 28), part 3, p.3, bears eloquent witness to the power of machines to ease the lot of mine workers. Under the heading 'Von Kunstlern' (concerning work-people) he talks of the harsh lot of the miners of past times, "die armen Leute wie Vieh haben ziehen", 'poor fellows toiling at their tasks like beasts', work which could now be accomplished easily and at small cost. The machines of past times that Löhneyss mentions are none other than those described by Agricola in 1556.

108. C. Ourthier, Journal d'un voyage au nord du 1736 et 1737, Paris 1744, p.182.

109. J.F. Sprengel, Beschreibung der Harzischer Bergwerke nach ihren ganzer Umfange, Berlin 1753, p.42 (footnote). At Clausthal field rod

lines led in all directions - one saw nothing else, "man sieht zu Clausthal lauter Feldgestänge" (p.41). Sprengel has a good deal to say about Leibniz' wind-driven pump of 1678, a failure like those put up by Schwarzkopf and Riedl.

110. C. Matschoss, Die Einführung der Dampfmaschine in Deutschland, Berlin 1905, p.4, note 2.

111.(i) J.F. Daubuisson, Les Mines de Freiberg en Saxe et de leur exploitation, Leipzig 1802, Vol. 1, p.239ff. In his introduction Daubuisson speaks of the Freiberg mines as "le chef d'oeuvre de l'art de l'exploitation, et les mineurs de presque toutes les parties de l'Europe sont allé les voir, et ils les ont prise pour modèle". This was especially true in the case of the machines for pumping and ore winding, "les machines qui y servent a l'épuisement, et surtout celles que l'on y employe pour élévér des minerais...sont supérieures par leur effet a tout ce que l'on voit ailleurs en fait de machines de ce genre". In all such machines the greatest need was for uniformity of motion, "on parvient encore à ce but en s'aident, au besoin, de balanciers ou bascules, dont une des extremités porte un arc de cercle, qui, au moyen d'une espèce de grosse chaine, est fixé au tiran et lui sert en même tems d'appui;

l'autre extremité port une caisse qu'on remplit de pierres...Ce balancier favorise la levée du tiran et rend le mouvement de la machine plus régulier"(p.352). So Mathias Höll's sectors and chains (fig.21) had finally travelled!

(ii) Martin Triewald, A short description of the atmospheric engine, The Newcomen Society for the Study of the History of Engineering and Technology, extra publication No. 1, London 1928, p.52, "The rod-system (has) generally to be renewed every tenth year".

112. F.E. Brückmann, Magnalia Dei in Locis Subterraneis oder Untererdisches Schatzkammer, Brunswick 1727, Vol. 1, p.168.

Chapter Four LEADS AND LAGS IN LATE 17TH CENTURY ENGLISH TECHNOLOGY

During the second half of the 17th century English craftsmen and mechanicians were rapidly acquiring a highly enviable reputation in Europe for the remarkable refinement and mechanical ingenuity of their manufactures. A French visitor to London in 1685, commenting on the material adornments of living he had observed in use among the English, noted that "dans les maisons nouvellement bâties, j'ai remarqué une chose fort commode. Ce sont de grands chassis de verre avec des coulisses qu'on leve sans qu'il soit besoin de cocher pour les arreter. Il y a un contrepoids qu'on ne voit point, aussi pesant que le chassis qui le contretient en quelque lieu qu'on le laisse, et sans craindre qu'il ne tombe sur le tête de ceux qui regarde par la fenêtre, ce qui m'a paru fort commode et agréable. Les Anglais sont fort adroits: ils ont des portes qui s'ouvrent des deux côtés, et se renfermer toutes seules sans passer jamais le lieu ou elles doivent se fermer. Vous connaissez la delicatesse de leur clefs et serrures...."[1].

The words commode and adroit put the emphasis very justly on precisely those qualities that were becoming conspicuous in English manufactures. If one wished to procure exquisite watches of great reliability that would also sound the hours then it was to London that one came. During the last quarter of the 17th century watchmakers such as Thomas Tompion and Daniel Quare raised English watchmaking to a pre-eminent position in Europe. In 1675 Tompion first used a balance spring in a watch made for Charles II; in 1687 Quare first constructed a watch with a repeating mechanism. Nor were contemporary English observers slow to notice what was happening although it is reassuring to find them repeating more or less precisely the story of excellence in the areas marked out above by M. de Sainte-Marie. Edward Chamberlayne in 1704 wrote that the English "are thought to be wanting in industry excepting mechanicks wherein they are, of all nations, the greatest improvers....There being few curiosities of art brought over from beyond sea but are here improved to a greater height. Here are the best clocks, watches, locks, barometers, thermometers...watches so curious....ordinarily of £50 or £60 a watch, and yet these prove profitable merchandise when we send them into foreign countries, so valuable and inimitable is the work..."[2]. Although work in steel and iron of all kinds and the making of scientific instruments were in the front rank of English manufactures, other sectors were not far behind. Moses Stringer could write in 1699 of "the extraordinary late improvement and nicety in all sorts of brass wares, great and small, in and about London, Birmingham and divers other parts of England"[3] and Charles Davenant, writing only slightly later, while admitting French technical superiority, drew attention to the great improvement in English silk and paper manufacture so that "there will not be after the war (of the Spanish succession) the same want of or call for French importations as formerly"[4].

It would be easy, but profoundly mistaken, to assume that such improvement and zeal to improve were characteristic of English industry as a whole, for outside the vastly important field, for a trading nation, of what would now be called "consumer durables" the picture is utterly different. Indeed, so far as such things are susceptible of being expressed quantitatively, England was at the end of the 17th century somewhere between one hundred and one hundred and fifty years behind the progressive areas of Europe in much of the mechanical equipment serving such basic industries as mining and metallurgy. This might appear an astonishing state of affairs given English precocity in the use of mineral fuel in a wide range of operations. Could this and the equally well-marked lead that was to appear in the exploitation of steam power in the 18th century co-exist with such a degree of backwardness? It is no difficult matter, as will shortly appear, to show that this backwardness existed, was inveterate, and showed little sign of yielding even at the end of the 17th century. One might take first Robert Plot's account of a journey, undertaken about 1680, to Ecton Hill copper mine. "All was out of order before I came thither" he says "and the famour wooden bellows that had no leather about them carried away to Snelston in Derbyshire whither I went to see them". Here, however, he found them buried under a pile of timbers in an outhouse and almost impossible to get at. It was only by dint of much dusty poking and note-taking that he was eventually able to carry away an idea of them. Later, with the help of a model kept in the repository of the Royal Society, he was able to prepare the drawing of them printed in his work[5]. Here was a 'curiosity of art' that had not been copied, let alone improved, and yet Ecton Hill, worked by Germans, had been in effect a centre of advanced technology (in English terms) in a number of respects, notably gun-powder blasting. It might very well have served as a model for English entrepreneurs, had any such been seeking one. But was Plot speaking only of Staffordshire? It seems difficult to believe after all that the economy of using wood in place of expensive and quickly worn out leather would fail to commend itself to English industrialists. It was precisely this spirit of rationality, as Landes has expressed it, this readiness to adopt new methods, which lay at the root of English success in creating a new kind of industrial society, in a word, a widely diffused acculturation to change. Despite this, one has Joachim Becher's statement that leatherless bellows, although well known in Germany in mines and smelters, and even available there in double-acting form, were still in 1680 quite unknown in England: "Ich habe in Teutschland bey den Bergwercken und Schmeltz-Hütten holzerne Blassbalge gesehen/welche gar ohn alles Leder starck blasen/....man kan auch solcher gestalt doppelte Blassbalge machen. Diese invention ist artlich und nützlich/und in Engelland noch nie bekannt/..."[6].

The advantages offered by wooden bellows were very considerable. According to Pierre Grignon writing in 1775 such bellows lasted between 65 and 80 years and besides being 60 per cent cheaper to set up cost only 20 per cent of the upkeep required for those made of leather. Nor was the technique a new one in the 1680's. It is reasonably safe to assume that they were coming into general use in Germany towards the end of the 16th century. Grignon believed that they had been adopted in the eastern parts of France such as Franche-Comté rather before 1700[7].

Nowhere, however, was English backwardness more marked than in mine-pumping, perhaps the one area where one would most expect to find a spirit keen for improvement and alert to foreign methods[8]. More importantly, most of the English mines that were of any economic significance were coal mines. Although mines of metals could and did support rich and varied societies in large regions of Europe which without such mines would have remained primeval forest, the English situation was quite different in kind. Coal mining likewise sustained large and prosperous communities in areas such as the Lothians, Durham and Tyneside, but beyond this the English economy as a whole was in large degree underpinned by the industry and dependent on it. The importance of coal in the development of the economy during the period 1560-1660 was growing at an unprecedented rate, as Nef has shown, and the conjunction of growing demand and insufficient pumping equipment was, to say the least, unfortunate[9]. By the late 17th century consumption of coal was running at a rate of about 3,000,000 tons per annum, and the point had long been passed at which it would have been possible, in default of supplies of coal, to have made good such quantities in terms of their timber and charcoal equivalent. Already in 1700 it would have required the setting aside of something approaching 8,000,000 acres (or 12,000 square miles) of good quality land for forest to have supplied an equivalent amount of fuel[10].

I have insisted on these figures and on the calculations in the footnote which accompanies them in order to show how uniquely England depended on mining. No such calculations would be needed for Brunswick, Saxony or Hungary, or indeed for any of the regions of intensive mining activity in Europe, although an exception might conceivably be made in the case of Liége. Only England, in other words, had departed substantially from the self-sustaining rhythms of an eotechnic economy and was therefore alone in having shifted its industrial base to mining. Nor was it, as noted, a position from which the country could retire in the event of the failure of its mining industry to sustain production. Efficient mine drainage was therefore a matter of national rather than regional significance. If this were the case, and there seems no reason to doubt it, it is scarcely credible, in view of the difficulties the industry was facing, that no sustained effort was made to discover what methods were in use in Europe or to draft in foreign experts[11]. All available evidence relating to actual practice in the pits suggests that nothing was done. There was indeed one initiative, that of the Royal Society in 1673, when it was learnt that Sir Joseph Williamson was to travel to Aachen. Henry Oldenburg was directed to draft enquiries to which it was hoped Sir Joseph would promote replies when he left England[12]. Among them was No. 4 in case he should visit Liége and have the opportunity to greet Canon René Sluse. He was to enquire about the depth of the pits there and the engines used to drain them. Sluse's reply, dated 8th February 1674 (NS) was read to the members on 19th February. He pointed out gently that the soles of the shafts in the coalfields (so he had been informed) had been sunk to one hundred fathoms and more,"ad centum et ultra orgyiarum profunditatem deprimi", something perhaps at which they might well marvel, "quod fortasse mirum tibi videatur", since they seemed to think that depths of 150 ells were considerable. As to the query by what arts the pits were freed from water he was frankly either uninformed or careless. He referred them to book six of Agricola and to the buckets and pumps displayed there, "vel situlis hauriunt, vel antliis, quales apud Agricolam in libris de Re Metall. videri licet"[13]. What seems extraordinary is that nobody should have thought of approaching either Walter Pope or Edward Browne both of whom, unlike René Sluse, had actually descended into mines and had seen at first hand the machines in use. Both, for instance, had had papers printed in the Philosophical Transactions on Idrija where the deepest sump was 140 fathoms (130 Lachters) below adit. Browne, of course, had in addition first hand knowledge of Liége itself[14].

Deep mining, that is to say work carried on at more than about 100 feet below adit, seems rarely to have been attempted in England, and what the German chronicler of the Harz mines, Hardanus Hake, wrote in 1583 that "The old timers could not drive their soles deeper than eleven Lachter (about 70 feet) below the headstock of the winding gear in the adit", "der Alte Mann unter dem Stollen von der Hengebank bis auf die Sohle nicht tiefer als 11 Lachter gewesen", seems to have been largely true still of late 17th century English mining practice[15]. Even in the 18th century English mines were still very shallow by continental standards. As late as 1769 William Sharpe in his Treatise upon Coal Mines cites no pit deeper than 350 feet while the average of all those listed is only a little over 200[16]. In 1744 Desaguliers could talk of 50 yards as "a great depth" in his discussion of mine pumping and its problems. At Liége, as has been noticed, 600 feet and more was the vertical depth of some of the shafts in 1674 and even when one has allowed for the hilly nature of the terrain about Liége which permitted the most effective and extensive use of adits, the discrepancy requires some explanation. What was the secret of the Liègeois? The answer is really quite simple. By the 1570s the exhaustion of easily won upper coal and the consequent deepening of shafts had led predictably to flooded workings. The critical stage had been reached where deep working below adit could only be pursued if adequate pumping equipment were available. It was not. The situation was so bad that one of the first acts of Prince-Bishop Ernst von Bayern (1581-1612) was to draw up in December 1581 and have publicly proclaimed to the sound of trumpets on 20th January 1582 from the 'peron' - a public platform in the market square - in Liége what came to be known as the Édit de Conquête. Anyone who could unwater the drowned out pits would be allowed to reap his reward and work them unmolested[17]. Fortunately for Liége it lay within the German language area, and just as itinerant engineers had brought Stangenkunst (rod engine) technology to Saxony in the 1550s and to the Harz in the 1560s, so it seems probable that in the later 1580s or 1590s Liége got its first machines although what seems to have been an attempt in 1586 to set up pumping engines worked by adit rods (Streckengestänge) seems not to have been successful. By the beginning of the 17th century, however, the problem had certainly been solved[18]. There is no question that, given a sufficiency of motor water, the rod engine provided the definitive solution to problems of flooding[19]. This technology in its mature form probably never reached England or at least was only ever an exotic, a fact which undoubtedly contributed materially to the success of the new and extremely expensive steam engine technology after 1712. But before that time the crisis in

English mining which virtually every historian of the early industrial revolution period in England has accepted as having been serious was real enough. The specific reasons for the crisis have never been properly examined. It is certain, however, that if English mine engineers were, before 1712, attempting to address the problem of deep mining with the pumping techniques of 1500 or even 1550, they were bound to encounter insuperable problems. Hake's description applied. As against this the general assumption, most clearly formulated by Nef, is that England was in these matters not a world apart but one fully cognisant of continental techniques. European machines would not serve English purposes, however, because English mines were deeper than those on the continent and therefore posed problems of a different order of magnitude[20]. The exact opposite of this is nearer the truth. England was a world apart and in making the critical transition to deep mining found in Newcomen's engine its own peculiar solution to the problems posed by that transition. In a sense the pattern of palaeotechnic development forced on England in the 16th century by reason of its lack of forests and the absence of the critical climatic conditions (winter precipitation in the form of snow and a spring melt) necessary for float/flume operations was here strongly reinforced by a simple failure of transmission[21]. It already had a distinctive fuel technology and now it developed in addition a distinct form of prime mover. The reasons why Stangenkunst technology never made its way in

England, so far as they can be determined, are not without interest: these however I shall reserve for the final section of this chapter. The first task is to establish that it had in fact failed to travel or at least that if it had travelled it had signally failed to establish itself.

The state of the art of mine pumping as it stood in England in 1659-1660 is fortunately clearly fixed in one of the best books ever to appear in English on the subject. This was R. D'Acres' The Art of Water Drawing[22]. It is not, unlike Poda's and Delius' excellent text books of the later 18th century, a manual of standard practice but a critical appraisal of technology in an extraordinarily unsettled state: that his critique should reveal this is of course illuminating in itself. D'Acres' identity has not been definitely established but if, as Rhys Jenkins supposed, the name was a pseudonym for Robert Thornton (1618-1679) of Brockhall Hall near Daventry, situated at no great distance from the Warwickshire coalfield, then D'Acres would indeed have been well placed, as he himself says, "to have known some experiments and those of no small expence, that have been lately tryed...". His preface clearly implies considerable familiarity with the actual conduct of mining, his avowed object being, as he says, to use it to expose "the delusions and fallacies of water-machines". Thus he would set "sea marks to keep those that come after from ship-wrack", a work of charity so obvious that he wonders it should not have been attempted before. To set up as an anti-projector and bubbleburster would seem an unlikely, not to say ludicrous, undertaking for someone not familiar with practice, and every page of his work makes it clear that he had had, as he would have said, both "practice and experience.... a firm and solid reason". Descriptions of the ordinarily used machines were omitted as superfluous for in D'Acres' view there was no better way than to go and look at them if one wished to learn how they worked. His purpose is, on the contrary, to mark out the area of uncertainty - the not usual and common - where a candid assessment of the performance of new machines and devices and of their scope for improvement might at once help to concentrate future effort on the most eligible machines and limit the damage able to be done to unknowing men by imposters. The simplest sort of Stangenkunst, without field rods, working directly over the shaft is nowhere described[23]. Did it, therefore, not exist?

The argument from silence would certainly be stronger if one could pass beyond it somewhat and point to what appeared to be a situation resulting directly from the inferred absence. D'Acres' work does in fact supply liberal quantities of evidence of this sort. So: if the Stangenkunst were really unknown to the English, then the problem that it had solved elsewhere would still be urgent and pressing in England. It is in this light, I think, that one should view those methods that D'Acres mentions as being in use to effect long distance transmissions of power in the vertical sense. The first system as described involved the use of long masts or baulks of timber, their ends set in "a stop of iron or brasse full of oyl", each deriving its motion through right-angled gear wheels at its top and delivering its torque through another set at its lower end. These were not slight affairs either for where a baulk needed to be longer than 60 feet it would be reinforced with collars of brass (presumably to secure the scarfing joints) while anti-friction rollers ensured that the assembly was kept moving in a straight line, "roulers of iron, thereby to be stayed with the least hindrance". But the longer they were made the thicker they had to be "lest in their shoggings they give a trembling palsie motion..."[24]. Arrangements such as these were, however, out of the question where the shaft was oblique and here "of late use" were "certain loose chains, which work in grove wheels, after the manner of jack-spit chains...". They worked well for a short space but were attended with very considerable inconveniences. Both the vertical axle method and the chain method were doing work, and that not to anything like the depth, or with anything like the ease, that would in Germany have been performed by the master rods of a Stangenkunst. Such rods were as easily adapted to kinks in the shaft as horizontal field rods were to above-ground changes in level or direction. It is scarcely credible that such unsatisfactory methods as D'Acres describes would have been persisted with if rod-engine techniques had been available. D'Acres, having examined the problem of transmission where prime movers were far removed from the"working tool" in the vertical sense, next turns to horizontal situations involving such long separations. In terms of Stangenkunst technology, of course, this was familiar ground, and runs of field-rods of a mile or more in length had been achieved in Germany some time before ever D'Acres was born, probably even as early as the 1590s. It is apparent from D'Acres' work that nothing of this was known in England although the picture is not one of total inactivity. Indeed, one has a curious feeling of <u>déjà-vu</u>: that the situation D'Acres displays may be not unlike a repeat performance of the situation that had obtained in Germany a century earlier. There too engineers had doubtless cast about in search of the best system of horizontal transmission before the success of the elaborated field-rod technique foreclosed all other options.

"There are" says D'Acres "many other wayes coming into practice" for moving water gins a "great way distance off from the place of the mover". The first method he describes is a rope drive able to work "admirable well two hundred yards remote" but which would be of better service in D'Acres' opinion if the drive could be rendered reciprocating instead of rotary. But it was another method of securing horizontal transmission involving the use of "wooden poles joynted one into the other" that seemed to some of the engineers with whom he was acquainted to most deserve research and development work being done upon it. The whole passage reveals to an extraordinary degree the isolation in which English engineering had been developing. "This work" (i.e. horizontal transmission) "may without ropes be effected with wooden poles joynted one into the other to reach a quarter of a mile in length, provided then, that the weight of these poles be taken off by some external means, happily by disposing the weight of the poles in divers places, to rest upon narrow moving centres..."[25]. What is being described here is the most elementary of all forms of Geschleppe, that is to say the simple flat rod moving on anti-friction rollers. Nothing is said about the pumping end of the line or how the rod was connected to the pump it worked but it seems reasonable to suppose that a T bob with a sector and chain raised a suction lift pump against gravity. Not, however, a tier of pumps, but rather something along the lines of Amos Barnes' bob gin at Heaton. But D'Acres has more to say: "This instrumental mover by poles deserves (as by some is conceived) as much experimental perfection as any the world hath yet (in this nature) laboured with. For hereby the strength and service of rivers.....too remote from the place where we need them, and which cannot be brought nearer by reason of the ascending ground, may become most commodious to the mineralists....". This experimental perfection had been previously attempted: "There hath been some years since an experimental assay made to take off the weight of these poles, by hanging them in several places, like bells or weights at the end of chains; but it being the first experiment of this nature and (nihil simul inventum est et perfectum) nothing....is at once and together invented and perfected, first invent, next amend, and lastly perfect, it happening in such unlucky times, the prime and chief designer and workman being since dead, in regard of these military discouraging times"[26]. A little later when D'Acres turns to discuss the various devices in use for converting rotary into straight line motion one learns that the experimental engine with hanging rods had not been worked through a crank but by means of cams or "tawmps or stops of wood or iron standing forth of the moving axeltrees". This means of setting the rods in motion is the same as that used in a machine drawn by Vavrinec Kricka in c.1560 although in Kricka's machine the rods merely rested on an anti-friction roller[27]. It is impossible to say of how long a standing these tentatives were in England but if the experimental hanging rods were, as it seems safe to suppose, the work of the decade 1642-51 (from Edgehill to Worcester) bearing in mind D'Acres "such unlucky times" then presumably the flat-rod system had been in use for some time previously Nor is it any easier to divine the origin of these ideas since single rods of the type described were most likely coming into use in Europe in the 1560s but were certainly being superseded by the 1580s or 1590s. Is one dealing with a product of stimulus diffusion or perhaps with some partial assimilation of ideas brought into Cumberland by Daniel Hochstetter in 1568? It is certain from this context at least that little was known of the German achievement, and the engines described might well have been a response to imprecise noisings and reports relating to such machines: how would an engineer translate into hardware (were he so moved) Edward Browne's report of the rod-engines at Liége opaquely hinted at by the words "strong woodwork moving backwards and forwards"?[28]. As for the possibility of transmission from Cumberland, that is something to which I shall return later. It would, however, be wrong to leave D'Acres without some comment on the experimental hanging rods. This idea is a curious anticipation of a system shown in a sketch made by Augustin Ehrensvard in 1729 of one of Christopher Polhem's machines at Falun. There is besides this other evidence of Swedish dissatisfaction with orthodox techniques[29]. In an English context, however, such ideas have a somewhat different significance, to be yet one more indication of the vacuum in which the anonymous designer was working. At no time do such notions appear to have played any part in the development of rod-engine systems on the continent in the 17th century. Indeed, the whole weight of experience seems rather to have deflected continental development away from single rod linkages of whatever kind, since, unlike double rod systems, they were not so well suited to respond to the unequal loadings thrown upon them in the operation of large assemblies of pumps. One feels obliged to add that even if these design studies in England had proceeded to a successful conclusion it is difficult to see what large purpose they (or the flat rods) would have served since unless they were to be hitched to a vertical tier or repetition of pumps they would have been of very limited value. And at no time is there any trace of such tiers in use, at least not before the 18th century. It is not without significance, I suspect, that in the earliest known drawing of this kind of machine Amos Barnes' sketch of 1733, referred to above, of a device at the Low Engine pit shaft at Heaton Colliery, near Newcastle, the pumps, there are two of them, are worked in echelon off individual pump rods and not off a master rod. It may be worth recalling here that when Agricola described his sipho septimus it was described as having two, but more usually three, pumps working off what was essentially a single rod. At Fresnes in the same year, 1733, when George Saunders completed setting up the first Newcomen engine in French Hainaut it is clear (from Belidor's engravings) that the master-pump rod system, an element of the Stangenkunst complex, was used and not the much less elegant 'English system' such as one sees in the pages of Desaguliers[30]. In other words, at Fresnes only the technique of the prime mover was being borrowed by Desandrouin's engineers and when it came to the shaft part of the business they had already a well-tried and familiar system to which to hitch it.

In 1668, eight years after the appearance of the second edition of D'Acres' work, Edward Browne set out on his second 'grand tour' but instead of following the well-trodden path through France and Italy he followed a very unorthodox itinerary. In the normal way the accounts of the orthodox grand tours offer few surprises; it is sometimes difficult to suppress a yawn as one comes upon yet another recital of the grotto del cane or yet another rendering of some proverbial praise for the sausages of Bologna or the courtesans of Venice. By contrast it would be a difficult matter to find dullness anywhere in Browne's narratives[31]. Indeed, when his journey takes him ultimately to the military frontier of Austria in the Balkans and later to Idrija and the fortress of Palma Nova in Friuli, one is given a unique glimpse of what was in a very real sense ultima Europa. Browne's interests too were more catholic than was normal, especially his absorption in mineralogy, mining and mine engineering. As for the last, it is clear from a number of his remarks that in many places the hydraulic engines he saw in use were quite outside his experience (and one presumes that of most Englishmen). One thing especially is very striking about what he has to say on the subject of mine pumping: whether he is talking about Liége, Saxony or Hungary it is quite clear that the evacuation of water from the deepest workings was ordinarily no problem. To be quite precise it was a problem in one place only, Schemnitz. There, in the worst of all possible mining situations, the difficulty caused by an almost complete absence of motor water above ground was compounded by very strong underground springs which posed a continuous threat to the working of the mines[32].

On a later journey in Europe in 1673 Browne passed through Aachen and spent some time visiting the zinc pits at La Calamine, five miles south-west of the city. "Of the works about the mine" he wrote "the most remarkable are these: an overshot wheel in the earth, which moves the pumps to pump out the water; and this is not placed in the mine, but to one side of it, and a passage cut out of the mine to the bottom of it, by which the mine is drained"[33]. This description is perhaps not sufficiently explicit to make it clear what was involved. The wheel, fed by water from some higher level, was evidently placed some way along an adit specially dug for the service of the mine. From the wheel horizontal adit-rods (Streckengestänge) stretched to the shaft where their motion was redirected downwards, through master rods to serve the tiers of pumps which lifted water from sump bottom to the adit. The exhaust water flowing under gravity eventually joined the spent water from the wheel itself. As he travelled on further westwards into the principality of Liége Browne again encountered the Stangenkunst with field rods. Most likely the ones he saw served pits to the east of Liége itself at Hervé (Erf) or Herstal. Liége was, of course, famous all over Europe for its deep and rich coal mines. "Their pumps and engines to draw out the water are very considerable at these mines; in some places moved by wheels at above a furlong's distance to which they are continued by strong woodwork, which moves backwards and forwards continually"[34]. It is clear that he has no name, any more than had D'Acres, for these field rods, or indeed for the rod-engines themselves. As witnesses, however, both D'Acres and Browne are of limited value: the former because he had narrowly defined objectives and the latter because he may, after all, have had only a very limited acquaintance with English mining. No hint is dropped in any of Browne's works, whether by way of parallel or allusion, that he had visited any of the great coalfields of England or was familiar with the machinery used in them. Fortunately, from this time onwards a considerable body of evidence is available which bears precisely on the question: what kind of machines were in use in English mines to keep them drained? The writers who together answer this question very comprehensively fail only to include Cornwall, an annoying omission since there is good reason to suppose that several initiatives of great interest took place there in the period in question (c.1670-1710). These will be reviewed later in the present discussion.

Stephen Primatt's The City and Country Purchaser and Builder published in London in 1667, is the earliest of a group of works in the period 1667-1708 concerned with routine practice in the mines. Primatt's purpose was to write an outline guide to alert the outsider to at least those basic questions a prudent prospective purchaser of real estate would wish to have answered before proceeding to treat. Coal mines might naturally enough figure among estates up for sale, in which case one is to consider "what engines they use to draw their water....."[35]. The answer for collieries, whether on the Tyne or the Wear, is clear: "In most collieries in the north they make use of chain pumps and do force the same either by horsewheels, treadwheels or by water wheels; and this they find the surest way for the drawing their water, although the charge of such.....is very great...". As for lead mines of Derbyshire, the picture is much the same but "that which is most used among them is a sough, they lying for the most part in hills"[36]. The rag and chain pump is here the principal pumping engine as it had been in the Erzgebirge described by Agricola. Yet that description had ceased to be valid within ten or twenty years of his death (in 1556). The re-equipment of the mines of Freiberg was begun by Martin Planer scarcely a year after the publication of De Re Metallica. Unless Primatt was hopelessly misinformed, the picture he draws of England's principal mining areas shows it still untouched by these changes after one hundred years. For a number of reasons it is unlikely that Primatt was wrong. When William Leybourne produced an enlarged second edition of the book in 1680, the information relating to drainage was in no way modified. Again in the pages of George Sinclair one finds a full length portrayal of the state of English engineering which amply substantiates Primatt's generalizations[37]. After remarking on evidence that seemed to him to suggest that the art of mining underground was of no very remote antiquity, there being visible in many parts "coal wasted in their cropps only" he goes on to consider the kinds of engines in use where adit drainage would not suffice. There are, he notes, ordinary buckets, horse works and water works, the last two consisting in either case of "a chain with plates and a pump"(by which he seems to mean the pipe through which the chain passed) or "a chain and buckets all which are very common, especially those we have in Scotland, they being capable to draw but a very small draught, making only use of one sink for that effect"[38]. But Sinclair had been 'abroad' and seen the greater works of 'Bishoprick' and in particular had seen and been impressed by the machinery in use at Sir Thomas Liddel's mine at Ravensworth on Tyne. His delight caused him to afford it a very full and clear description. I have previously suggested a parallel between late 17th century English pumping practice and that of Agricola's Saxony about 1550. Perhaps the comparison should now be advanced a few years since the Ravensworth engines put one in mind of nothing so much as some of Ramelli's mechanical confections, No. XLII perhaps or No. LII, but easily beating both in point of numbers of gears involved. Sinclair is careful to draw attention to the great depth from which the water was drawn; in this case above 40 fathoms. Although this hardly compares with the 200 Lachter[39] lifts being achieved at this time in Saxony, and it is surely fair to set extreme case beside extreme case, it nevertheless sounds a respectable enough depth and had not Sinclair gone on to describe how it was achieved one would certainly carry away a quite false picture of modest hydraulic competence, at least among the northern English. As it is "water is drawn about forty fathoms in perpendicular but not all in one sink". Instead the lift was split up into three, of 12, 14 and 12 fathoms respectively. The first lift was effected by a machine employing two vertical axles. The first of these was driven through right-angled gearing by an overshot water wheel. This axle, of the sort that D'Acres had described, was about 8 or 10 fathoms long and through another set of gears at its base turned another such shaft set below it "and so down till it come to the wheel which turns the axle trees by which the chain is drawn"[40]. This rag and chain pump raised water 12 fathoms. The exhaust flowed along a gallery to a second sump (or sink as Sinclair termed it) where an engine similar to the first but having only one shaft raised it a further 14 fathoms. A third machine drawing this water 12 fathoms from a third sump exhausted it into the adit along which flowed the day water which had driven the three wheels of the complex. There was no question here obviously of want of water, or of difficult or oblique shafts, "the axle tree goes right down in the sink", simply lack of an adequate technology. Indeed, the handling of water in relays in the style of Ravensworth brings to mind the possibility that in such matters the English had put themselves to school with quite the wrong masters and drawn on Dutch practice. If the use of mills in series was derived from the molengang idea which Simon Stevin had patented in 1589, then it was, of course, a totally inappropriate technology to borrow[41]. However well suited it was to the problem of clearing the dead water of polders in a series of shallow lifts, it was clearly a technology which did not translate well into mining conditions. The idea of using broken lifts in a mine was absurd when normal practice required the placing of the sump precisely in the place where it would best serve the future development of the work. Still, polder technique was doubtless better than no technique at all, and prompts the reflection that the diffusion of Stangenkunst technology westwards had met, so to speak, a _cordon sanitaire_ in the Netherlands, beyond which it could not pass. The frontier areas of that tradition were, therefore, too remote from the English for it to pass easily to them. The Dutch did not need it except in such mines as existed in the secluded eastern parts of the country such as Limburg, while the French, for whatever reasons, were as ignorant of it as the English despite their more favourable position[42]. The linguistic divide between French and German speech running from Wallonia across the Vosges to Franche-Comté was effectively the limit of rod-engine technology at this time. Certainly, many of D'Acres' remarks are more readily understandable once the fact of English isolation is predicated.

For the 1680s one has a further description of Tyneside from the recollections of Chief Justice Francis North while on the northern circuit. North was curious to visit the coal mines and eventually saw those at Lumley Park, "the greatest in The North", belonging to Sir Ralph Delavel. In discussion Delavel is said by North to have remarked that "chain pumps were the best engines for they draw constant and even" but that one could have but two stories of them. The description which follows is unfortunately far from clear, so that it may or may not be a variation of the Ravensworth model that was being described[43]. Much the same picture is drawn for Staffordshire at about this time by Robert Plot. "It may not be amiss" he says "to add a word or two concerning the methods they use in laying their coals dry, when anything troubled with water, which because they are not so frequently or so much, as in some other countreys, they are not forced upon such variety of expensive engines. The ordinary ways are by sough or by gin...when they have no fall (i.e. no adit) they draw it up by gin....which is twofold, either by chain, or by barrels; the chain is made with leather suckers....the gin by barrels; whereof always one goes up as the other goes downe"[44].

Finally, in 1708, almost on the eve of Newcomen's success at Dudley Castle, a booklet appeared entitled _The Compleat Collier; or the whole art of sinking Coal Mines_ by J.C. Nothing had changed since the days of Plot and Primatt. Water was still a menace, of course: "indeed were it not for water, a colliery in these parts (i.e. Tyneside) might be termed a golden mine to purpose...". As for the means of voiding it, "....if the pit be sunk more than thirty fathom then we use the horse engine which....serves also....to draw up the wrought coals. Which engine, tho' it be but of a plain fashion, yet it is found by experience to be more serviceable and expeditious, to draw both water and coal than any other engine we have seen in these parts yet, notwithstanding we have had many pretenders in many kinds and methods; though we will be glad any ingenious artist could show us a more effectual way, for expedition and service, then we now use hereabouts. In some places we draw water by water, with water wheels or long axel trees....If it would be made apparent, that as we have it noised abroad, there is this or that invention found out to draw out all great old waists or drowned collieries, of what depth soever, I dare assure such artists may have such encouragement as would keep them their coach and six, for we cannot do it by our engines and there are several good collieries which lye unwrought and drowned for want of such noble engines or methods as are talked of or pretended to....."[45].

One could repeat for 18th century France the same sad tale of unwrought riches, at Pontpéan and Poullaouen for instance, and find at Almaden in Spain an even more desperate backwardness. Montesquieu was wrong in thinking that "il n'y a que les Turcs qui ne profitent point des lumières de la société humaine"[46]. All the English (and the French, Spanish and Turks) needed were a few German mine directors, or at least men trained in the German tradition, to put their lost pits securely and profitably back into operation. Newcomen's engine was, it will be conceded, sorely needed, in default of such expertise. The rate of engine construction tells its own story to some extent but recent research has revealed in sharp detail the ferocious sharks which quickly infested the seas of the new technology[47]. The success of the Newcomen engine unleashed a desperate clamour from coal owners each anxious to be served ahead of rivals which, given the shortage of skilled erectors and materials, could not possibly be satisfied. It was in these circumstances that glib middlemen like Stonier Parrott and George Sparrow began to play off one client against another in order to secure preferential rights, and slices of real estate against promises to bring in their precious know-how. The prime cost of the engine, the substantial running costs, to say nothing of the royalties payable to the proprietors of the patent, were as nothing if the alternative to paying up was to go out of business. It was, however, to a large degree a phoney crisis.

There are nevertheless certain features in the English mining situation at this time which deserve to be mentioned, especially since they might be thought to modify somewhat the bleak picture of backwardness this survey has revealed. It is interesting, for instance, to reflect on what the early state of pumping arrangements at Griff colliery reveals when contrasted with standard German practice. The Griff arrangements are those presented by Desaguliers in his A Course of Experimental Philosophy but based on reports supplied to him by Henry Beighton[48]. They may refer to the engine erected in 1714. The total lift of 150 feet was modest enough by continental standards and involved only a tier of three pumps, but for Desaguliers this was to bring up water from "a great depth". The pipes were of wood, fixed together in Agricolan fashion forming a lift unit raising a column of water 7¾ inches in diameter fifty feet. Each of the three pipes in the unit had a distinctive name: first the sucking tree, its end submerged in the sump, then the pump barrel, and finally the upper tree of delivery. The second lift took its water from the exhaust of the first, the third from the second. This was, of course, orthodox Stangenkunst technique even if the pumps were set in motion by a new prime mover. A further parallel may be seen in the three part pipe arrangement which matches perfectly the descriptions one finds in contemporary German mining lexicons[49]. Once again the question of some partial assimilation of German practice arises, for where else did the pump tier idea exist? And how long had such arrangements been in use before one first gets this glimpse? All one can say is that even here the parallel is not remarkably close. The system lacks the master rods (Hauptstangen) of the normal rod engine and uses a mode of forking the rods that has about it an unmistakable one-off cobbled-up appearance. The same air of improvisation clings to the forking arrangements at Heaton Colliery as sketched by Amos Barnes in 1733[50]. Nevertheless, like those examples in D'Acres' work, one seems to have here further evidence of a partially assimilated technique. I have referred elsewhere to the Geschleppe type pump shown in Barnes' drawing. Even there each pump has its own pump rod. The machine is called a bob gin, a name which occurs in an inventory of engines drawn up at Griff Colliery in 1711. Engines driving flat rods were in use in the Derbyshire lead mines at about this period. Later than any of these examples are the hydraulic bob engines driven by giant wheels which worked at the Bullen Garden mine, Camborne. William Pryce who described them in 1778 says nothing about how long they had stood there or who had built them. Another engine of this kind at the Cooke Kitchen mine, its wheel forty-eight feet in diameter, drew water from 80 fathoms below adit in four lifts and according to Pryce would have worked down a further 40 fathoms if more water had been available to fill the buckets. The column of water lifted was nine inches. Elsewhere Pryce states that John Coster had inaugurated such large wheels (and presumably the tiers of pumps that went with them) in the early years of the

18th century: "About four score years back, small wheels of twelve or fifteen feet diameter were thought the best machinery for draining the mines, and if one or two were insufficient, more were often applied to that purpose, all worked by the same stream of water. I have heard of seven in one mine worked over each other...However soon after the above date (sic) Mr. John Costar of Bristol came into this country and taught the natives an improvement in this machinery, by demolishing these petit engines, and substituting one large wheel of between thirty to forty feet diameter in their stead..."[51]. Once again one is confronted by enigmatic evidence. Here are engines almost up to Stangenkunst levels of performance, using tiers of pumps and yet completely original in their power transmission system. Were they earlier or later than the first Newcomen engines? This is an important question since they might well appear to copy the beam and sector arrangements of those engines. On the other hand it is easy also to find affinities with the pumping engine of 1608 at La Samaritaine, on the Pont Neuf, Paris. One can amid these questions be perfectly certain of one thing: the type was not widely diffused. It is simply inconceivable that where sufficient motor water existed one would ever have encountered vertical axle-trees if such an excellent alternative to them had been available. Men such as Delavel and Liddel were not, after all, slow to take up the completely novel fire engine technology and were well endowed with that pre-requisite of technological innovation, the mentalité de profit, the capitalist spirit. But earlier in Cornwall than Coster was Joachim Becher. He had worked there for some months in 1681-2 and it is entirely possible that during that time he himself may have had a hand in introducing Stangenkunst technology into the area (if indeed elements of it were not already there). Erik Odhelius, a member of the Bergkollegium at Falun, who visited the mines of Cornwall some eight years later in the course of a metallurgical tour of Europe in the years 1690-2, noted in his travel journal that "the position of the mines extremely seldom allows hydraulic engines to be used, although shortly before his death Dr. Becher is said to have set one up at a place in Cornwall that was extremely effective": "ehuruwähl Dr. Becher Berättades kort för sin död en sadan hafwa pa ett ställe i Cornwall med särdeles nytta inrättat"[52]. If Odhelius' information was correct it is likely that one has here the date of the first rod-engine in Cornwall. But not perhaps the first in England. D'Acres' remarks on rod engine work, given their due weight, point to the precarious survival of Stangenkunst technology or rather some isolated elements belonging to it, in the inventories of English engineering practice from some much earlier period. It is clear, in fact, that those elements belong to the earliest period of field rod development simpler even than the suspended single rod design appearing in Jean Errard's book of machines of 1584. There is only one place to look in seeking the origins of such an underdeveloped technology in Elizabethan England and that is in the events which brought German miners from Gastein and Schwatz to Cumberland in 1568. Their role and that of the Augsburg finance house of Haug & Co. in seeking to develop the copper ores of that region has been closely studied and it seems reasonably certain that in order to drive the workings below adit at the Goldscope (Gottesgab) mine at Newlands Daniel Hochstetter set up a rod-engine to drain the sump. Already in May 1568 the terms of the patent to be granted to him for a machine for draining mines had been drafted. The account book for 1569, furthermore, contains a number of entries which taken together strongly suggest that the fabrication and assembly of the components necessary for the construction of such a machine was carried through from April to September of that year. On 25th April the axle of the water wheel was carted to the site along with what may have been a toothed gear; on 23rd May the carpenter was paid for the construction of water troughs; and so on 13th September were the carters for the cost of the carriage of four great augers to bore the wooden pipes. And that is all: the account book for 1570 does not survive[53].

Whatever the form of the machine set up by Hochstetter, there can surely be little doubt about the nature of the machine at the site described by George Bowes and Francis Nedham in their report of 1602. They talk of a newly erected water engine, which is perfectly understandable for the wheels of rod-engines did not usually last longer than about fifteen years and Hochstetter's original would then have been in situ for at least twice as long, if indeed it still existed. Bowes' and Nedham's engine might well have been the third set up on the spot. The report mentioned first the leat, 1200 yards long which brought water into the mine to serve the engine. As for this, they say "We viewed the.....water engine newly erected in Gods Gift (Gottesgab) and the course of the stream that stirs the double wheel....which engine serves as well to draw up the ores and deadworks when need requires, as to draw the water out of the bottom of the mine through many pumps which is performed very effectually and doth lay the mine so dry that when we were in the bottom we did stand where the nethermost pickmen did work, without any annoyance of water"[54]. Hochstetter's machine, like the one described here (if there were indeed two) may well have served a double purpose also if a rather cryptic reference to a "senstochk" (?zahnstock) in the accounts for April 1569 is to be understood as 'tooth-piece'. A number of drawings made about 1560 in Prague show such combined hoisting and pumping machines and the artist/engineer Vavrinec Kricka in whose note-books they occur would seem in a good many respects a comparable figure with Hochstetter. The place that Kricka's engines seem to occupy in the evolution of Stangenkunst design has been discussed elsewhere, and the Newlands 'machine' built some time between 1570 and 1602 fits very well into this scheme. Doubtless in small scale operations, and the 'Gift of God' was certainly no very flourishing affair, it would have been grossly uneconomical to set up two machines, a Stangenkunst for pumping and a Kehrrad (or double wheel) for hoisting, although generally this was standard equipment, as was the case, for instance, at Idrija in 1596. But two wheels would never have been tolerated for long if either had been left standing idle for considerable periods: the accounting techniques of the period extended to infinitely finer points of cost effectiveness than this.

In the light of all this the history of the Stangenkunst in England would appear to be both more complicated and more interesting than one involving a simple failure of transmission. It appears much more likely that the failure of these techniques to take root in England was connected with the early demise of the one mining area into which they had been imported. Cumberland was, after all, a great disappointment, and even the richest mine ever found there appears to have better deserved the name of "Leerestasch" (empty purse) than "Gottesgab" (God's gift) the latter name corrupted by a quaint irony into "Goldscope", the very thing that, except in the sense of a drain, it was not. Haug & Co. had lost perhaps as much as £19,000 before they called it a day. Unsupported hypothesising is never very profitable but one has only to imagine Cumberland copper mining as a sustained operation having a long and successful life to see how naturally in such circumstances Stangenkunst technology would then have been successfully domesticated in England[55]. The first experts were naturally enough Germans with the local English serving above ground as an unskilled labour force carting wood and fuel to the site, rather in the way Slovaks performed all the ancillary services called into existence and sustained by the purely German mining communities of the 'Ungarische Bergstädte'[56]. But a division of labour along ethnic lines would scarcely have persisted long in England. As the original Germans intermarried or retired or died, so would the German complexion of the mining force have begun to give way to a mixed situation in which even the sons of these men spoke English. Within a generation perhaps even a few native Englishmen would be familiar enough with the technology to be able to transplant it to other mining areas of England as the need arose. How else indeed were complicated techniques ever transferred? This was exactly the manner in which the first European experts in atmospheric engine construction acquired their mastery and took over from their English teachers as death or old age removed these from the scene. Manifestly this never happened in England because the conditions necessary for it to happen did not exist: that is, an on-going profitable mining operation. This the meagre lodes of Cumberland could not sustain.

The workings there were more than halfway to the owl-haunted condition dear to the Gothic imagination when they were trodden by the naturalist, Thomas Robinson, in 1709, a natural evolutionary forerunner perhaps of the full-blown nature-poets of the end of the century.

1. (i) *Un Voyageur Français à Londres en 1685*, ed. G. Roth, Paris 1968. The MS in the Bibliothèque Municipale de Cherbourg consists of three letters written probably by C.A. de Sainte-Marie to M. d'Englequeville, marquis d'Auvers. The quotation is taken from a letter dated 8th May 1685.

(ii) R. Plot, *The Natural History of Staffordshire*, Oxford 1686, gives a number of examples of the sort of exquisite craftsmanship that took Sainte-Marie's eye. See p.376 for a description of recording devices fitted to locks to show how often they had been opened, and p.384 for a machine to perform elaborate turning for the production of 'wreath-work', made by John Ensor of Tamworth.

2. E. Chamberlayne, *Anglia Notitia, or the Present State of England*, London 1704, pp.49-50. On p.51 there is mention of a "very agreeable consort .....performed by clock-work". Then there were "the late great improvements in making glass" and a list containing over twenty further items. The same sort of picture is drawn by T. Smith, *Art's Improvement*, London 1703.

3. M. Stringer, *A Brief Essay on the Copper and Brass Manufactures of England*, London 1699, p.9.

4. C. Davenant, An Account of the Trade between Great Britain, France, Holland.....etc., London 1715, p.54. I have not been able to discover an earlier edition although the reference to "after the war" points to a date of composition between 1702 and 1713. It is interesting that, as far as all the arts mentioned so far are concerned, J. Roquet's The Present State of the Arts in England, London 1753, confirms the picture of half a century earlier and indeed adds new items such as the stamped or imprinted porcelain manufacture carried on near Chelsea.

5. R. Plot, op. cit., plate X. But see also p.164 and his remark about "the vast advantage which they (the iron-workers) have from the new invention of slitting mills for cutting their bars into rods". According, however, to H. Schubert, History of the British Iron and Steel Industry, London 1957, p.304, Richard Foley had set up such a mill at Hydehouse-on-Stour, Worcestershire, some time about 1625. In view of the well known fact that a slitting mill was in use at the Saugus ironworks in Massachusetts in the 17th century and that the works was out of operation by 1670, it might seem that Schubert's chronology was more accurate than Plot's. But whether one takes either example it is clear that by comparison with continental standards

the idea had been taken over rather tardily. Jean Errard in his Le premier livre des instruments mathématiques méchaniques, pictures such a mill in 1584 and mentions that it was the invention of Charles Desrue, "the first to make the demonstration and experiment". In Bar-le-Duc or Nancy perhaps, but not in Nuremberg. Eobanus Hessus in the 'Officini Ferraria', a section of his Urbs Noriberga illustrata carmine heroico of 1532, talks of a "magna rota ingentem vi fluminis acta" and its wheels and gears "quibus atri lamina ferri scinditur...".

6. J. Becher, Närrische Weissheit und Weise Narrheit, Frankfurt, 1682, p.113, No. 42. The section goes on to mention wooden pistons which similarly do away with the need for leather. Plot's drawing shows incidentally that the bellows in use c.1665 at Ecton Hill was double acting, a type more usual in small forges such as those of enamel workers, where the work required a continuous flame. A history of bellows and blowers would be a study well worth undertaking and one which would, in the case of wooden bellows, certainly lead back to 15th century Italy. What is certain is that here as elsewhere England's development proceeded separately from the rest of Europe. The use of piston blowers in English

smelters, beginning as far as one can judge in the 1740s, would be not the least interesting part of the story.

7. P. Grignon, 'Mémoire sur les Soufflets de forges à fer', Mémoires de Physique sur l'art de Fabriquer le fer, d'en fondre....., Paris 1775. This admirable memoir on bellows reveals no knowledge of piston-blowers. According to Grignon leather bellows well looked after might last fifty years although quite how this is to be reconciled with H. Calvor's statement in Acta Historico-Chronologico-Mechanica circa Metallurgiam in Hercynia Superiori....., Brunswick 1763, p.162, that they only lasted six or seven years I do not know. Who is right, or are both wrong?

8. Since the economically significant coalfields had long been in the hands of wealthy capitalists, men in no way committed to traditional methods except insofar as these were useful, it seems strange that more energy was not displayed in seeking foreign help. Plainly men with a mentalité de profit were a necessary but not a sufficient reason for technical advance or innovation.

9. J.U. Nef, The Rise of the British Coal Industry, London 1932, Vol. 1, p.123. "The first three quarters of the 19th century have usually been regarded as incomparably the period of most rapid expansion in British coal mining. But, measured

by the rate of increase in the use of coal, the period 1550-1700 may, without qualification, be compared to it". But see tables IX and X, pp.123-4.

10. G. Huffel, Économie Forestière, Paris 1910, p.10. Huffel takes one ton of coal to yield seven million calories. One stère of wood (i.e. one cubic metre) yields 1.7 million calories. Four stères are very nearly equal, therefore, to one ton of coal. Four stères are the annual production of one hectare of good forest. English coal consumption in 1700, running at something like three million tons per annum, represented the calorific equivalent of the yield from three million hectares (or nearly 7.5 million acres) of forest.

11. At least one can say that if such efforts were made, they have left remarkably little trace. Perhaps, however, a too great (and mistaken) reliance was placed on Dutch engineers. It would be possible to argue, of course, that the very wealth of England's coal endowment acted as a deterrent to setting up new equipment for deeper extraction. As long as one could pillage the surface layers and move on, this was doubtless the way things were done, and could only be done. But the grubbing would be shallow grubbing indeed if the water problem were to be avoided. The almost universal use in England of the rag and chain pump and the

bucket hoist was doubtless as costly a way of raising water here as it was in Germany and would no doubt have yielded enormous savings if such gear had been replaced by Stangenkünste. Martin Planer's re-equipment of the Freiberg mines after 1557 cut pumping costs by 90 to 95 per cent.

12. A.R. Hall and M.B. Hall, The Correspondence of Henry Oldenburg, Vol. IX, London 1973, pp.625-631, Nos. 2219 and 2219a. The translation of ulnarum in query No. 4, p.627, "in earum profunditatem sitnea ea 150 ulnarum, ut fertur" as fathoms cannot, I think, be correct. But see note 13 below.

13. René de Sluse's reply is printed in T. Birch, The History of the Royal Society of London, London 1757, Vol. III, pp.125-7. It seems certain that the parties to this correspondence were talking somewhat at cross purposes as far as the question of the depths of the pits at Liége was concerned. Ulna (aune) was anciently in Liége a measure equal to 25.836 inches and indeed this was, with trifling variations, what the measure (under its various names) equalled in most parts of Europe. For Sluse "150 ulnarum" undoubtedly meant 300 feet, and his remarks make sense only if this is understood to be so: hence his care to equate "Orgyia" with "toise". The Liége toise was in fact less than an English fathom by 2½ inches, or

decimally 5.8 feet, unless, that is, the Berglachter (mining fathom) of 6.5 feet is the measure intended. But Sluse reckoned without the English (or London) ell, a rogue measure that was nearly twice as great, 45 inches, as the normal (continental) ell. Hence arose the confusion, for Oldenburg was not asking whether the pits of Liége were 300 feet deep but wished Sluse to confirm that they had reached 600 feet, which of course they had. Altogether the futility of the exchange seems to me to be well characterized by this misunderstanding.

14. He had not yet published his Account of Several Travels through a great part of Germany, London 1677, in which he described the field-rod engines of Liége.

15. The evidence to be reviewed in this chapter yields numerous instances of something like this being the effective limit still in 17th century England. A lift of about 80 feet was "a great height" for D'Acres writing in 1660. Although Agricola talks of rag and chain pumps working down to 240 feet, it seems clear that these were exceptionally large machines. Hake presumably meant to refer to the earlier part of the 15th century.

16. William Sharpe, A Treatise upon Coal Mines, London 1769, p.52.

17. See G. de Louvrex, Recueil contenant les édits et

<u>règlements faits pour le païs de Liége et comté de Looz par les évêques et princes</u>, Liege 1750, Vol. 2, pp.203-4, for the text of the "édit du Prince Ernest de Bavière touchant la manière de conquerir les mineraux extans dans le fond d'autrui".

18. Although the situation is somewhat obscure, a privilege granted to David Remacle of Limburg on the 27th February 1601 makes it clear that he had succeeded in draining the long abandoned lead mines at Prayon, about four miles south of Liége. It may well have been the case that at this time it was a shortage of capital that was the problem rather than of technical skill. In 1585, when Georg-Johann, Comte de Velden, proposed to drain the flooded coal mines, he referred to machines (single field-rod engines presumably) unknown to the Liègeois, which he had employed on his own estates. He certainly intended to attack the problem comprehensively, but after 18th July 1586 - on which day Leonard le Redouté (master carpenter) of Liége and Johann Godschalk (engineer ?) a German, reported to the burgermasters that they had concluded terms with Count Velden and begun work - all is silence.

19. One might cite a number of instances in France in which, steam engines proving too expensive, rod-engines were installed in their place: for the French it was merely a choice between which

of two foreign techniques was the more economic. They were, after all, 'committed' to neither.

20. J.U. Nef, op. cit., p.242. "Try as they would, the British found it impossible, with the pumping devices which had served the copper and silver mines of Bohemia, Hungary, the Tyrol or the Harz, to force a column of water high enough to drain the deeper pits". But it is clear that Nef is assuming what he has to prove. Citations from Agricola are not enough. In view of what has been said both earlier in this chapter and elsewhere one might well fail to agree with Nef when he states (p.256) that "it was precisely in the district around Liége, where the coal mines had been most intensively exploited, that the most notable strides in inventive effort and technical skill were made during the 17th and 18th centuries".

21. For a brief description of float-flume technology (Flösse) and a resumé of its historical development see appendix. The importance of such long-range transport systems in overcoming localized fuel shortages brought on by the needs of smelters, brine works and urban centres has been completely ignored in English writing on the history of technology, with the exception of the brief account to be found in the English translation of J.G. Beckmann's <u>History of Inventions</u> (Geschichte der Erfindungen).

22. Two editions were produced in 1659 and 1660 but without change in the text. It was reprinted as Extra Publication No. 2(1930) by the Newcomen Society.

23. In fact at the end of his work D'Acres does list, in summary form, the known engines of common use. The Stangenkunst, or anything recognisable as such, does not appear among them.

24. D'Acres, op. cit., p.15.

25. Ibid, p.16.

27. F. Pisek (ed), Vavrinec Kricky z Bitysky (Mathesis Bohemica) Prague 1947, fig. 44.

28. E. Browne, An Account of Several Travels through a great part of Germany, London 1677, p.171.

29. A. Ehrensvard, Les Machines de Monsr. Polhem, 1729, f.61r. The MS is in the possession of the Tekniska Museet, Stockholm. This is not the only evidence of an experimental temper at work among Swedish engineers. Gabriel Jars at Falun in 1767 noted horizontally mounted systems of field rod transmission lines which appear from the evidence to be a further development of Polhem's ideas. But both, it should be noted, were deliberate departures from a standard technique which had been fully mastered in the second half of the 17th century. All techniques possibly benefit from being seen with fresh eyes outside their classic ground. They may, equally, be

degraded.

30. J.T. Desaguliers, A Course of Experimental Philosophy, London 1744, Vol. 2, plate 34, fig.9. This shows the forking of the pump rods at Griff Colliery, Warwickshire.

31. I refer particularly to his A Brief Account of some travels in Hungary, Austria......, London 1673.

32. The shortage of ground (surface) water was such that even the modest quantities of water required for the use of the steam engines set up by Isaac Potter in and after 1732 proved difficult to procure.

33. An Account of Several Travels through a great part of Germany, London 1677, p.163.

34. Ibid, p.171.

35. Op. cit., p.28.

36. Ibid, p.33.

37. George Sinclair, The Hydro-Staticks....together with some miscellany observations, Edinburgh 1672,

38. Op. cit., p.298.

39. See Christian Meltzer, Bergklaufftige Beschreibung der Churfürstlichen Sachsischen Freyen.... Bergk-Stadt Schneebergk, Schneeberg 1684, p.99, where the extreme lifts achievable by means of rag and chain pumps, bucket hoists and Stangenkünste are compared.

40. G. Sinclair, op. cit., p.299.

41. The Principal Works of Simon Stevin, Vol. 5 Engineering, ed. R.J. Forbes, Amsterdam 1966, p.14. See No. 1 of a portmanteau patent granted by the States General on 28th Nov. 1589. This seems to me the most obvious source for these sorts of machines; that there were others appears from Francis North's remarks of about 1680. The idea of linked sequences of machines goes back much further than Stevin's patent and seems likely to belong to the early part of the 16th century, that is, to Biringuccio's experiments at Boccheggiano in 1510.

42. This is evident from contemporary French comment on the Marly machine which invariably characterises it as a marvellous special creation and quite ignores its pedigree. This latter is stated very precisely by Martin Lister in his <u>A Journey to Paris in the year 1698</u>, London 1699, p.213. The "invention (is)" he says "the same with what is practised in the deep coal pits about Leeds (Liége) in Lower Germany. To see the pipes lying bare is to imagine a deep coal mine turned wrong side outward".

43. R. North, <u>The Life of Francis North, Lord Keeper of the Great Seal</u>, London 1742, p.135. Francis North's visit to the coal pits was made during the period when he was a chief justice (1675-1683).

44. R. Plot, op. cit., p.148.

45. J.C. op. cit., pp.28-29.

46. A. de Montesquieu (ed.), Voyages de C. de Secondat, marquis de Montesquieu, Bordeaux 1896, Vol. 2, p.262. The diffusion of engineering know-how was far from being as general as Montesquieu (à present, tout se communique) assumed.

47. See M.B. Rowlands, 'Stonier Parrott and the Newcomen Engine', Transactions of the Newcomen Society, Vol. XLI, 1968-69, p.49, for a most illuminating study of this situation. Parrott knew well how to bait the hook, if I may change the metaphor. Parrott's reward for helping at Ravensworth would have been something like £300 per annum and a one-fifth share in Park Colliery.

48. J.T. Desaguliers, op. cit., p.478.

49. As for instance C. Berward, Interpres Phraseologiae Metallurgicae, 1673, or J. Hübner, Curieuses und Reales....Lexicon, 1713.

50. Amos Barnes, View Book, 1733. The MS is in the library of the North of England Institute of Mining and Mechanical Engineers, Newcastle. At Idrija in 1596 each of the tiers contained 26 pumps, each tier being set in motion by a single principal shaft rod.

51. W. Pryce, Mineralogia Cornubiensis, London 1778,

pp.307-8. John Coster, father and son, took out a patent in 1714, No. 397, 27th May, for an engine for drawing water out of deep mines. This was an ingenious device for making use of small flows of water insufficient to turn a wheel and was really an inverted rag and chain pump. The small arm of water flowing into the pipe forced down the rags successively, the torque on the bottom axle serving to put in motion a sprocket wheel to draw up the rags through the pipe of a lower machine in the normal way. This seems to be an important device in the sense that pistons being put into motion by water pressure, as they were here, plainly prefigure (as do floating pistons) the water pressure engines of the period immediately following this time.

52. Erik Odhelius, Berattelse om utlandska bergverken 1690-2, p.462, MS H.602, Uppsala Universitets-bibliotek, Uppsala. (Reports on foreign mine engineering).

53. W.G. Collingwood, 'Elizabethan Keswick. Extracts from the original account books 1564-1577, of the German miners, in the archives of Augsburg', Cumberland and Westmorland Antiquarian and Archaeological Society Transactions, Tract Series No. X, Kendal 1912.

54. The report is quoted at length in M.B. Donald,

Elizabethan Copper, London 1955, pp.166-7.

55. M. Daumas, 'L'acquisition des techniques par les pays non initiateurs', <u>Documents pour l'histoire des techniques</u>, Cahier 8, 1970, p.9, puts the point rather well in talking of the Slovakian and Saxon mining regions as each having, "une population de mineurs expérimentés qui se renouvelait de génération en génération sur des bassins minières concentrés".

56. P. Deffontaines, 'La Vie Forestière en Slovaquie', <u>Travaux publies par l'Institut d'Études Slaves</u>, Vol. XIII, 1932, p.47. "À côté des mineurs, s'établirent des bûcherons et charbonniers de bois ce furent le plus souvent des Slovaques ou Ruthènes qui se spécialisèrent dans ce travail pour le compte des Allemands. Un peuplement slave pénétra ainsi dans la zone des colonies Saxonnes". At Tajov a specialism was developed by Slovak cobblers in making boots for the German miners.

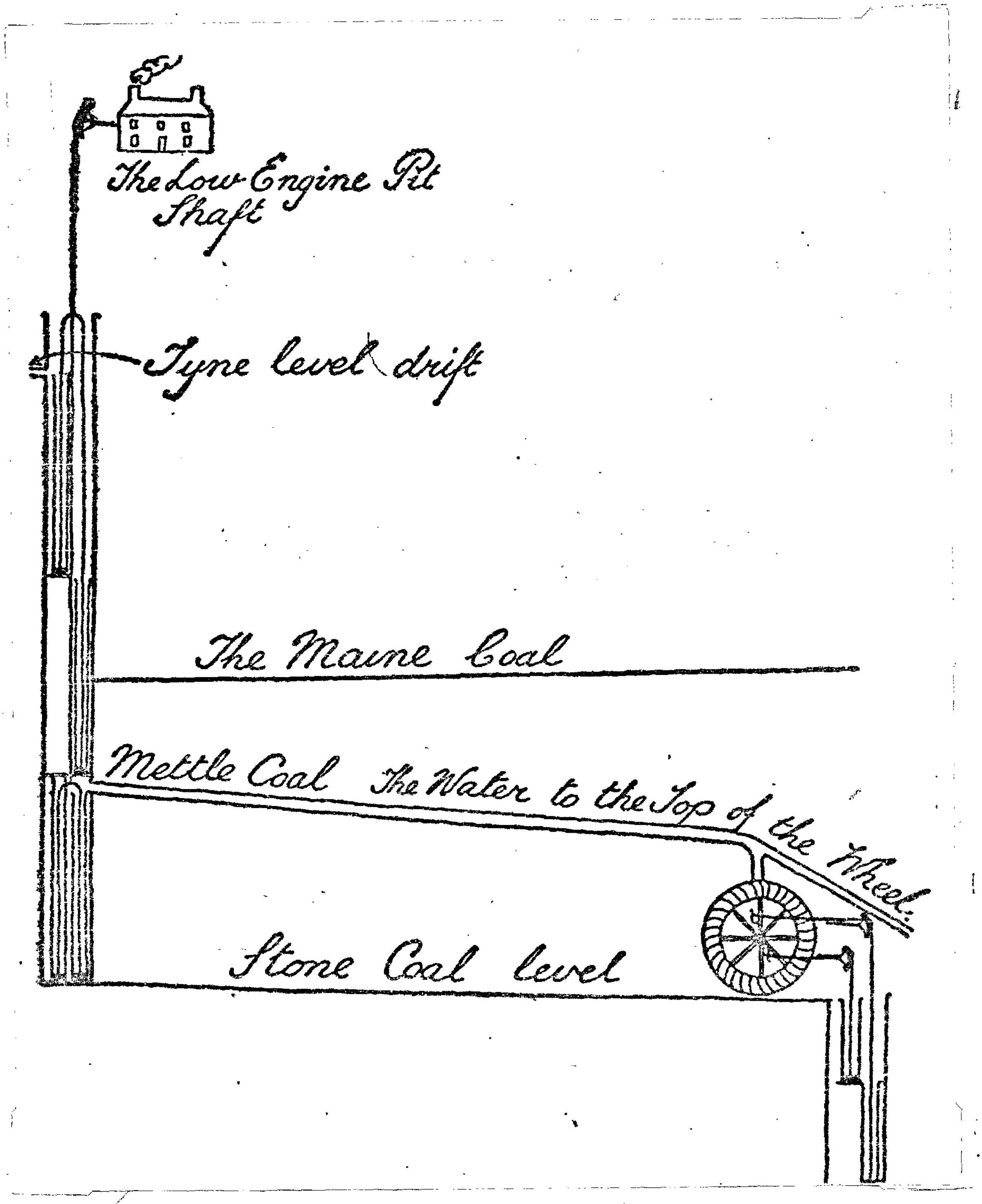
Chapter Five THE INTRODUCTION OF THE NEWCOMEN ENGINE INTO EUROPE (1720 - c.1780).

It has been suggested that inventions are to history what mutations are to biology, and yet, however interesting the circumstances in which such 'mutations' arise (and for fairly obvious reasons their origins are usually cloaked in considerable obscurity), it is only the later stage of the acceptance of the new technique or machine in the area of its origin and its diffusion into remoter regions (if this takes place) which can affect the course of events in society. Looked at like this success stories alone ever receive attention, and rightly so, since in such cases alone is it possible to gain an idea of the nature of the social and economic conditions that were the prerequisites for the successful adoption of the new technique. Of no less interest are the situations that arise when the technique is transplanted into a series of new environments which may well lack certain of the resources available in the cradle area. Gerschenkron's idea of levels of backwardness, derived from the study of such situations during the period of industrialization in 19th century Europe, has revealed clearly enough the importance of the insights that may be gained from an examination of these aspects of the process of technical change[1]. That they are important scarcely needs stressing, for they have to do with what does and does not render an environment responsive to new techniques. Here is one of the major problems of history and one which technical and economic causes alone may well be incompetent to explain. The revolution in the textile industry in north western Europe during the 16th century, for example, which led to the introduction of the 'new draperies' may well have come about as a result of movements of fashion and taste in northern Italy, to be explained ultimately in terms of the cultural and aesthetic preferences of the Tuscan and Milanese urban bourgeoisie[2]. There is, in short, little reason to doubt the importance of research into the diffusion of techniques as revelatory of social and economic structures.

Apart from such larger issues which the study of the diffusion of any technology raises, there remains what might be termed, however inadequately, the internal history of the process, the matter of provision of human skills and material resources that permit it to take place. The diffusion of the Newcomen or atmospheric engine into Europe is a story worth pursuing from both points of view. It is one which has never, to my knowledge, been undertaken[3]. As a preliminary it is worthwhile first to recall the circumstances in which Newcomen brought his machine into use in England. I have endeavoured to show elsewhere that the Stangenkunst in its variety of developed forms, the near definitive solution to the problem of deep mine pumping in central and northern Europe, does not seem to have reached England even by the beginning of the 18th century; or rather had failed to prosper on the one occasion when in all likelihood it had been introduced[4]. Thomas Newcomen's work was, in short, an indigenous response to a problem that German miners had overcome in a very different fashion some century and a half earlier. This had to do with the overwhelmingly important business of how to drain water from a mine sunk far below adit, that is, the level of free drainage. Difficult though it is to quantify, there is little reason to doubt that the English coal industry generally was in a critical state towards the close of the 17th century and that the crisis had been brought on by failure to solve this problem; not perhaps in the sense that pits could no longer be drained at all, although there were such, but rather because the cost of conventional means of drainage was threatening to make many undertakings too ruinously expensive to continue. The myth of the five hundred horses working pumps at Griff colliery in Warwickshire in 1702 notwithstanding, it was just as Savery remarked in the same year in answer to the question of how to clear an old work full of water; "by the common ways of tubs or chain pumps (and)...could the constant charge of those engines be afforded, numbers of them will empty and keep under any work; but it is the constant charge..."[5]. Unless in fact there was something like a general crisis in the making, it is hardly possible to understand the almost frantic eagerness with which coal owners in the midlands and the north strove at vast expense to engage the, at first, rare practitioners of the new mystery. Such a general crisis, it cannot be emphasized strongly enough, did not exist at this time in Europe, except indeed in those regions as backward as England, that is to say France and Spain, countries into which rod-engine technology was not to penetrate until about the mid 18th century[6]. There were, of course, certain 'hydraulic deserts', areas so deficient in permanent streams that it was virtually impossible, without enormous catchment reseroir construction, to procure enough water to drive pumping engines. The famous Windschacht and Siglisberg mines near Schemnitz (Banska Stiavnica) in Slovakia were a classic example of such a desert. The three great lodes virtually outcropped along the summit ridge of a spur of the Tatra mountains, and until well into the 18th century the mines continued to depend largely upon horse-driven Stangenkünste (Rosskünste). Vedrin lead mine near Namur was likewise virtually on the top of a mountain, or rather of 'une petite montagne'. Such locations as these were naturally enough among the first into which the atmospheric steam engine was introduced. Yet another variety of 'desert' existed in French and Imperial Hainaut. There, the low lying nature of the land as well as the lack of running water ruled out the possibility of using water-driven pumps. "Les terrains unis, éloignés de tous courants d'eau, telles que celles de Flandre" were, as Monnet remarked, places very naturally suited to steam engines[7]. Still, the enormous cost of such engines might well have deterred mine owners who were after all well used to horse operated pumps had it not been for the unusual geological conditions of the region stretching from Mons to Valenciennes and further west. No ordinary problem of mine pumping presented itself here. When Jean-Jacques Desandroüin's engineers began to sink shafts on French soil at Fresnes near Condé in search of the hidden extension of the coalfield that outcropped to the north east across the frontier in the vicinity of Mons, they discovered that a vast underground sea lay beneath their feet. This the miners called the "niveau". "Le premier filon était à trois cents pieds...Pour y arriver il avait fallu franchir un torrent intérieur qui couvrit tout l'espace dans l'entendue de plusieurs lieues. On touchait la mine avec une sonde..." - a touch of rhetoric too, but which Mirabeau may be forgiven[8]. The great problem was to keep the shafts drained as they were sunk through some two hundred or so feet of saturated chalk. Sometimes with appalling difficulty horse pumps were able to keep pace with flooding, but, as will be seen, the development of the portable steam engine, the "machine à feu en bois" as it was called in Hainaut, alone eventually permitted a relatively easy passage through the niveau[9].

So far one has been talking of areas in which, although Stangenkunst technology was freely available, conditions rendered it largely useless, or at least very expensive to use. Slovakia indeed was most probably the originating area of the technology, and it appears clearly enough that Hainaut also lay within the Stangenkunst 'frontier'. The use of master shaft rods (Hauptstangen, tiges-maîtresse), standard practice in that technology, was universally adop-

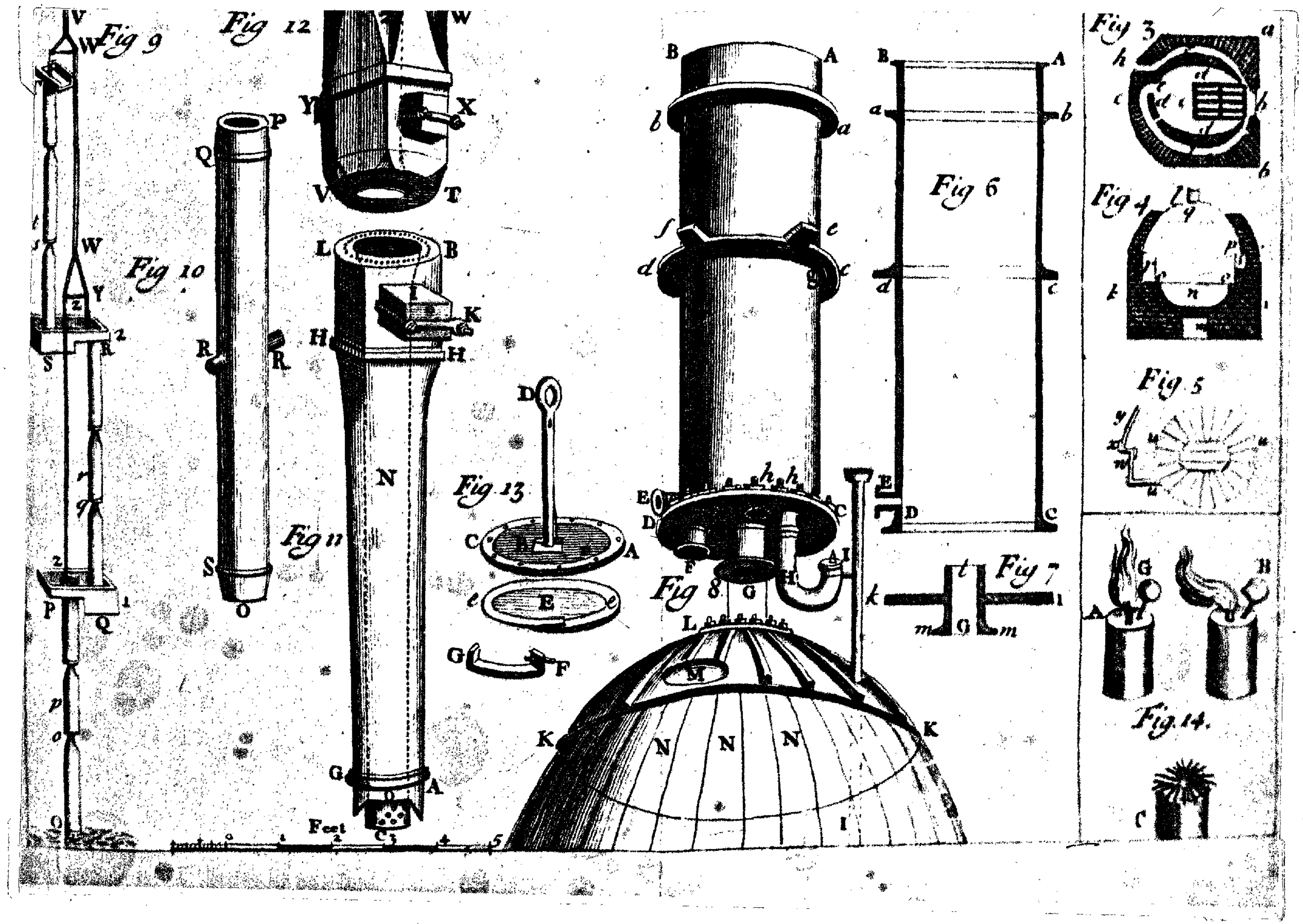
Fig. 1.



The forking of the shaft rods at Heaton colliery, Northumberland.
Source: A. Barnes, View Book, 1733.

Fig. 2.

The forking of the shaft rods at Griff colliery, Warwickshire. Source: J. Desaguliers, A course of experimental philosophy, London 1744, Vol. 2, plate 34, fig. 9.



* Figs. 3 and 4 show the construction of the circular brickwork flue round the boiler in order to provide for flame-coursing.

ted wherever steam engines were set up. In other words, the prime mover only was being borrowed from England and not the arrangement of split or forked shaft rods such as Barnes showed in use at Heaton (fig. 1) in 1733, or which Desaguliers figured at Griff (fig. 2) in Warwickshire in 1744[10]. But there were as well, of course, vast areas beyond the frontier or home ground of either steam or Stangenkunst technology in which the attempt to struggle along with what was virtually pre-Agricolan pumping equipment was soon given up once a thoroughgoing entrepreneurial exploitation of mineral resources got under way. Such were the numerous mining sites in Normandy, Anjou and Brittany, many of which experimented with varying degrees of success with steam engines. Here English and German technology were in direct competition on new territory, and it is an interesting part of the diffusion process to see how evenly success was divided between the two systems outside their areas of initial development[11].

But to return to England; after Newcomen's success at Dudley Castle in 1712 the setting up of further machines undoubtedly proceeded at a brisk pace governed only by the shortage of mechanics capable of undertaking such work. By 1720 at least twenty-five engines had been built and virtually every mining area of any importance had at least one machine in operation[12]. It was a remarkable achievement. Although very little is known of how the work force was recruited which put up these machines, the number of men able to undertake such work manifestly grew at a great pace.

It consisted at one extreme of 'experimental philosophers', sometimes with considerable experience in the actual business of erection and certainly well able to calculate the sizes and powers of engines, and at the other of men of practice alone, tradesmen skilled in metalwork but unable to calculate powers, with perhaps some few members of the higher artisanate, Thomas Newcomen at their head, possessing in considerable measure both theoretical and practical skills.

At the same time another class was emerging, the full-time minders of engines, who would in due course form another body of builders themselves. Georges de Goumoëns' experience at Newcastle in 1719, to be related below, is instructive in this respect. In any event engines were being erected at a rate certainly in excess of three a year between 1712 and 1720, a figure that it seems certain will have to be revised upwards as research is carried further. Furthermore, the fact that it is possible to draw up for this period a provisional list of erectors, containing nearly twenty names, certainly suggests that the known rate of construction was still comfortably within the capacity of the work force[13]. The real purpose in dwelling on these matters will however become clear in the course of this study. Here it is sufficient to show that there was enough activity going on to attract the attention of observers in Europe. Industrial espionage was no new thing in the early 18th century, and one may be reasonably confident that the advertisement placed in the London Gazette in August 1716 by the proprietors of the fire-engine patent was but one of many cues which foreign intelligencers could scarcely afford to ignore[14]. Nor did they. By no later than 1719 it is certain that mining interests in both Vienna and Liége were negotiating with English mechanics, though whether with the knowledge of the proprietors is unclear, in order to secure the benefits of the new technology for their mines. Unfortunately the details of both sets of negotiations are so scantily documented that it is difficult to say more than that they took place, were concluded to the satisfaction of the parties concerned and that as a result by the early summer of 1720 Isaac Potter was already in Vienna while by September of the same year John O'Kelly had arrived in Liége.

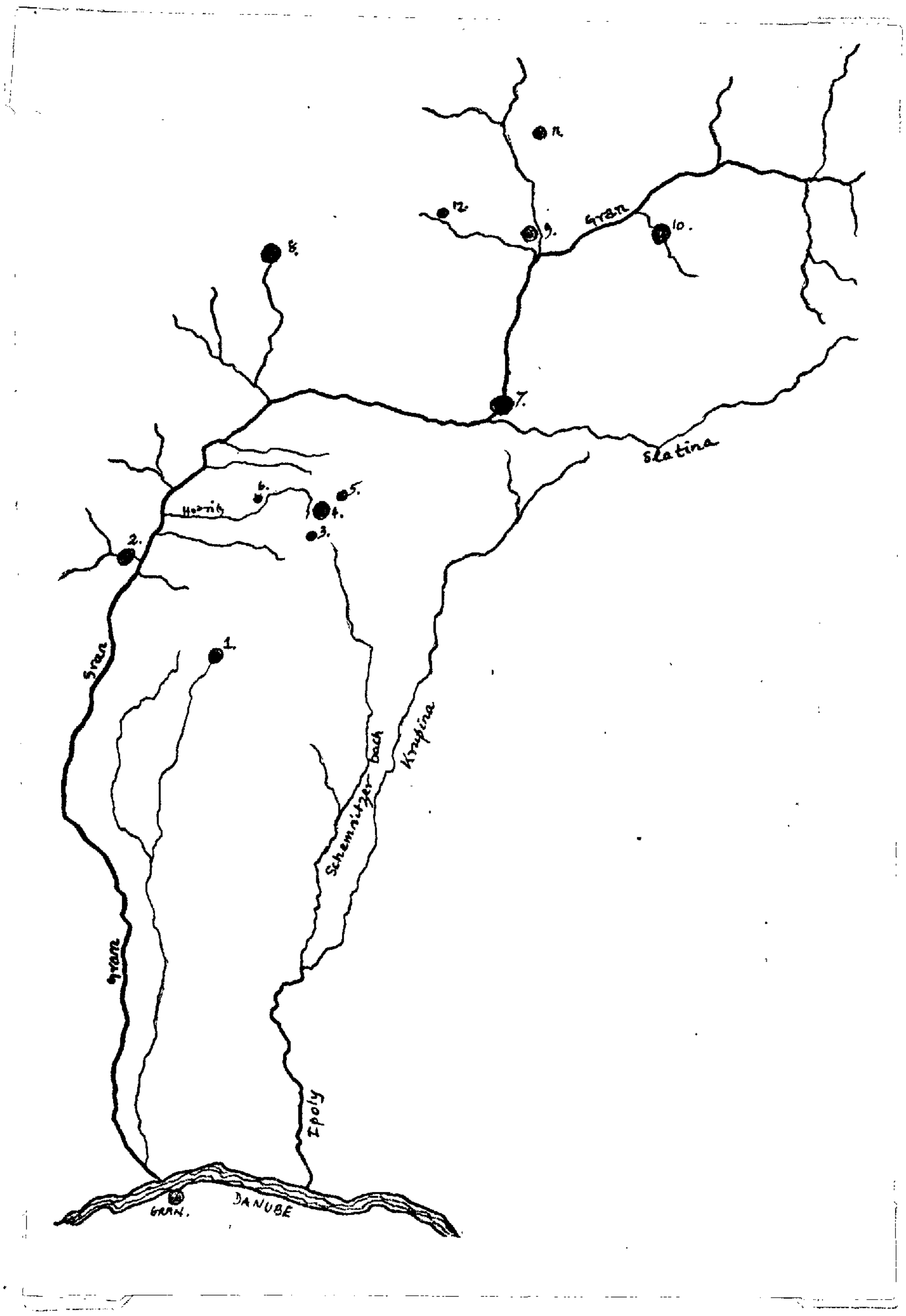
(i) The Steam Engine in Central Europe

It is evident that the Hofkammer in Vienna knew something of the existence of the steam engine no later than July 1718[15]. How the imperial ministers came by that information is not known, although it has been surmised (on little enough evidence it must be said) that Leibniz, whose connections with England and with Austria were equally close, may have informed Vienna shortly before his death in November 1716[16]. Leibniz had certainly followed the earlier work of Savery and Papin with close interest, as his correspondence with Papin makes clear[17]. In order to acquaint themselves more fully with the new machines the imperial councillors resolved on 18th July 1718 to instruct Joseph Fischer von Erlach, at that time completing his study tour in London, to do all he could to familiarize himself with their working. How and where he did this is not known, although his connection with Desaguliers must undoubtedly have proved of great value to him[18]. His curriculum vitae, which might have yielded details of this period, is missing from the government archives in Vienna. According to Dr. Daniel von Guldenberg, the Hanoverian ambassador to the court of Vienna, who was on close terms with von Erlach and had his information from the horse's mouth as it were, the latter had had to disguise himself in labourer's clothing and work as a day labourer during his time in England in order to come at the secrets of atmospheric steam engine work. This appears in a letter of Dr. Guldenberg's dated Vienna, 23rd June 1725, addressed to Berghauptmann Heinrich Bussche of Clausthal in the Harz which speaks of "...Herr Fischer, als er in England die Maschine penetriren wollen, sich vor ein Tagwerker verkleiden und mitarbeiten müssen, um hinter die Geheimnisse zu kommen..."[19]. The circumstances surrounding the introduction of the first atmospheric steam engines into Europe are liberally embroidered with such picturesque and no doubt often fictitious details, but whether von Erlach had improved the hour for von Guldenberg's benefit or not he must certainly have applied himself to the business considerably in 1718 and 1719, for by the time he was back in Vienna (in early 1720) he was already negotiating for a monopoly of the construction of such machines in Germany for mine drainage and other purposes[20]. During 1718-19 von Erlach must also have approached

Isaac Potter with a proposal that he should enter the service of the emperor. Since the Potter family lived and worked in Durham and Tyneside during the 1720s and 30s, it is not impossible that von Erlach made contact with Potter at Newcastle, a scene of very concentrated engine building activity, where no less than eight machines were at work by 1719. Certainly there would have been little for a 'spy' to have observed in London at that date unless it were the business of casting the brass engine cylinders. At all events, by June 1720 von Erlach had conducted to Vienna a small party consisting of Potter, Potter's servant Lumley, Lumley's daughter and Potter's assistant engineer, Pierre Sabathery.

At first the pace of events following Potter's arrival in Vienna was extremely rapid. On 3rd July 1720 Hofkammerrat von Peyer wrote to the chief administrator at Schemnitz, J. Aigner, informing him that a certain Englishman had presented himself to the emperor and had put forward proposals for pumping water from mines at low cost by means of fire. The emperor's response had been to direct him to von Peyer whose task it would be to make the necessary arrangements with Windschacht (Schemnitz) so that he, his interpreter and his assistant engineer could go there to view the installations. Finally, von Peyer urged on Aigner the extreme importance of satisfying the Englishman so that he could not complain of obstruction on his return from the mines. The next day von Peyer wrote again: the Englishman's name was Isaac Potter. Schemnitz replied on 7th July promising to show Potter everything but suggesting that the

Map 1.



The mine towns of Lower Hungary (Central Slovakia)

Key:
1. Buchantz
2. Konigsberg (Nova Bana)
3. Windschacht
4. Schemnitz (Banska Stiavnica)
5. Dilln
6. Hodritz
7. Altsohl
8. Kremnitz
9. Neusohl (Banska Bystrica)
10. Libethen
11. Herrengrund
12. Tajov

engine could be more usefully employed at one of the smaller mines. When Schemnitz wrote again on 18th July it was to announce that Potter had already made his visit and had decided that the best place for his engine would be the long-abandoned workings at Kőnigsberg (Nova Bana), some three Hungarian miles (about sixteen English) away from the area of active exploitation at Windschacht (map 1)[21]. But why did Potter choose this particular site? Had he been steered there deliberately by the Schemnitz officials and given what appeared to them a hopeless task which would discredit him and which would serve additionally to preserve the status quo at Windschacht from unwelcome interference?* Evidence for such a presumption is provided by two letters dated 23rd June and 1st August 1725 respectively from the pen of Dr. Guldenberg, the reporter of von Erlach's English incognito[22]. Both letters were responses to a request he had received from Heinrich von dem Bussche, Berghauptmann at Clausthal, for information about the fire machine now installed at Königsberg**. In his letter of 23rd June Guldenberg remarked that the potential value of the machine for the Harz mines had struck him some time previously and that what he had been able to learn concerning it since then confirmed him in the idea. Indeed, he had become so curious that he had gone many times to Prince Schwarzenberg's gardens in the Rennweg[23] to observe the engine put up there by the emperor's

* I return to this point again. See pp. 300-304.

** A description of this engine is given below. See pp. 306-313.

architect Fischer (von Erlach): as for this latter, he not only understood the theory of the machine but was master of its practice also. He had successfully engineered Schwarzenberg's engine and been rewarded by the Prince: "Der Kaiserliche hiesige Ingenieur Fischer hat des Engländers Invention zu Königsberg in Ungarn nicht allein examiniret sondern auch dergestalt penitriret und approfondiret, dass er sie in des Fürsten von Schwarzenberg Garten nachgemacht und glücklich Zustande gebracht hat, wovor ihn der Fürst von Schwarzenberg regaliret hat". This being the case Guldenberg had decided to try to learn more about the machine from von Erlach directly. This seemed easy because they had long been on close terms. Guldenberg comments: I got to know him as an excellent fellow already in the lifetime of his father and he has often since been a guest at my house. I long ago asked him whether such an engine might not also be useful in our Harz mines, whereupon he answered that it would indeed if it were that hydraulic machines would no longer serve, and that he would entrust me with a confidential report on it if by so doing he could serve his majesty (King George I, elector of Hanover); "wenn man in dem Harz nicht mehr mit den Wassern, welche die Räder und diese die Pumpen treiben, das Wasser aus der Teufe würde gewinnen können, solche Maschine wohl notwendig werden dürfe und es auch wohl angehen würde. Er hat sich auch allenfalls erboten, mir von diesem Arcano im Vertrauen Nachricht zu geben, wann ihro königlichen Majestät er darunter dienen könnte". But Guldenberg was not content with fair words and now proceeded to exploit an acquaintance he had made with a Swedish nobleman, Abraham von Schönström, in order to manoeuvre von Erlach into a more definite undertaking.

Von Schönström, on a study tour of European mines, had, not long before the time in question, arrived in Vienna from Hungary and Guldenberg soon learned that he had not only seen the Königsberg machine but had made two very careful drawings of it[24]. Guldenberg wined and dined the Swede to such good effect that finally he turned his drawings over to the ambassador so that he could have them copied. Guldenberg had then taken these drawings to von Erlach and made great play of his ignorance and total incapacity to understand them. What an unspeakable pleasure it would be if only he were able to do so! The strategem appeared to work: "Damit habe ich ihn nun piquiret", and von Erlach finally agreed to provide Guldenberg with a better drawing than those which he had brought with him. This drawing, he continued, was now in his possession[25]. In addition, Fischer had promised a description of the machine's performance and mode of action "worin die Operation des Dampfes vom Wasser bestehet" without which Guldenberg confessed he would be scarcely able to interpret the sketches, and this despite the fact that he had closely watched the Schwarzenberg machine working for several hours. What a mystery "der Engländer Bolter"(sic) and Fischer made of it all!

This being the case, he would keep all these materials until the engineer, under pressure from the court to present his proposals for the improvement of Vienna, found time to deliver his description.

On 1st August von Guldenberg wrote again to Bussche. Accompanying his letter were the three drawings and the description of the machine which von Erlach had brought in person the previous day. In case yet further information would be useful he explained at some length that the Schwarzenberg engine in Vienna was in every respect an accurate but smaller copy of the Königsberg machine - "eigentlich nur ein Modell von dem grössen Werk in Ungarn ist". It pumped water to a height of 75 feet and had cost 12,000 florins. The Hungarian machine had cost three times as much and was three times as large[26]. At this point Guldenberg recounted a story which he must certainly have had from von Erlach himself. This was that as far as the Königsberg machine was concerned, it had really been intended for Schemnitz where five hundred horses were employed in pumping water. However, since practically all the people there had a financial interest in keeping the horses at work it had not been possible to overcome their opposition. "Die eigentliche Absicht, die Maschine zu Königsberg anzulegen, ist nur auf die Bergwerk in Schemnitz destiniret gewesen, allwo 500 Pferde gehalten werde. Weil aberfast alle Leute an der Unterhaltung der 500 Pferde ihr privates Interesse finden, so haben die Oppositiones nicht können überwunden werden...". His majesty, at whose expense the machine had been built, would himself have to resolve the deadlock. A beginning had been made on the task of getting the machine moved to Schemnitz and on eliminating the five hundred horses. To this end the imperial minister of mines (kaiserliche Berggraf) had been summoned to Vienna from Hungary. Bussche was to understand that although Schemnitz had indeed a number of great storage reservoirs which fed the water wheels, water was always wanting in summer. It was because of this that horses had to be used instead of which it was intended to use the steam engine (Feuer Maschine), but this one couldn't yet see one's way to doing. Such a machine, Guldenberg remarked further, even if it were not required to lift water from great depths, could act equally well as a water returning engine and was easily able to lift through 40 feet (6 Klafters) enough water to set a wheel turning and to keep up a permanent circulation: "Wenn auch die Feuer Maschine nicht zu so grösser Tiefe das Wasser heraufzuheben, sondern zu einem Wasser-Rad das davon abfallende Wasser nur wieder hinauf auf das Rad oder eine Hohe nur von 6 Klafter zu heben zu gebrauchen wäre, so könnte das Wasser...durch die Feuer Maschine per circulationem immer wieder in die Höhe gehoben werden"[27].

Von Guldenberg's letters throw an interesting light, admittedly long after the event, on the exchanges of July 1720. Potter had been side-tracked: the Königsberg machine, when work on it finally began late in 1721, was a pis-aller. What one seems to catch as well are echoes of points that had been urged since then in the continuing debate of the horse versus the fire-engine faction, the former strong at Windschacht, the latter at court. If, in the view of the horse party, the new machine could not be entrusted with the task of deep pumping,and the breakdown rate of Potter's machine would be well known to the opposition and urged, unfairly as it would appear, as sufficient reason for such a view, and indeed an insuperable objection to its use, then perhaps the steam engine group could counter by pointing out that the expense of using five hundred horses was the nub of the argument, and not whether there should be a root and branch replacement of water wheels by steam engines. Horses were an auxiliary source of power employed when water failed. But water need never fail since steam engines could as easily be used to recirculate water and so keep the wheels turning as they could be in pumping water from great depths by their own power. Either way, they were clearly more economical to use than horses.

So much for von Guldenberg's letters: the information they contain suggests that the ambassador was as much used as user in his dealings with von Erlach, who for his part seems to have employed Guldenberg as a sounding board for prospects in Hanover. Furthermore, von Erlach had not scrupled to deceive him. The 'better' drawing of the Königsberg engine that he handed over was nothing of the sort but was a drawing of his own machine in the Schwarzenberg garden. As for von Schönström's drawings, the fact is that far from being somehow deficient as von Erlach implied, they are, on the contrary, quite outstanding, and yield far more technical detail than von Erlach's which is really little more than a picture of an engine. When one turns to the technical description of the 'arcanum' which von Erlach gave to Guldenberg, another situation discloses itself. While it might well be seen simply as a sales prospectus, or publicity for the machine, one has only to remember the five hundred horses eating untold quantities of oats at Windschacht to see that it is equally a broadside in the struggle to replace them. Von Erlach states the work of the Königsberg engine as equal to the work of ninety-six horses. The engine could lift 540 Eimer (8,640 gallons) an hour or 9 Eimer (144 gallons) a minute from 400 feet. If one compared this with an example of horse pumping from Schemnitz, one found that one horse could raise 22 Eimer an hour. It would therefore take 24 horses to come near the pumping rate of the steam engine, that is to say, 528 Eimer. But for every horse actually at work there were three that had to be resting and so at least 96 would be needed altogether to match, approximately, the fire-engine's performance[28]. Against this the machine burned 3½ cubic Klafter (about 500 cubic feet) of wood per day and needed only seven or eight men to attend it. In a postscript he presents the case for using the machine as a water returning engine in mines dependent on water wheels. In such situations one placed the machine next to the wheel so that if in summer, as was commonly the case, water looked like becoming unavailable, then instead of the tail race water being allowed to run away uselessly, it was instead pumped up above such a wheel, and, running over it again, produced a perpetual circulation. Such a fire-engine lifting water only 40 feet was capable of raising 5,100 Eimer (rather over

80,000 gallons) an hour, which would certainly exceed by a good margin the quantity of water needed to drive a water wheel: "...eine dergleichen Feuer-Maschine, nächst dem Wasser-Kunst-Rad zustellen, dass, wenn in sommerzeit Mangel an Wasser,...kann angelassen werden, um das abgefallene Wasser, so vergeblich wegfliesset, wieder auf solches Rad aufzuheben, und zu bewegen, und also circulieren zu machen...kann solche Feuer-Maschine...jede Stunde 5,100 Eimer, welche fahig sind, mehr als ein Kunstrad zu treiben"[29].

For Gottfried Kortum, a doctor from Bielitz in Upper Silesia, who visited Königsberg in the summer of 1725 and whose meticulous description of Potter's engine is a document of great value (although not the earliest account of a steam engine's mode of operation it is the earliest description of an actual engine), the selection of the site seemed a straight-forward enough matter; but then he was far away from court politics. He relates that the Althandel mine at Königsberg had flourished in the time of King Mathias (Hunyadi/Corvinus.d.1490) but had been drowned out when water burst into the workings some eighty years before the time of writing.

One might assume nowadays, Kortum continued, that costly rod-engines would be built but no motor water could be brought near to the site and the very strong flow of water in the mine was too much for horse pumps to cope with. It seemed therefore that the deep rich lodes would have to be left abandoned. However, since wood was in abundant and overflowing supply, and that was what was required,Althandel was the spot chosen to build the machine: "Weil nun die rudera der kostbahresten Stangenkünste vermuthung gegeben, das in der Tieffe reiche Anbrüche müssen verlassen seyn, in der Nähe aber keine Aufschlage-Wasser anzubringen, und mit Ross-künsten die starcken Wasser nicht zu halten, hingegen Holz genug und überflussig, so ist eben dieser Althandel erwählt worden, obige Machine darauf zu bauen"[30]. That such ample provision of fuel was a matter of great importance can hardly be doubted, given its daily consumption of three cubic Klafters of wood. Three cubic Klafters, or rather over thirteen stères (cubic metres) of wood are equivalent to a coal consumption of over three tons a day and would have required the setting aside of something like five square miles of prime forest to have kept the en-engine adequately supplied on a yearly basis.

Whatever the logic, or logistics, of the choice of the Althandel site at Königsberg, it was evidently one which gave the Hofkammer in Vienna considerable pause. Over a year passed before a firm decision was taken to proceed with construction there. The contract between the Hofkammer and Potter was not finally agreed until 19th August 1721. The terms were that the engine should be erected at the Crown's expense and should be able to lift 42,000 Eimer (672,000 gallons) a day from a depth of 300 or more Klafters (over 2,000 feet). A sum of 6,000 gulden (£600) was allotted for its construction with a possibility of a hundred or so gulden extra for unforeseen contingencies. The engine was to be ready to begin work at the end of six to eight months during which period Potter was to receive eight gulden a day (he was given an advance of 250 gulden with a further 50 to pay for his journey to Königsberg). Further, he was to instruct an apprentice in the art of the machine. If the final tests were successful, the privilege of further engine construction would be his exclusive right for twenty years in all the hereditary lands of the crown. Potter was certainly to be handsomely paid for his troubles which now indeed were to begin in earnest.

Some years later, in 1728, Charles de Secondat, marquis de Montesquieu, visited the site to see the famous engine and spent some hours with Potter drinking copious draughts of Tokay and hearing a long account of the tribulations he had suffered. In his memoirs Montesquieu wrote: "Le sieur Potters, gentilhomme anglais et un tres galant homme, a la direction de cette machine, il a éprouvé des difficultés sans nombre de la part des inhabitants... Potters me mena chez lui. Il avait d'excellent vin de Tokay; nous en bûmes largement...". Montesquieu carried away a very lively impression of how the "grandes difficultés que l'on trouve dans les nouveaux établissements viennent des inhabitants...ceux qui louent des chevaux pour les mines, ceux qui vendent les provisions pour leur subsistence, ceux qui les font travailler, sont autants de gens qui ont leurs intérêts à defendre"[31]. Apart from this, or perhaps one should say because of this, there was the difficulty of dealing with the mine bureaucracy. Certain officials were reluctant to deliver the quantities and qualities of material that Potter had ordered and were dilatory in paying the tradesmen to whom Potter entrusted the fabrication of the cylinder, pipes and valves, and other parts of the engine. Then too there were further difficulties arising from the poor quality of the work delivered to the site. Apart from this generalized resistance there were the not inconsiderable difficulties arising from what looks like the rather unscrupulous financial control exercised over the project by the mine bureaucracy. It appears that money intended for the machine was spent instead on Potter's salary, on repairs to the shaft and on road maintenance.

On arriving in Königsberg early in September 1721 Potter waited in vain for an expert metal worker who was supposed to come to him there from Neusohl (Banska Bystrica). Eventually Potter went to Neusohl (map 1) himself and made arrangements with thelocal bell-founder, Johann Klug, for the casting of the cylinder, and for the making of the boiler, pipes and valves. But Neffzer, treasurer of the Neusohl mine administration, held up the delivery of material to Klug. He refused to let work begin since he and Klug could not agree on the price per quintal for the work he was to do. The dispute could only be settled by both men riding over to Potter at Königsberg. But even this was not enough, for it was necessary to go to Schemnitz itself to get authorization for Neusohl to transfer materials to Klug. Neffzer then delivered sub-standard copper. After this was remedied Klug refused to begin drilling until he was given 200 gulden, but as there was not enough money to pay him Potter was obliged to give him 50 gulden out of his own pocket to make up the deficiency and to get the work started. Finally Klug delivered the cylinder to Königsberg on 1st May 1722. It was eight feet long and thirty inches in diameter. Already the eight months allowed for construction had passed and even now the cylinder was not finished. It was a poor casting, the bore still in need of further attention and requiring a good deal of lead to plug its cavities. The contract period having expired, Potter's daily allowance was now cut off and he was soon deep in debt, dunned by creditors and threatened with imprisonment. It is scarcely a wonder that he was often drunk. It was only eight years later, in 1730, that the Hofkammer finally agreed to pay him for the further five months of work he had put in from May to September 1722. By September, however, the engine was at last ready for its preliminary tests. Further tests followed in November and December. Despite many stoppages the machine was able to perform as per contract when it was actually working. The main tests took place from 12th January to 6th February 1723. The high failure rate continued at the rate of one stoppage per day for the first three weeks although in the last week the engine stopped only once. But when one looks into the nature of the failures as they appear in the 'Bericht von der Engellandischen Machine' (Report on the English machine) the report drawn up by Karol Riedl and Jacob Schindler on these final trials, it is clear that many of them were trifling affairs[32]. But what in any case was the normal stoppage rate for atmospheric engines? Modern experience suggests very clearly how extremely temperamental and sensitive to small maladjustments such engines are[33]. That stand-stills were common in the 18th century appears clearly enough from an 'Estimate of the Difference of the Expence in drawing water by Fire Engine and Drawing it by horses, made December 11 1752', drawn up in the north of England. In the course of the comparison it is stated that "in 24 hours (the fire engine) will need 6 hours for drawing and putting in buckets and clacks, repairs to shaft, cleaning and repairing boiler etc., stops, accidents, etc., leaving 18 hours to draw water in each 24 hours"[34]. Potter's engine was clearly doing well rather than badly judged by these standards.

Kortum, however, reported that the machine was not fully perfected until February 1724 and that although Potter had taken it through its tests several others had had to work on it, among whom the greatest improver had been the incomparable Baron von Erlach: "Isaac Potter... die erste Probe gemacht, da aber verschiedenes anders müssen aptirt werden, welche Verbesserung hauptsachlich von dem unvergleichlichen Hrn Baron Fischer von Erlachen dependirt, so ist dieselbe allererst, Ao.1724, Mens Febr. zu Perfection und in bestandigen Gang kommen"[35]. Although, unfortunately, Kortum gives no hint of what these improvements were, it is possible by comparing what he has to say with what is revealed by von Schönström's sketches and by bearing in mind also some of the claims advanced by von Erlach himself, to form at least some idea of what had taken place.

Apart from all this there is, of course, the considerable interest that attaches to Kortum's report by reason of its being the earliest detailed description of any steam engine whether in Europe or England. It seems useful first to dispel the unfortunate idea that Potter had built the engine without a safety valve[36]. The final test report of 1723 records that on 31st January the box of stones which kept the safety valve closed suffered a mishap, causing the engine to be stopped for three hours while it was repaired. But in any case Kortum's engraving shows that it had a pipe leading to the outside of the engine house (as in the Dudley Castle engine)[37]. Nevertheless the boiler seemed to him to behave in an alarming manner, for when the engine was not going, or when the fire was raked too vigorously, the whole thing, as he put it, pushed itself out like a person drawing breath: "der gantze Kessel ausgedehnet wird wie die Brust beym respiren"[38]. The overflowing steam was, however, able to make its escape through a wooden pipe, blowing off with a tremendous noise. The piston was of cast copper two inches thick wound round with hemp, the latter kept in place by lead weights and a lead securing ring: "...mit hanffenen Gurt und ½ zoll dick Bley engefasset, auch noch mit einem bleyernen Ring beschwehrt..."[39].

The boiler itself was of primitive design much on the lines of the one shown in Barney's engraving, that is to say, it had a concave bottom but with side walls having neither taper nor flange. A boiler of this form cannot but provoke the thought as to whether any provision had originally been made for a circular flue in order to provide a 'wheel draught'. Kortum says nothing about the flame being circulated round the boiler although the absence of a buoy pipe certainly suggests that steaming was at least no problem in 1725. Here it should be noted that von Erlach was to claim that he had invented the idea of threading the flame round the boiler, a claim which seems to imply that Potter had not known of the idea and that this was one of the improvements von Erlach made to the machine. This seems not unlikely. The idea had, after all, appeared for the first time in England (i.e. in the context of atmospheric engine) only in 1717 when Henry Beighton built the first flanged boiler 'en champignon'. In Beighton's drawing, however, the buoy pipe is visible above the boiler despite the latter's sophisticated shape, from which it seems safe to conclude that the modification had not long been made since it was this very type of boiler which permitted such a pipe to be dispensed with. Another primitive feature of Potter's boiler is the single try cock for testing water depth[40].

The Königsberg machine had to pump water from a considerably greater depth than any English engine is known to have had to cope with at that time. In July 1725, according to Kortum, it was drawing water from 460 feet (70 Lachter) at a rate of nearly 270 gallons a minute. This may explain a novel feature of the machine: its double beam. It had not started off with two, however, for both Leupold and von Schönström show it with only one, assisted by a separate balance bob next to the pumping shaft. Kortum's engraving indicates that this bob had been removed in 1725 and the engine supplied with a second lever in its place. Its purpose was, as he explains, to bring the weight of the pump rods into equilibrium with the weight on the cylinder end of the machine. The second beam had a box full of stones to serve as counterweight: "Der obere Wage-Balcken...ist auf der Seite der Machine mit einem Kasten voll Steinen beschweret, welcher die Last des Gruben-Gestänges ins AEquilibrium bringen..."[41]. Yet this was what the balance bob was designed to achieve! It seems likely that the change was made when the decision was taken that the machine should pump not simply to adit level, as originally intended, but should be made to discharge water at the surface. This involved the lift of 460 feet mentioned above in place of one of only some 250 feet. What advantage, if any, a double lever had over a balance bob in all this is hard to say but it is certain that it was employed on all the next five machines to be constructed in Hungary. When Gabriel Jars visited Windschacht in 1758 he was moved to comment at some length on the fact that all the machines which were then in position there (their history will be related presently) were so equipped. His comment is worth quoting in full: "...chacune d'elles a deux balanciers au lieu d'un, placés tant sur l'un que sur l'autre, et qui on leurs tourillons dans le milieu, au lieu que dans celles que <u>nous voyons en France</u> le balancier est plus long tant depuis la chaine qui tient le piston du cylindre jusqu'à son axe, que depuis le même axe jusqu'a l'extremité du balancier où est la chaine à laquelle sont attachés les tirans des pompes qui entrent dans les puits. De cette manière on s'est conservé une plus grande levée pour le jeu des pistons, c'est à dire, la meme qu'a le piston dans le cylindre; et comme il falloit avoir un contre-poids pour faire l'équilibre avec les tirans et les pistons, on a mis un second balancier chargé de pierre à son extremité en suffisante quantite afin que les tirans de pompes aient assez de pesanteur pour relever le piston du cylindre à mesure que la vapeur y entre; de cette façon la machine n'a que l'eau à élévér, et le frottement des pistons et des tirans à vaincre". But it is in his final comment that Jars suggests what may be the answer. Unequally poised levers may, he says, be brought into equilibrium with just as much perfection: "on a le même effet, et même on le préfère on plusieurs cas, c'est à dire, de donner moins de levée au piston de pompes mais un plus grande diametre aux corps de pompe, pour avoir à chaque coup de piston une même quantité d'eau..."[42]. But would this serve in very deep mines where the weight of the water column augmented in this way might well be impossible to manage? Were balance bobs, placed at intervals down the shaft, at the cost of much excavation, rejected for this reason? Unless it was that double levers were easier to manage in the second case, and simply the only solution in the first, I must confess I have no answers to these questions. Nor yet to whether the idea of unequal levers was peculiar to France or had been borrowed from England[43]. Interestingly enough, the Slovakian double beams were later adopted in France. It may be no more than coincidence, of course, but in 1783, three years after Jars' report was published (in 1780), the first machine in French Hainaut, at the Beau Jardin pit at Anzin, was fitted with a second lever, what came to be called the balancier hydraulique[44].

At all events the Königsberg machine was a success and more than a match for the water pouring into the Althandel mine[45]. In eight hours it cleared the accumulation of twenty-four. Nor in English terms had it proved unduly expensive to construct, although the unrealistic contract price of 6,000 gulden (£600) was hugely exceeded. Even so the final cost, with Potter's salary, the workers' wages and the engine house included, amounted only to something like 16,000 gulden (£1,600), a modest enough price to pay for the introduction of a new and demanding technology. By comparison Desandrouin's engine at Fresnes, the first in the French coalfields, cost 75,000 livres (£3,750) in 1732.

After the completion of the engine tests in February 1723 Potter returned to Vienna and with the help of friends at court tried to interest the Schemnitz Bergkammer (Chamber of Mines) in building four engines to work at the Oberbiberstollen at Windschacht. His proposals meeting with solid resistance, he then requested the Hofkammer in Vienna to grant him the right to exploit the Königsberg mines, for by this time it was clear to Potter's associates that substantial financial backing would be available for the venture could such a grant be obtained. In June 1723 Schemnitz agreed to the idea, and before the end of the year a shareholding company, the Ungarische Gewerkschaft, had been set up to exploit Königsberg.

Potter's engine began pumping again in February 1724. The venture was soon to prove a disaster, however. Far from receiving rich dividends, the shareholders found themselves facing further calls, and if 1726 was a bad year, 1727 was a worse. Finally, by April 1728, the Schemnitz Bergkammer began to lend the company technical assistance and even took over some of the shares. Losses continued, however, and amounted to some £900 alone for the period April 1728 to August 1729. Soon there was no longer any money left even to buy fuel for the engine which stopped working on 23rd July 1729. The company broke up and Potter once more found himself in grave financial difficulties. At this critical time Johann von Steinbach, Oberstkammergraf in den nieder-ungarische Bergstädten (Principal Count of the Chamber of the Lower Hungarian mining towns) intervened on Potter's behalf. Whether it was that Potter appealed to him directly, or whether the performance of the Königsberg engine had finally convinced him that Schemnitz's obscurantism in the matter had been unduly protracted and ought now to be brought to an end, the fact remains that in April 1730 von Steinbach was suggesting to Vienna that Potter should be paid four gulden a week pending a decision on the construction of further engines[46].

Before turning to this next phase of engine construction in Slovakia one ought to glance briefly at von Erlach's activities in Vienna, for it seems quite likely that a steam engine was at work there also by the end of 1722. This was the machine Prince Adam Schwarzenberg had had installed in the garden of his palace in the suburb of Rennweg, outside the walls of Vienna[47]. Its task was to pump back to the header tank the water which fed the cascades and fountains. The contract for the engine was drawn up early in 1722 and it could well have been working by the end of the year. A payment of 400 gulden was made to von Erlach in 1723 on account of the making of the water machine in the garden, "wegen der gemachten Wasser-maschine im Garten"[48]. In view of the distance from Vienna to Königsberg, as the crow flies one hundred and twenty miles, and bearing in mind Potter's heavy involvement in procuring materials for his engine, it seems unlikely that he would have had time to pay more than fleeting visits to Vienna (for which there is, in any case, no evidence) and therefore probably had little part in the setting up of the Schwarzenberg engine. As for von Erlach, he had no scruples about claiming it as his own. It became immediately one of the sights of Vienna and attracted almost as much attention as the Königsberg machine. It was discussed in some detail in reports published in 1727[49], 1728[50] and 1730[51].

In February 1727 the monthly journal Das Merckwürdige Wienn oder Monatliche Unterredungen carried a long account of the machine by "Polydorus", "Amyntas" and "Theobulus", names which seem not altogether inappropriate in view of its pastoral setting. As later reports were to do also Das Merckwürdige Wien opens its account by naming von Erlach as the first introducer and builder of the fire-engine in Germany, a reference to the machine erected in Cassel in 1722. The authors obtained an introduction to von Erlach through his colleague and close associate, Hofkammerrat Anton von Schmerling, and were received the same day. Von Erlach gave them a sketch of the machine, related the machine's history in detail, so far as it was known, and explained how it worked. It had, he said, first been found of value in the English coal mines and was fired there with coal. He had been the first in 1722 to bring it into Germany when Charles, Landsgrave of Hesse-Cassel, had charged him to set up a machine. After this another of the same kind was set up at the abandoned Königsberg mine in Hungary by an Englishman, Isaac Potter. It pumped 20,000 Eimer of water daily from a depth of some 30 Klafters and had, by working day and night for over two years, permitted the whole mine to be recovered. At almost the same time, "dass fast zu gleiche Zeit", he had set up the third such machine here in Vienna[52]. The final section of the report contains a detailed description of the engine. The account of the boiler design is of special interest for, as the report relates, it was bricked around in such a way that the fire burned not only beneath it but was led like a fiery tongue twice round its sides, "wie eine feurige Zunge zweymahl rund um die Seiten des Kessels herumschlagen", the smoke being so well consumed that little or none could be perceived issuing from its chimney. This new device of fire coursing was von Erlach's invention, "diese neue Manier das Feuer circulirend zu machen, hat...Herr von Fischer zuerst erfunden"[53], and permitted notable economies in fuel consumption. The cylinder was nine feet high, had a diameter of twenty-four inches, and weighed 1,200 lbs. The piston was bound with leather and made fifteen to sixteen strokes a minute. The supply of water to the injection water tank was automatically regulated by a floating ball cock[54]. Every 24 hours, 11,800 Eimer (nearly 8,000 gallons per hour) were pumped through 300 Klafters diagonally with a total rise of 75 feet. One person was required to fuel and direct it. The potential value of such machines was inestimable, "unbeschreiblichen Nützen", if only they could be set up where they were needed. It was sheer ignorance to compare them with Savery's or Papin's fire machines. Who needed to bother now with Savery's, Papin's or Leupold's ideas? They could all be lightly set aside if one had Potter's machine[55].

As for the Cassel engine, although most historians have been reluctant to accept its existence, they seem not to have taken into account the evidence related above[56]. This seems clear enough, for von Erlach would hardly have chosen to give such wide publicity to a blatant fiction. There is, as well, other evidence for its existence. J. Allamand in his biography of G.J. 'sGravesande mentions that the latter was invited to Cassel in order to advise the Landsgrave on certain machines he wished to have constructed, a journey he made in the summer of 1721. "Il y trouva le Baron Fischers, qui lui avoit été recommandé par M. Desaguliers, comme un très bon méchanicien...(Fischer) travailloit dans ce tems la à accrediter en Allemagne les machines à feu.....Le Landgrave, pour lui accorder sa protection, n'attendoit que la decision de Mr.'sGravesande; celui-ci prononça en faveur de la nouvelle invention, qui lui étoit bien connue...Il fit même avec Mrs. Fischers et Roman (de Badeveld) un contract en date du 3 Août 1721, par lequel ils s'engageoient tous trois à travailler à la perfection de ces machines, et à obtenir un octroy pour en faire construire dans les mines, et autres endroits en Allemagne .....De concert avec M. Fischers il s'appliqua d'abord à remplir le premier article de ce contract; il fit construire un petit modèle de cette machine..."[57]. But Fischer failed to obtain the privileges he needed and the project came to nothing. Whether this 'petit modèle' was the machine that von Erlach was to claim in 1727 as the second engine or whether there was yet another is unclear. The word "model" should in any case be understood to mean copy, the sense in which von Guldenberg had used the word in 1725 in referring to the Schwarzenberg machine[58].

By 1730, as has been noted, Potter was finally working at Schemnitz but before any decision on engine construction could be taken it was clear to von Steinbach that certain difficulties had to be resolved. Wood was scarce at Windschacht, and a search had to be made for usable coal. Much of Potter's time in 1730-31 was spent in this way[59]. Then there was the question of how many engines and of what size would be needed to handle the pumping of water at Windschacht. Von Steinbach found that Potter's grasp of mathematics and mechanics was altogether too inadequate to permit him to supply answers in which one could place any reliance. He might be an honest man but his protestations and promises were not enough. Then too there was the problem of his drinking. Finally in December 1731 von Steinbach wrote to the Hofkammer setting forth the situation. If steam engines were to be built they had to be capable of lifting at least 12,000 Eimer (200,000 gallons) a day through some 65 Klafters (440 feet). Von Erlach, who was able to calculate sizes and powers with great exactitude, should be asked to draw up the specifications for the engines. As for Potter, he could be placed in charge of construction, for he had, of course, great practical experience, but only if he could be kept under strict supervision. He should undertake to train two assistants in engine building, and might thereafter be allowed a modest salary as director of the machines. The proposal was accepted and a contract for the construction of two engines was signed in July 1732. Both machines, of 32½ inches, were completed by the end of 1733 and began pumping at the Josephischacht in January 1734. In June 1734 a new contract was signed for two further machines but before they were finished Potter fell ill and died (18th February 1735). These machines were completed and began pumping later in that year at the Magdalena shaft. In 1737 they were dismantled and re-erected alongside the two machines already pumping the Joseph shaft, their place at Magdalena being taken by a larger machine likewise designed by von Erlach. This was already in position and working by December 1738. The earliest detailed description of these machines and the work they performed is that provided by Nicholas Poda in 1771[60]. The first four, constructed in 1732-35, were identical in size. Their beams were 24 feet long, their cylinders 9 feet high and 32½ inches in diameter. At the Joseph shaft they worked at eight strokes a minute each delivering 10,368 Eimer per day (115 gallons a minute), all four consuming three cubic Klafter of wood each a day. It is unclear how the first two of these machines were used at Joseph in 1734 but from 1737 when all four were pumping there the arrangement was that two should lift water from the fifth Szargoczi level to the Piroch Lauf (drain) through 57 Lachter (380 feet) via tiers of seven pumps[61]. These were perhaps the two original engines. The second pair lifted the water exhausted by the first pair through a further 51 Lachter (337 feet) in six stages to the main drain, the Bibererbstollen (Beaver hereditary adit). These, it need hardly be said, were extraordinary depths by English standards. The depth from the surface at the Joseph shaft to the fifth Szargoczi level sump was 134 Lachter so that the shaft rods of the two machines

Map 2.

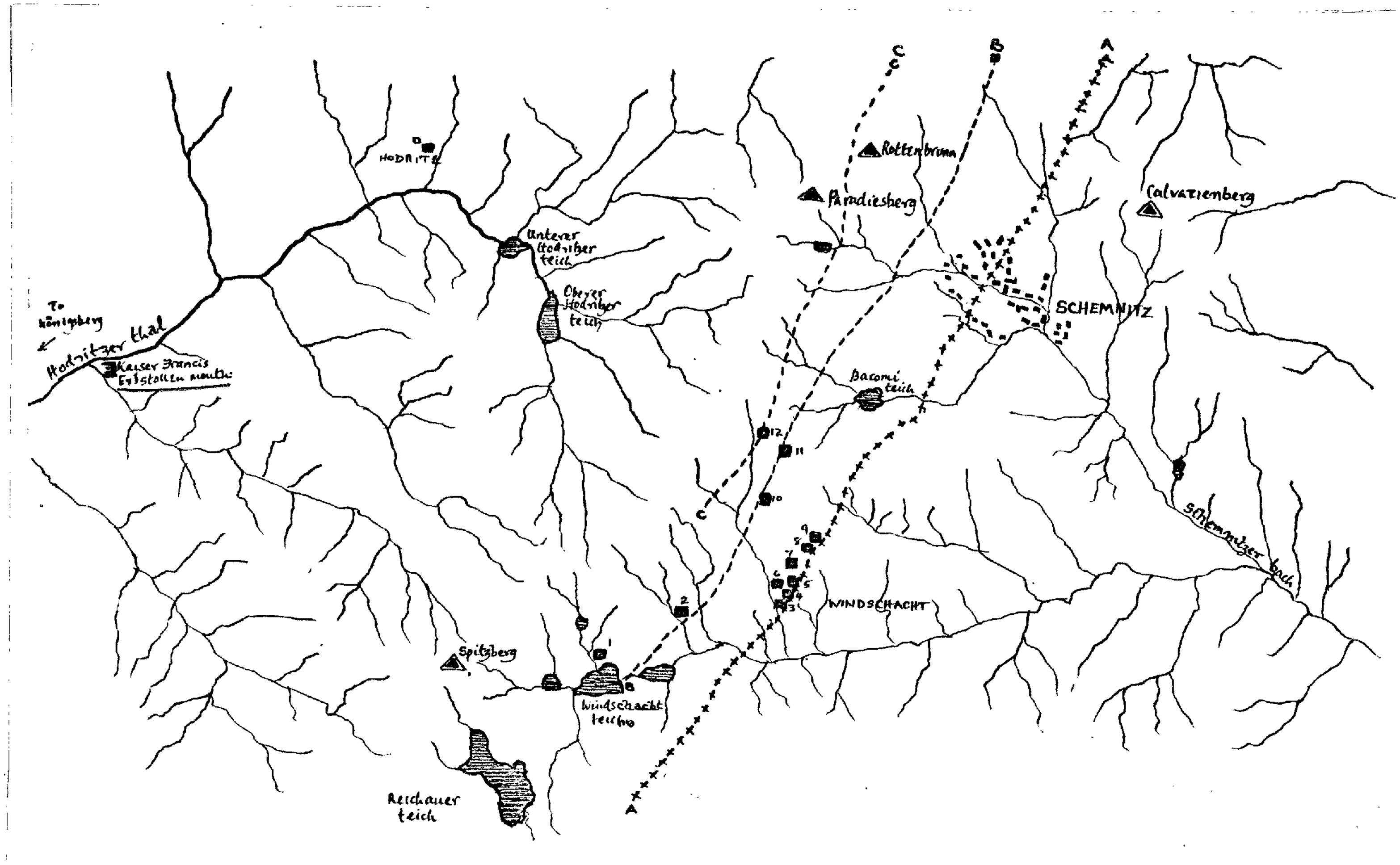
The three great lodes, the shaft sites and the terrain around Windschacht.

The principal lodes:

A++++A Spitalerhauptgang
B----B Biberstollnerhauptgang
C----C Thereserhauptgang

Shafts:

1. Konigsegger
2. Siglisberg
3. Magdalena
4. Caroli
5. Josephi
6. Leopold
7. Eleonora
8. Alte Windschacht
9. Neue Windschacht
10. Ferdinand
11. Amalia
12. Theresia



which lifted water from this level were 900 feet long, those of the others 520 feet.

But the deepest shaft of all was the Magdalena at 189 Lachter. The machine here, of 36 inches, lifted water 212 feet from sump to adit by means of shaft rods 1255 feet long from surface to pit bottom. All four engines at Joseph continued to work in this way until 1766 when a new low level adit, the Kaiser Francis (map 2), begun in 1748, was finally driven through to that shaft[62]. From this time two engines only were required to pump water 110 feet at the rate of 230 gallons a minute from the Szargoczi level to the new adit (some 700 feet below the level of the old Bibererbstollen).

Even before 1766, however, all five machines were sparingly used. The construction of new and highly efficient water pressure engines in 1749 and 1750 meant that motor water was far less prodigally used and ensured therefore that the steam engines were restricted to an auxiliary role. They were used when water was scarce by reason of dry winters or when the flow of flood water in the workings was too much for the hydraulic machines to handle. For all these reasons it was, as Jars reported in 1758, "fort rare que ces cinq machines aillent en même tems, on ne s'en sert que dans le cas où les hydrauliques n'ont pas assez d'eau extérieure, ou bien lorsqu'il y a une surabondance d'eau intérieure. Il arrive aussi quelquefois, comme nous l'avons vu, qu'aucune de ces machines ne travaille; mais çela dure tout au plus quinze jours où trois semaines"[63].

After 1738 only one other steam engine was built during the 18th century at Windschacht. This was the machine, designed and set up by Oberkunstmeister Joseph Karl Höll in 1758, which pumped the Königsegger shaft three hundred yards west of the Joseph shaft and some five hundred feet higher up the mountain side. This extreme elevation had created a serious problem some years before 1758 when Königsegger was first sunk below adit and pumping became necessary there. The water for the wheel could only come from the Reichauer Teich, the largest of the catchment reservoirs at Windschacht completed in 1742. However, the sluices at the base of the dam were lower than the eye of the shaft at Königsegger and when it became essential to supply water to the site it was necessary to construct two siphons in order to obtain a high enough head for the purpose. When the reservoir was full, all was well, and the larger of the siphons, which was the one then used, was able to supply 98,000 cubic feet per day or rather over 4,000 cubic feet of water an hour. This siphon ceased to work, however, when the reservoir level fell more than 12 feet 7 inches. The wheel was then fed by the second siphon but only at the very much reduced rate of 36,900 cubic feet per day with a consequent reduction of pumping capacity. It was this situation which compelled the construction of the sixth steam engine at Windschacht[64]. Its designer, Joseph Höll, who had perhaps been trained by Isaac Potter in

1733-34, certainly showed remarkable flair in solving the problem imposed on him by the Königsegger site. Because of the broken ground Höll was forced to place his machine two hundred feet from the shaft and arrange for it to work the shaft rods through flat rods, the earliest example in Europe I have found of such an expedient[65]. The engine of 36 inches lifted over 100 gallons a minute from 466 feet. It was an exceptional engine in an exceptional situation, for the work of Joseph Höll had effectively cut short the further development of steam power at Windschacht years before. Already in 1734 at the age of twenty he had entered on a remarkable career of mechanical invention largely concerned with improving the efficiency of hydraulic engines. His first attempt to reduce the waste of water in orthodox wheel-driven machines was his wheel-less Wasserheb-maschine of 1734, a beam engine mimicking very closely the kinematics of the steam engine[66]. The conventional wheel at the time he began work had (according to Poda whose figures I use in what follows) a ratio of water consumed as against water raised of something like 80:1. Höll's machine of 1734 achieved 21:1. The figure for his first water pressure engines of 1749 and 1750 was 4.3:1; for the Luftmachine (compressed air machine) of 1753 2:1; for the later water pressure engines of 1759-68 a remarkable 1.6:1. By way of comparison von Erlach's Magdalena steam engine measured on Poda's basis achieved a ratio of 1:6, Höll's machine of 1758 doing less well with 1:2, a low figure which points very clearly to the enormous power loss sustained by reason of its having to set flat rods in motion[67].

(ii) The Steam Engine in Western Europe.

When Johann Fischer von Erlach, studying in London, received instructions from Vienna in 1718 to look into the business of fire-engine work, it might be conceived that he had been given a difficult task. Certainly he was later not disinclined to invest the business with an air of clandestinity. It might well be wondered, however, whether it was really so difficult for a foreigner, at that time, to contrive to see an engine and learn how it worked. It has been noted that both 'sGravesande (in 1716) and von Erlach himself (in 1718-19) had made the acquaintance of John Desaguliers in London and it is making no very great assumption to conclude that he had throughly inducted both into the theory of the machine. Marten Triewald (in 1717) was yet another visitor to England to be initiated by Desaguliers into its secrets. It is worth bearing in mind also that when Johann Keysler visited Vienna about 1729 he was to remark, in connection with the Schwarzenberg machine, that von Erlach was by no means to be considered its inventor. The English nation had to be thanked for its discovery. The first time he had seen an atmospheric engine working was during a visit to London when a model had been demonstrated before the members of the Royal Society: "Die ersten Proben davon im Kleinen habe ich in London im Jahre 1718 vor der englischen Societät der Wissenschaft zu London machen sehen"[68].

In fact even outside London it was possible to see an engine, interview its director and obtain a plan complete with legend. This much appears from a letter written on 18th January 1720 by Lt. Colonel Georges de Goumoëns to his brother-in-law Gilles-Matthieu de Ghequier, seigneur de Montquin. De Goumoëns, a professional soldier returning from anti-Jacobite service in Scotland, arrived in Newcastle some time towards the end of 1719. There, as he says, he saw "une machine pareille à çelle que je vous envoie eçe (sic) le plan et je vous avoue que si je n'avais pas vu la machine exister à mes deux yeux et vu l'effet je ne l'aurai jamais pu croire, c'est la deuxième qui s'est faite en Angleterre, avec un petit feu qui fait bouillir perpétuellement de l'eau qui est dans une chaudière dont la fumée fait aller un angin, qui tire toutes les heures trois cents tonnes d'eau (about 130 gallons a minute) et çela quatre vingts brasses profond (some 240 feet)....je demande au maître s'il voudrait bien venir a Liége faire une pareille machine, il me dit que oui, et la machine toute posée couterait trois milles d'écus (£900), sans compter les frais de son voyage, cela couterait beaucoup, mais aussi tout le pays de Liége en tirerait un grand avantage si une fois on en avait l'usage...je vous envoie le dessin*, les remarques sont en Anglais, mais il y aura bien quelque jesuite anglais qui pourra vous l'expliquer, elle sert à tirer les eaux, point tirer dela houille, c'est

* The engraving has not survived.

à dire les eaux qui innondent les houillères car pour la houille se tire separement et cette machine ne peut tirer uniquement que l'eau...."[69].

De Ghequier, joint owner with de Goumoëns, of a coal mine in the pays de Liége, was not slow to act. He made contact with the English jesuits at Liége who, since they had a long and distinguished tradition of mechanical studies, were not only able to explain the plan to him but seem to have proceeded to build him a small scale model of the engine[70]. To succeed in this, as they seem to have done, was no mean feat for recent experience in connection with the construction of a machine one third of the normal size has revealed the extraordinary difficulty of the task[71]. Be that as it may, de Ghequier's machine was completed in 1720 and by 4th January 1721, declaring himself ready to begin operations, he sought the protection of a patent. Whether or not he actually proceeded to place a machine at the mine that he and de Goumoëns owned is not known. The patent application was in any case almost certainly intended as a spoiling operation in order to overturn an application made earlier in May 1720 by another group of associates in Liége, for by a curious coincidence two sets of entrepreneurs were seeking simultaneously to introduce the Newcomen engine into the Liége coalfield although at first neither group knew what the other was about.

As early, in fact, as 26th March 1720 Berthold de

Wanzoulle, Lambert van Stein and Ferdinand d'Eynstatten d'Aubée had signed a contract of association with a Colonel John O'Kelly (then still in England) under the terms of which O'Kelly, acting as technical expert, was to undertake the construction of engines in Liége[72]. By the end of May 1720, the partners having completed the details of their association, Canon Wanzoulle, a man of considerable standing in Liége, was soliciting the help of baron du Roost, one of the court officials of Joseph-Clement, prince-bishop of Liége, in seeking a forty-year patent for the construction of engines in the pays should their engine prove successful. The partners were more ambitious still and began to think of seeking a similar privilege in Imperial Hainaut, their thoughts fixed on the idea of draining the long abandoned lead mine at Vedrin near Namur. No privilege is however recorded even for the pays de Liége which makes it seem likely that de Ghequier had timed his counterclaim very well and succeeded in thwarting the would-be monopolists. Earlier he had induced other coal owners to seek the cancellation of the patent (which was no doubt at first granted), some of them indeed not stopping short of offering O'Kelly physical menaces. Despite the sound and fury O'Kelly went ahead with the work of actual construction and by February 1721 had completed his engine. It was evidently a success, for in June of that year the prince-bishop was enquiring of him as to whether he would be willing to go into Westphalia to drain certain mines there. Although this scheme was without issue it is curious that at the very time von Erlach was seeking an opening in Germany, similar notions should have been mooted further west. But it is evident that at many levels there is a remarkable correspondence between events in western and central Europe in the years 1720-1722.*

How Wanzoulle and his associates came to know of O'Kelly or how indeed O'Kelly had acquired his knowledge of steam engine construction are questions to which there is at present no answer. It is clear, however, that such knowledge was fairly widely disseminated in England, at least among those of the cognoscenti with a taste for experimental philosophy: that O'Kelly is to be numbered among such men appears from an elegant and lucid description (in French) of the machine and its mode of operation drafted by him, in early 1725, for the members of the Bergkollegium in Stockholm. At all events he arrived in Liége in September 1720, and despite a good deal of confusion and recrimination, had, as has been observed, completed his machine early in 1721.

Such expedition was evidently only possible because O'Kelly had carefully planned the ordering and delivery of the main engine components well in advance. The cylinder of 25 inches and the valve gear, made in England, were dispatched to Rotterdam in August 1720. When O'Kelly arrived in Liége in September, however, he found nothing had been started. The engine house had not been begun, the boiler was still being made, and the cylinder with the English technicians he had engaged reached the city only

*It is clear also that O'Kelly knew that Potter was then in Vienna.

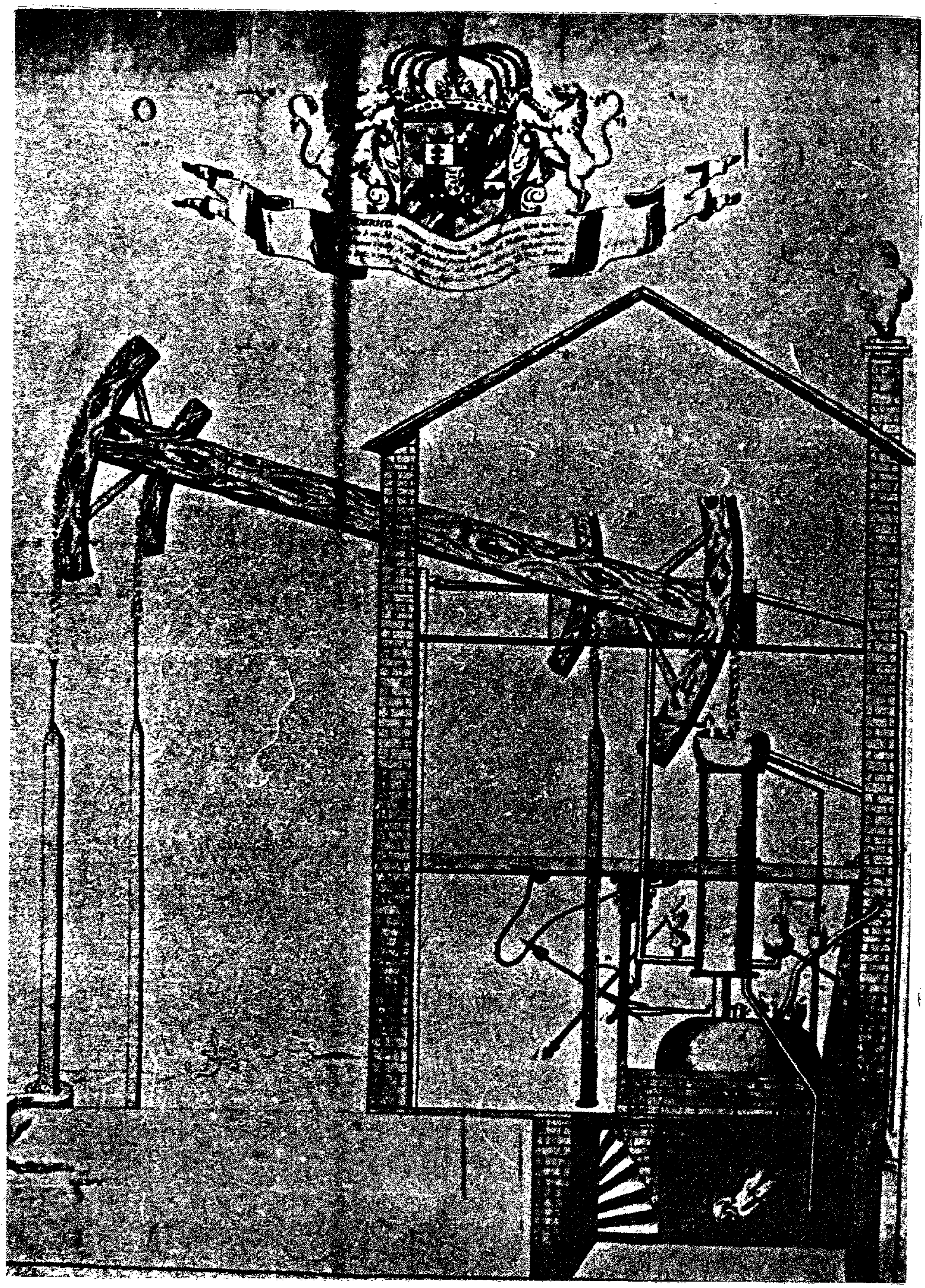
on 4th October. The engine was destined for a mine at Groumet, near Jemeppe-sur-Meuse, a mile or two west of Liége, belonging to Mathieu Raick, but then when all was ready the partners encountered a fresh problem. Although the pit was some 300 feet deep the engine had been designed to lift water not to the surface but only to the level of an adit 65 feet above the sump. Its maximum lifting capacity, through a rising pipe 9 inches in diameter, was something like 175 gallons a minute. Unfortunately Raick had thought to save money by renovating an old adit for the discharge of the engine water instead of driving a new one. In the end, after a succession of collapses in the old tunnel, he was finally forced to begin work, in March 1721, on a new drainage gallery. The delay in getting the engine built and then the unexpected hold up at the pit had by this time put the partners under severe financial strain. In February O'Kelly was complaining to Wanzoulle, then in Vienna, that he had spent 15,000 florins and had even had to sell his watch. Thereafter all is silence until 1723. By that year, however, O'Kelly, disillusioned with his partners, had sold his share in the engine to an Englishman named Blackmore, but had not yet retired from Liége since there still seemed some prospect that his negotiations with the owners of the Vedrin mine would lead to an order for an engine. The Groumet machine's final destination after it was moved in 1723 is not known although it is likely that it and the engine known to have been working at Péry, near Groumet, in 1725 were one and the same[73]. O'Kelly's movements in 1724 are unknown but early in 1725 he was in Holland, probably in Amsterdam, and on the point of winding up his affairs there before returning to London. In March 1725 his negotiations with the Spanish ambassador in London concerning a project to build an engine or engines in the mines of the Biscay region were at an advanced stage, and, in the first week of April, on their successful conclusion, he had in fact returned to England. Before this, however, he had on 12th March called on the Swedish Resident in The Hague, Joachim Preiss, in order to deliver a letter offering his services to the Swedish crown. The circumstances that had led to his doing this were curious.

In early 1723 when O'Kelly was still in Liége, his one-time associates had received a request from Prince William of Hesse, brother of the King of Sweden, to use their assistance in bringing him into acquaintance with the engineer who had constructed the steam engine, for what he had heard concerning it greatly interested him. It seemed to the Prince also that its constructor should think of journeying to Sweden to offer his services to the crown. For whatever reason O'Kelly's associates, or rather former associates for it seems likely that by the time of these events he had severed his ties with them, kept all knowledge of the prince's initiative from him. They had not, however, been able to suppress the matter altogether, for one of O'Kelly's technicians, somehow learning of the matter, had presented himself to the prince and claimed that he was thoroughly familiar with the business of engine construction. From what O'Kelly was later to tell Preiss it is clear that this man was indeed a skilful workman and had spent several years learning from him how things were done. He was well able to build an engine once he had been given its specification. What he could not do was initiate a scheme, for he was no theoretician and was ignorant of the scientific basis of machine design. The calculation of powers and proportions was quite beyond him and it was precisely this sort of expertise that O'Kelly wished to bring to the service of Sweden[75].

At all events Prince William had given O'Kelly's assistant one hundred pistoles (about £55) to cover the cost of his journey to Sweden. From other evidence it appears that the man in question was a Colonel de Valoir. Once in Sweden he had lost no time in obtaining a patent, granted in October 1723, giving him the exclusive right to erect engines. O'Kelly's information was that he had in fact set one up at a silver mine but that it had not been a success. This appears not to have been the case. Even by 1725 de Valoir had yet to build a machine, and the shock to him must have been quite severe when the Bergkollegium, in May 1725, proposed, in effect, that since he had not yet begun to build a machine, much less clear a mine, he should be stripped of his privilege in order to leave the field open for O'Kelly.

Such was the substance of what O'Kelly told Preiss in the course of their conversation on 12th March, all of which Preiss reported the next day in a dispatch to his government. With it he sent O'Kelly's letter, in which, as noted, he made offer of his services and declared his readiness to send one of his workmen, Saunders by name, if that were the crown's desire. A week later O'Kelly called on Preiss again to tell him that Saunders had left for London and would probably not be returning. In his place he offered to send his own son who was equally proficient in theory and practice. More importantly, he left with Preiss a letter dated 17th March in which he explained, with admirable precision, the machine's principles of operation and the functions of the various members of which it was composed. He promised to make a drawing of the machine he had put up at Jemeppe since the prints available were not accurate: "vous entendrez tout cecy beaucoup mieux par une ébauche de la machine que je vous ferai faire. Car les plans imprimés sont expressement faux[76]. Je vous en dresserai donc un de la machine que j'ai erigée à Gemeppe prez de Liége". Finally, he offered his services and those of his son: "Si, Monsieur, cette invention peut être de service à la nation Suédoise je vous offre mon fils, qui l'etend fort bien et dans la theorie et dans la pratique: Et même quoique je me suis engagé pour aller autre part, s'il seroit possible de faire le voyage de Suède et

Fig. 3.



The 'authentic' drawing of an atmospheric engine executed for the King of Sweden.
Source: J. O'Kelly, Sketch, 1725.

retourner en quattre mois de la datte, je visiterai les fosses avec lui"[77]. Preiss dispatched this letter on 20th March. O'Kelly was as good as his word. Early in April he delivered Preiss a drawing, based, it would appear, on Sutton Nicholl's engraving, but showing a different design for the water injection gear. The buoy pipe had gone, its place taken by a toothed quarter wheel worked by the plug rod (fig. 3).

Preiss was to write three more letters to Stockholm concerning O'Kelly. On 6th April he dispatched the drawing; on 9th April he wrote to say that O'Kelly had gone to London; on 16th July to report that he had not returned nor replied to the letter he had sent him. This letter was almost certainly accompanied by a copy of the report on O'Kelly's proposals that had been submitted by the Bergkollegium to the royal council on 14th May. Their critique is of the greatest interest and may serve as conclusion to this account of O'Kelly's activities. As they saw it there were five disadvantages to the use of steam engines. Firstly, they drew attention to the quantity of fuel such engines required. Unless there were abundant stocks of timber it could not be used without putting at risk supplies for the mines themselves and for smelting. At Newcastle or Liége the situation was quite different for there the very mines themselves produced fuel. Secondly, they doubted whether such machines would work to full effect if wood only were available for fuel. Thirdly, such machines were very costly and difficult to build and needed highly experienced persons to attend them, something which it might not be possible to guarantee at all times. And, as a mine grew deeper, would not such machines have to be enlarged to manage the extra work, a task again beyond the powers of an ordinary artisan? Fourthly, as a mine grew deeper and the master shaft rod had to be lengthened, how could the machine's motion be directed horizontally or to a variety of places through rod work? This seemed likely to be difficult to achieve with such machines. Fifthly, most mines in Sweden were already adequately equipped but where the flooding problem was too great for ordinary machines to handle or where mines had been abandoned and could not be drained by hydraulic engines, or where there was no motor water to be had at all but fuel was in adequate supply, in such situations the machine would be useful and indeed necessary[78].

By 1725, with one machine built in five years, it would seem difficult to resist the conclusion that the attempt to domesticate the steam engine in western Europe had, in effect, failed. Such was not really the case, however. O'Kelly had not laboured in vain, and 'take-off' was not to be long delayed. George Saunders, the workman O'Kelly had with him in Holland in March 1725 and whom he had hoped to send to Sweden, appears again as the "expert et entrepreneur étranger" who arrived in Hainaut early in 1730 to set up a steam engine on the silver/lead mine at Vedrin-lez-Namur[79]. It seems likely, however, that he was not exactly a stranger in such parts, for although he only appears for the first time shortly before his departure from Holland in 1725, it is not unreasonable to suppose that he had been with O'Kelly in Liége from as early as 1720. It is in fact only by supposing that he had worked there that his appearance at Vedrin in 1730 becomes explicable, for how else would the mine owners have known of him or where to find him in England? It may well have been Lambert van den Steen, O'Kelly's partner in the original engine venture of 1720-21, who acted as intermediary in the affair, for he is known to have had a business interest in the Vedrin mines. It is unfortunately a matter unlikely ever to be resolved since the Vedrin archives no longer exist[80].

As for the mines themselves, which lay scattered over a broken and waterless plateau of some twenty-five square miles immediately to the north of Namur, they had, by 1730, been in active exploitation for rather over a hundred years. The first vein of lead in the area had been found accidentally in 1612 by workers digging for alluvial iron, but other finds followed in the next few years. In 1624 a vein was discovered at the village of Vedrin itself and five years later, in 1629, yet another about a mile and a half to the south between Frizet and Haye-aux-Pecquets. The several owners of these mines, foreseeing conflicts and litigation as the workings were extended, decided in 1633 to join forces to work the mines in a unified way and from that time until 1804 all the mines were run by an irrevocable association, the 'Associés à la traité de plomb de Vedrin'[81]. The agreement covered a roughly circular area some six miles from east to west and four miles from north to south, and was intended to apply not only to the veins then actually in exploitation but also to any that might be discovered in the future. Further finds within the zone were in fact made in 1650 near Saint-Marc on its western, and in 1743 at Grand-Celles on its eastern edge.

The whole mining area was virtually waterless while the mine situated in Vedrin itself could scarcely have been less propitiously placed, set as it was on its own small mountain. But if water was lacking on the surface, its abundance was a great problem in the workings. Shortly after 1660 a Stangenkunst driving adit-rods (Streckengestänge) was set up in the valley beneath the mountain and the little Vedrin brook was dammed to provide water for it, a sure sign that drainage by means of adits was no longer possible.* With the advantage of hindsight it is clear that any such pumping engine could have been only of limited assistance, given the inadequacy of the steam that fed it. Indeed, it would seem that by 1680 or soon after the mine was completely drowned out, for according to a report written in 1740 it had stood abandoned for fifty years before it was decided to try what steam pumping could achieve[82]. The parallel with Königsberg is striking. Both mines must have appeared as totally hopeless cases before the atmospheric steam engine appeared to offer a

* The work of Paulus and Rennequin Sualem.

solution. All the same, the decision to bring in George Saunders was a bold one and that it had been preceded by a long debate may perhaps be gleaned from the fact that the conseil des finances of Namur had agreed as early as February 1723 to reduce the royalties payable by the associés from one-third to one-sixth for a period of ten years, in order to assist them to recruit more workers, repair the smelting furnaces at Vedrin and Frizet, and to set up new pumping engines. Taken together such moves clearly seem to indicate a resolution to recover Vedrin, and O'Kelly, then in Liége, had evidently had good reason to feel hopeful about what the outcome of these moves might mean for him. Perhaps the long wrangle about the placing of his machine at Liége dashed his hopes for it was no more than common prudence in the associates of Vedrin to hold off until such matters were settled and they had seen its capacity for sustained work. Perhaps too the machine pumping successfully at Péry in 1725 also played its part. At all events, Saunders had his engine working by the end of 1730 or early 1731, and to begin with the machine was well able to handle the flow of water. The associés were now free to sink deeper and win a great deal of lead, "mais commes les fosses s'approfondissaient à mesure qu'on y creusait, les eaux y entrèrent en si grande abondance qu'en 1735, on fut obligé de faire une second machine et, pour les mêmes raisons, une troisième en 1738. Chacune de ces machines retire quinz tonnes d'eau par minute du fond de la fosse qui n'a pas moins de quarante toises de profondeur"[83]. If Saumery's information was correct the three machines were lifting nearly 800 gallons a minute from some 260 feet. But even this was not enough. By 1740 a fourth machine was in position increasing what must have been the already colossal running costs. The sequel can perhaps be guessed and was not long in coming. The report of 1740, already referred to, written before this last engine was in operation, estimated that in the ten years during which the pumping of the mine had been kept up the prime cost of the three engines with their maintenance had involved the associés in a total expenditure of 60,000 florins, that is, about £5,000, which the receipts from sales of metal had been quite insufficient to offset, the cumulative loss over the period 1730-40 amounting to some 15,000 florins. The fourth engine was evidently unable to stabilize the flooding problem, and as early as 1741 it was decided to stop all the machines.

This did not signal the abandonment of the mine, however. According to Gabriel Jars work had already begun in 1740 on a new low level adit. This, when completed, was nearly three miles long and emptied directly into the Meuse. At Vedrin it intercepted the vein some 20 - 25 metres below the sole of the shaft and thus permitted extraction to begin again. Jars does not mention when this adit was completed but evidently it had been in use for some time, for when he visited the mine in 1765 he reported that the workings had then been carried down to the level of the gallery[84].

With the shut-down of the engines Saunders was compelled to move on. In 1741 he moved to Charleroi and began working for a powerful mining company, the Société de Sacré Madame, the owners of the coal mines at Damprémy, two miles west of the city. There is little doubt that he was the builder of the engine erected there some time in the period 1741-45. After this Saunders is not heard of again[85].

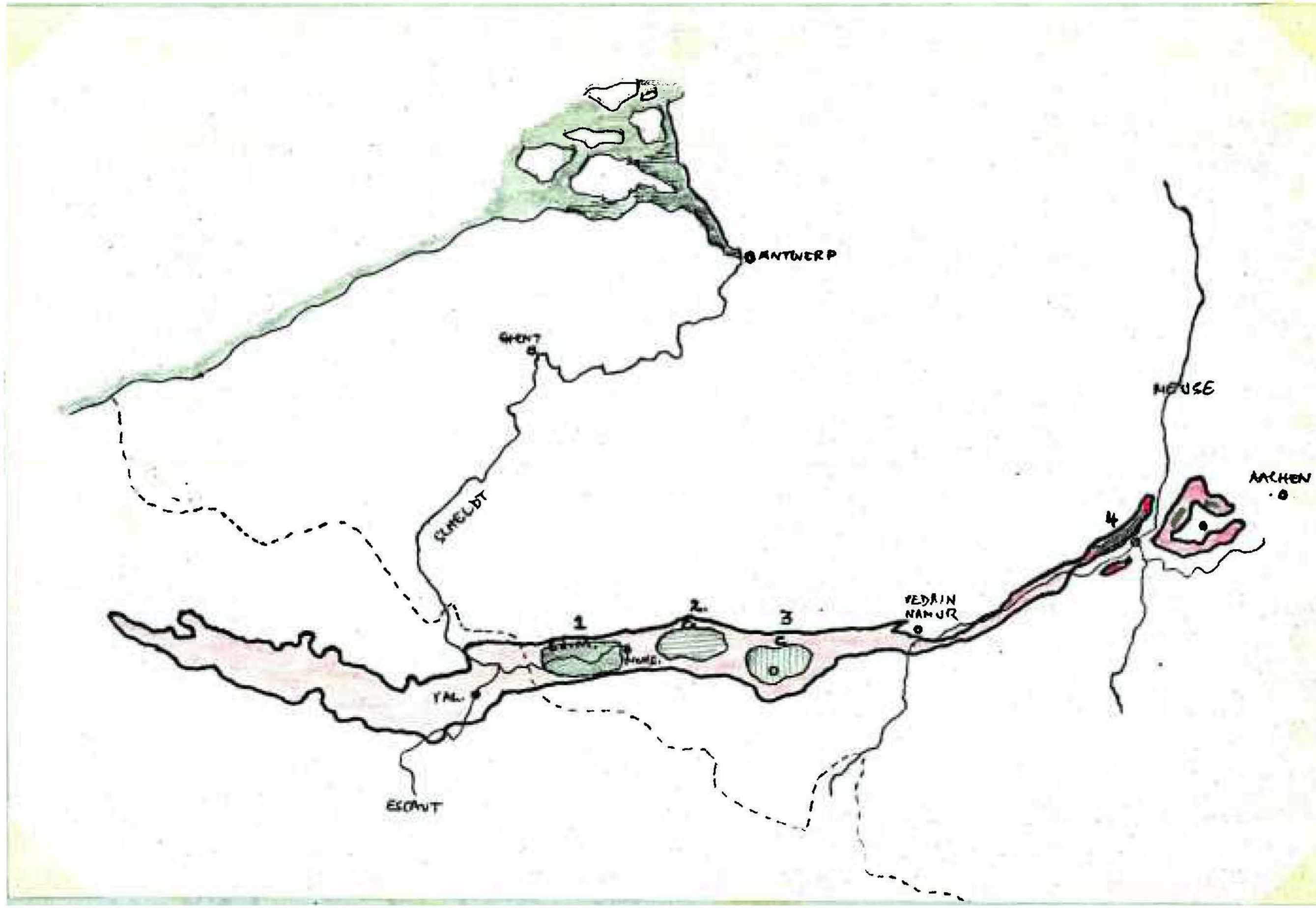
By 1740, of course, it had long been obvious to financiers and coal owners along the whole length of the northern coalfield that the steam engine was uniquely valuable in those situations where neither adits nor hydraulically-driven machines could be applied. Although Liége had been the scene of the first experiment, it was not an area that at this early stage stood very much in need of steam engines. As late as 1767 when Jars composed his fourteenth memoir on the coalfields of the area he noted only four machines presently in use, "on en compte quatre actuellement en action", although he did not doubt that this number would grow in the future[86]. It seems rather that it was the events at Vedrin which acted powerfully on the thinking of the entrepreneurs of Hainaut. For here was a large-scale operation extending over many years, conducted by a resident English engineer, which had brought a long-abandoned mine back into production by means of engines of enormous power. Even more important was the fact that the associés

Map 3.

The northern coalfields of France and Belgium. The shaded areas indicate zones where the seams outcropped.

Key:

1. Borinage (Couchant de Mons)
2. Bassin du Centre
3. Charleroi
4. Liege.



gave Saunders considerable freedom not only to travel to England in order to procure engine materials and keep himself abreast of changes in technique but also to undertake the erection of machines for other mining groups. In 1732 Desandrouin called him in to reform the machine at Fresnes in French Hainaut and again in 1735 to build an engine to drain the Fayat pit at Lodelinsart in the Pays de Charleroi.

Nor was this all, for during his ten years at Vedrin Saunders had introduced a number of local craftsmen to the technique of engine construction. It would be overstating the case to speak of a miniature diaspora of engine builders forced out into the coalfields (mainly of the Borinage)* when the Vedrin engines were shut down since two at least of Saunders' assistants, like Saunders himself, had already, before 1741, undertaken work outside Vedrin and erected engines on their own account. Nevertheless, the fact remains that all alike were forced to move. Lambert Rorive, for instance, who had worked with Saunders since at least 1732, put up his first engine at Montegnée near Liége in 1738 and in 1745 built the famous machine at Bois de Bossu, west of Mons, remarked on by Perronet in 1756 as the most perfect in the region[87]. Another technician at Vedrin, Robert Fastré, had similarly worked on his own and set up a machine at Auvergnies (Paturages) also west of Mons, some time in the period 1734-40.

*The Borinage was the coal mining region west of Mons, known less colloquially as the Couchant de Mons (map 3).

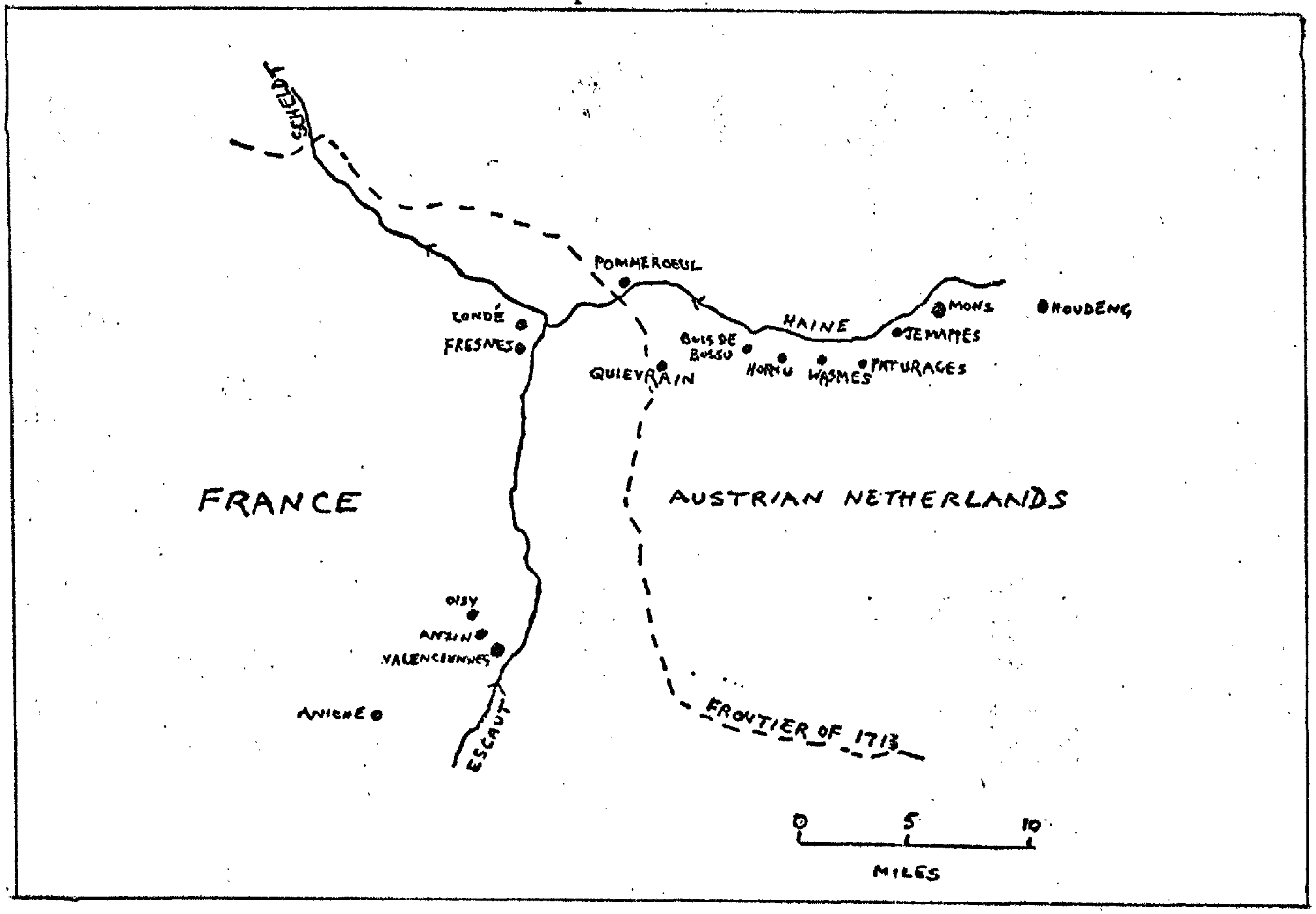
Francois Dorzée of Namur was yet another of Saunders' pupils at Vedrin and although no such early engine can be credited to him, there is no doubt that he and other members of his family were responsible for great numbers of machines throughout the Borinage[88]. A Philippe Dorzée was the builder of an engine at Sart-Allet in 1767, while yet another Dorzée supplied the engine for Aniche (in French Hainaut) in 1780-81.

In the light of all this the importance of the decision taken at Vedrin in 1729-30 is hardly open to question. The long-term nature of the steam engine operation there had resulted in the formation of a body of workers capable of sustaining permanently the new technology after Saunders' death.

This in summary fashion reveals the main lines of development in western Europe, but it would be to leave too much unsaid not to comment in turn upon two regions in particular, the Couchant de Mons (the Borinage) and French Hainaut, which reveal the very different levels of economic organization behind the large-scale building of engines that transformed coal mining in those areas. The Liége coalfields, as has been noted, were not a scene of early great activity and neither for that matter was the Bassin du Centre or the coalfield of the Charleroi area.

Well before the end of the 17th century there was a general awareness in the Couchant de Mons of the great crisis that was looming over the future of the coal pits[89]. The government, merchants and coal owners foresaw a time when the continued working of the mines would take

Map 4.



The Borinage and the coalfields of French Hainaut.

first one pit, then another, and finally all, below the level of free drainage, from which moment the steadily mounting expense of pumping them clear of water would drive all indifferently, slowly but surely into insolvency. Responding to the growing disquiet the imperial council actively encouraged the amalgamation of small societies into bigger groupings better able to afford the building of costly drainage engines, and was in addition behind the setting up of finance houses expressly concerned with providing capital for the provision of such equipment. The estates of Hainaut were concerned also, and in 1728 put forward a plan for the digging of two new low level adits, to be driven from the river Haine, in order to drain off water encumbering the pits of Jemappes and Wasmes. Their initiative stimulated the government itself to commission an engineer, J.J. Plon, to look into the question, who in his report presented a comprehensive scheme for the whole coalfield. Plon was able to show that the plan for drainage galleries proposed by the estates was totally useless since many owners were already working seams some seven to eight toises (fifty to sixty feet) lower than the bed of the Haine and therefore lower than the levels of the proposed outfalls. His memoir, presented in 1732, envisaged the digging of an adit to run diagonally across the whole of the Borinage which would have its outfall at Pommeroeul just above the confluence of the Haine and the Escaut at Condé (map 4). The various mines could connect their own adits to this principal gallery, the discharge from which would provide sufficient water to supply a canal to be constructed to Ath for the purpose of opening up new outlets for local coal. The cost of the principal gallery (which would have been at least eight miles long) would, Plon estimated, amount to 51,445 florins (about £4,300). The government, which alone could have met the cost of such a scheme, recoiled[90].

Before this time, however, the idea of pumping the mines with steam engines was attracting attention and was beginning to make such vast schemes seem unnecessary. The news was spreading in the Borinage of what was being done with such machines at Liége and Vedrin and Fresnes, and, according to Decamps, "de 1727 à 1738 nous voyons frequemment les capitalistes et les ouvriers interessés dans ses charbonnages insister sur l'utilité qu'il y avait à le(s) substituer aux machines à molettes"[91]. Although there was then great interest at an early stage in getting rid of horse-driven water bag hoists, documentary evidence, capable of yielding a more precise idea of where and when engine building began, is largely lacking for the period before 1745. Whether such enthusiasm was based on any very firm cost/benefit analysis is not clear, but it must have been well known, at least to the men who put up the capital, that steam pumping was several times cheaper than the use of horse-driven pumps. It was therefore possible for them to estimate the period required to amortize the prime cost of installation and what rate of return would allow them an adequate return on the capital invested. According to an anonymous report of c.1760 the "carbenneux", peasant coal miners, who entered into arrangements with financiers in order to install engines were rarely in any case in a position to bargain: necessity drove them. "Or les pauvres ouvriers charbonniers n'étaient riens moins qu'en état de faire ces machines à feu; ils devaient recourir a des plus puissants qui, sous le prétexte de désinteressement enlevaient tout le gain que devroient faire ces pauvres malheureux"[92].

Such industrial peasants, poor and usually working small concessions, had indeed to admit rich outsiders to a large share in the product of their mines if they were to obtain engines. The price was usually high, perhaps as much as every eleventh bucket of coal raised, but in any case rarely less than the fourteenth. A typical situation was that of two small societies, the Fosse du Bois and Bonnet-sur-Dames, which joined forces in 1748 in order to put up an engine. Lacking sufficient capital for this, they approached Ferdinand Lequeux, a coal merchant of Mons, who advanced them 28,500 livres (£1,425) in return for the twelfth basket. The contract was signed in April 1752 and Lambert Rorivé and his son built the engine which was working by June 1753. The cylinder of 35 inches was imported from England. The machine was, however, poorly engineered and in 1756 Francois Dorzée was brought from Namur to remedy its defects[93]. A similar arrangement was concluded between a number of societies at Horiau near Jemappes, and Nicolas de Behault, écuyer and prévôt of Mons, the parties agreeing in November 1752 on the fourteenth basket. The engine began working in July 1754. It was of entirely English manufacture and was reckoned to be one of the best in the whole Borinage. The next one that Behault was to buy and have set up near the first was, however, 'home-made' in Liége and had the more usual and less costly wrought-iron cylinder typical of Borinage engines[94].

The first engine known in the Borinage was that put up by Robert Fastré at Auvergnies (Paturages) some time in the period 1734-40. It was not well built and in 1749-50 needed alteration and worked only until 1755. While working it pumped water from 29 toises (about 185 feet). The second was at Bois de Bossu, put up in 1745-46 by Lambert Rorive at a cost of 55,000 livres (£2,750) and described in the <u>Encyclopédie</u> in 1756 as "la plus parfaite que nous ayons dans les environs"[95]. It had a cylinder of 30½ inches, worked at 14 strokes a minute, and burned well over two tons of coal every 24 hours. The third was at Champ des Sarts (1749) and drew water from 55 toises (about 370 feet).

By 1767 at least twelve engines were at work in the Borinage, by 1777 nineteen, while a census of 1790 recorded no fewer than thirty-nine, twenty of which were working. Figures for the same year 1790 for the fields further east were: Bassin du Centre, five; Charleroi, nine; and Liége, fifteen[96]. The Borinage's well marked lead was due to two main factors: the lack of water to power hydraulically-driven engines, and access to markets large enough to warrant the setting up of expensive steam engines. The Bassin du Centre by contrast was more slowly mechanized by reason of its lack of markets and because its shallow and outcropping seams presented fewer problems of drainage. Its first engine was set up as late as 1766[97].

The development of mining in the Pays de Charleroi was arrested by reason of the complexity of the internal tariff barriers which rendered its coal expensive in the neighbouring territories. "Pour la région de Charleroi, l'enchevêtrement des quatre provinces (comtés de Hainaut et de Namur, duché de Brabant, évêché de Liége) avait gené le developpement de l'exploitation charbonnière. Chaque province, avait en effet, sa propre barrière douanière et appliquait des droits d'entrée et de sortie pour toute marchandise en transit"[98]. Liége, as has been noted, was long able to manage with adits and rod engines (Stangenkünste).

As for the Borinage, enormously damaging floods in 1748-49 greatly accelerated the making of such agreements as have been noted above, but although the increasing rate of engine construction assured Saunders' one-time assistants a future of lucrative employment, it cannot be said that the standard of their workmanship was very high. When John Wilkinson visited the Liége region in 1782 he considered the engines no better than those used in England twenty years previously. Constantine Perier, a few years later, was to comment in a similar fashion on those in use at Anzin in French Hainaut. For whatever reason the craft of engine building in the northern coal-fields remained throughout the 18th century and until well into the 19th at much the level at which George Saunders had left it about 1740. Each engine was typically the highly variable product of bringing together a group of workers assembled for the occasion: a black-smith (as cylinder maker), a boiler maker, carpenters and pit workmen, and sending for a Fastré from Mons or a Dorzée from Namur to oversee its assembly. Cast iron cylinders were the exception, and it was only in the 1820s that they began to replace those made up from sheet copper or wrought iron. At much the same time the old circular boilers "en champignon" began to be replaced by the box type "en caisson" with internal flue first used by Watt some fifty years earlier[99].

What appears inexplicable is the failure of any of the local engine builders ever to develop beyond what one might call the 'jobbing' stage of machine construction in the way, for example, that Bateman and Sherratt developed on extensive manufacture in Salford in the 1780s from rather simpler beginnings as pump makers and foundrymen[100]. The success of the Periers at Chaillot after 1778 in establishing a manufactory that even Watt had to admire is proof enough that a market existed in western Europe capable of sustaining such enterprises. Nor can it be readily supposed that the Austrian Netherlands lacked men of entrepreneurial vigour, for, as will be seen presently, Jean-Jacques Desandrouin, seigneur of Lodelinsart, had precisely that "volonté...de constituer dans un terrain inexploré de grandes entreprises de type moderne"[101].

It is in fact to Desandrouin's activity in opening up the coalfields of French Hainaut that one must now turn. As late as 1699 a government enquiry into the economic potential of the Scarpe and Escaut region characterized it as an exclusively agricultural land of wheat and rye peopled by peasants wresting a mean living from a grudging soil. As for minerals, "il n'y a pas d'autres richesses souterraines que les pierres blanches"[102]. Yet under these "morts terrains, les steriles" at a depth of between 200 and 250 feet lay the concealed continuation of the coalfield which outcropped to the west of Mons. It was these coalfields exploited by the "paysans aux houilles" which had long supplied the needs of all Hainaut. The treaty of Utrecht (1713) ended all this by cutting in two what had been one economic region. The Austrians placed high tariffs on coal crossing the frontier into French Hainaut, an act which precipitated, almost immediately, attempts to find coal on French soil. Coal was after all dug on the right bank of the Escaut and it seemed reasonable to Nicolas Desaubois to begin searching on the left bank at Fresnes, a village in the same alignment as mines across the frontier at Quiévrain, Bois de

Bossu and Wasmes. He formed a company for this purpose and in May 1717 obtained his first concession. As partners he had an already rich and experienced mine owner from Lodelinsart (near Charleroi) J.J. Desandrouin, Pierre Desandrouin, and Pierre Taffin. This first company found coal on 3rd February 1720 but it was of poor quality and virtually worthless. Desaubois now retired from the business, his purse not deep enough, but Jean-Jacques Desandrouin with the other partners persisted. Desandrouin disposed not only of ample financial resources, but, in the force of miners he had brought from Lodelinsart and in his engineer Jacques Mathieu, had expert miners equal to the challenge offered by the geological structure of the area. Its difficult nature has been described above. Two hundred and fifty feet of saturated chalk covered the coal seams. At a depth of 250 feet the chalk gave place to a layer of impermeable clay (dief, glaise) about 50 to 60 feet thick. Under the glaise lay the highly contorted coal seams, none thicker than three feet and most more easily measured in palms[103]. The chances of missing such thin and almost vertical seams even when the chalk beds had been successfully passed were high, and in fact nine 'dry' pits were sunk between 1725 and 1732. The search was for good quality domestic coal so that even after "La Petite Fosse" at Fresnes was in production and had been equipped in 1732 with the first steam engine in northern France, the search continued[104]. A new shaft was begun at Anzin, near Valenciennes, in August 1733 and after ten months finally struck, on 24th June 1734, a vein called Maugrétout, a fat coal of the best quality. The placing of the shaft, however, had been a matter of the purest luck[105].

The shafts sunk in these early years were achieved at enormous cost. The fight against flood water was always extremely severe and often lost. Only a highly sophisticated cuvelage technique involving the construction of a double wooden shell filled with a mixture of cinders and hydraulic cement, creating what was virtually a seamless tube, permitted work to be carried on at all[106].

The first of the steam engines to work Desandrouin's concessions was that set up at Fresnes in 1732. Through the tangle of myth that grew up about this machine one can discern that Desandrouin and Mathieu obtained the plans for it from Liége but were finally forced to call in George Saunders from Vedrin to make it work. Their difficulty seems to have been due to a failure to perceive that the boiler had to have a flange (plat-bord) in order to accommodate the circular flue necessary for good steam production (or to know of the flue at all). The days of buoy pipes were over, and one has it on the authority of Bossut that without such a "cheminée de la chaudière" it was not possible to raise sufficient steam for satisfactory working[107]. According to Jacques Mathieu the engine cost 75,000 livres (£3,750). Another with a wrought iron cylinder was set up at Anzin in 1737. By 1756 five were at work altogether; by 1783, ten.

The quality of these engines was rather better than those of the Borinage but no attempt was made to assimilate newer techniques from England. Gabriel Jars found those he saw at Windschacht in 1767 rather superior to those in French Hainaut. Later still, Constantine Perier noted that "au moment où j'ai commencé a m'en occuper, il (the Anzin company) n'y avait que quelques-unes de ces machines près de Valenciennes; elles étaient sur l'ancien principe, et telles que sont décrites par Belidor"[108]. The first single acting Watt-type engine from Perier's works was put up at Anzin only in 1802.

There were, however, two innovations. One was the use of double levers and seems, according to a contemporary report, to have been first employed at the Beau-Jardin pits at Anzin in 1783[109]. As at Windschacht, the great depth of the shaft seems to have made this necessary. The second was of even greater importance. The Anzin company (as the merger of Desandrouin's company with its rivals was called after 1757) had made what appears to have been a major break-through in developing a transportable steam engine supported by a timber frame, the "machine à feu en bois", for use in draining trial shafts (fosses en tentative) while they were passing through the niveau. The flooding problem was of course at its worst during such work and in fact all the time until the cuvelage was put down into the glaise. In what was essentially a wild-catting operation, with many more failures than successes, the utility of a machine that could be hauled rapidly into position and begin working immediately without the loss of time and money involved in putting up a great wall of masonry, was soon grasped. An attempt to use such an engine was made at Fresnes in 1744. But was the idea Jacques Mathieu's or not? The question of mobile steam engines, despite its considerable interest, appears to have attracted no attention at all beyond Farey's brief note (in 1827) of Smeaton's scheme for a mobile engine of 1765[110]. The beginnings of experimentation may, however, be glimpsed much earlier in Stephen Switzer's Introduction to a general system of Hydrostaticks and Hydraulicks of 1729. It might have been expected that when he came to illustrate Newcomen's steam engine he would have chosen to show a conventional machine. In fact he did not. The caption to the engraving runs, 'A Description of the engine to raise water by fire, fixed in a frame of timber, instead of the usual engine house...'[111]. The engraving itself shows the engine beam supported by a trestle, with the boiler standing on the timber base of the frame. The latter had a brickwork setting (not shown) with the usual kind of circular external flue. Little though this is to go on the implication seems clear enough: such an engine rig is plainly easier to move about than one furnished with a great lever wall, although as far as mobility was concerned it would have been preferable to have avoided 'on board' brickwork which would almost inevitably suffer damage when the frame was moved, a problem that Smeaton's mobile engine of 1765 with an internal flue boiler was evidently designed to solve.

As for Switzer, although he omits to comment further on the singularity of his "engine...fixed in a frame of timber", John Allen in his <u>Specimina Ichnographia</u> of 1730 permits the matter to be advanced somewhat. In his description of 'A New Invention for Heating and Boiling Water...' he describes at length the merits of a new kind of boiler he had devised. It had an internal flue: "In the method I am speaking of, the fire is not to be made on the outside of the boiler... but in the...midst of the water to be boiled". It consumed only half the fuel needed by a conventional boiler while evaporating one-third more water. It had even a further advantage, he continued, for "...it is capable of being removed and shifted with great ease from one place to another, which cannot be so readily done in furnaces that are set in brickwork. By this means it may, without great trouble, be adapted to this or that shaft of a mine, as occasion may require"[112].

Such a confluence of suggestive hints seems to indicate that the notion of mobility was very early in the air if not yet on the ground. In 1744, however, according to Pierre Mathieu (d.1778), Jacques Mathieu, his father, had attempted to use a "machine en bois" at the Elizabeth Dahiez trial shafts at Fresnes[113]. After they had been sunk 200 feet flooding caused both to be abandoned. Although this first trial was therefore less than successful, the idea was persisted with and despite a further failure at Anzin it seems likely that the difficulties (whatever they were) had been overcome by the 1750s. It is certain that trial shafts sunk at Oisy and St. Pierre in 1777 were drained by such machines and that they were then no longer a novelty[114]. Once the pit lining (cuvelage) had been successfully bottomed into the clay the lifting of water by means of "machines à feu fixes" was a relatively minor task. What is not clear is the form that these French mobile steam engines took.

Whatever conclusions may be drawn from Switzer's machine, it appears likely that such framed machines were also in use in England by the 1760s for Smeaton's design of 1765 for a "portable fire engine" for draining temporary structures, such as coffer dams for bridge foundations, seems to be a consciously made attempt to reduce their bulk and thus increase mobility still further. In the design of 1765 a wheel or large pulley some six feet in diameter took the place of the beam and permitted the platform base to be greatly reduced in size from, say, approximately 20 feet by 20 feet for Switzer's machine to 12 feet 4 inches by 10 feet 7 inches exclusive of boiler space[115]. A later design of 1777 shows that Smeaton had found it desirable to modify his original scheme. The internal flue boiler of 1765, standing to the side of the frame, was not persisted with, and was in 1777 replaced by one of conventional design standing likewise outside the framework. This latter consisted of two 'A' shaped members each 23 feet high and having a base of 27 feet. These stood 5 feet apart and supported the pulley axis[116]. Smeaton built a machine of this type for Long Benton Colliery in 1777 which, proving successful, was soon followed by others. They were used to raise water for wheel-driven winding engines. But Smeaton's machines were of modest size with cylinders of some 20 inches or so, and it is perhaps unlikely that the giant mobile engines of French Hainaut worked with pulleys. In his report on Anzin in the Journal des Mines of 1805 Daubuisson was to mention how, in order to overcome the monstrous flooding experienced in sinking the Bleuse-Borne shaft in 1783, three such machines were used simultaneously throughout the sinking and the construction of the cuvelage. Two were of 60 inches and one of 40. So powerfully did water pour in and so powerfully was it drawn off that the bed of the moat of the citadel at Valenciennes, two miles away, was laid bare, an unlooked for feat which "excita les plaintes du commandant de cette place"[117].

The mining areas which were the scenes of the earliest steam engine building activity in Europe have now been surveyed and the paradoxical situation that emerges will not have gone unnoticed. Whereas the prevailing standard of English technique was sustained and indeed improved upon by native engine builders in Slovakia only for such developing expertise to be cut short and rendered largely fruitless by reason of the energetic development of new types of hydraulically-powered engines, in the coal mines of the west, where the utility of the steam engine was as early recognized and the need for it was even greater, and where moreover competition from water-driven machines could scarcely develop, the art of engine building stagnated even if it did not actually regress. Evidently the establishment of the mining academy at Schemnitz in 1763 was only de jure recognition of the fact that a highly sophisticated and consciously critical tradition of machine building had long existed there[118]. Such a tradition was to be found also at Freiberg in Saxony which, following Schemnitz' lead, established its own Bergakademie in 1765[119]. But nothing of the sort was to be found in the coalfields of western Europe. Success in domesticating the techniques of steam engine building was in both the regions discussed, east and west, in another sense of the paradox a false beginning, for neither was to develop, as has been seen, as a centre in which the burgeoning of English mechanical art would be intelligently studied and followed as it advanced. The effective introduction of the steam engine embodying Watt's improvements into France was, as Ballot long ago remarked, effected by the Perier brothers with government backing at their Chaillot manufactory after 1778[120]. It was Chaillot which furnished the steam engines for that other great showplace of English technology, the iron works at Le Creusot in Burgundy (set up under the direction of William Wilkinson). In central Europe the first setting for the successful domestication of up-to-date (i.e. late 18th century) English technology in an ongoing fashion was Upper Silesia where the enterprise was the work of the Prussian government consciously fostering, as a matter of state policy, the creation of a complex of industries at Gleiwitz, Tarnowitz and Malapane, a Chaillot and a Le Creusot, as it were, rolled into one.

Overall the pattern of industrialization in 18th century Europe that emerges from these events, a matter of private capital in the low countries, of large-scale capitalistic enterprises encouraged by government support in France, and of state funded and directed enterprises in Slovakia and Silesia, offers striking confirmation (in the 18th century) of the similar pattern of industrialization which, according to Gerschenkron, characterized the intensive phase of the industrialization process as it developed in Europe in the 19th century. Gerschenkron's argument, in a nutshell, is that since the'pre-requisites' for an English type industrial revolution either did not exist or only existed weakly in Europe (he is thinking largely of capital requirements) the way in which the various continental industrial revolutions of the 19th century were launched necessarily took different forms, the forms conditioned by the degree of backwardness (or distance from the set of conditions necessary for a self-generating 'take-off' into industrial growth of the English type) in each of the economies involved. Each industrial revolution would, in other words, be largely <u>sui generis</u>[121].

One must note also that only where English technicians moved to Europe and were able to train native workmen did the steam engine prove a success. This study has surveyed the successes and not the failures that occurred in the course of the diffusion of the atmospheric steam engine[122].

But what is of greater interest than anything else is the fact that the steam engine during the 18th century and for much of the 19th was so symbiotically linked to the mining of coal that even in an extreme case such as Schemnitz it could not in any significant or lasting way break clear of the technological matrix in which it had first come to maturity. It was simply uneconomic to build such engines unless the product mined was coal, a fact recognized at the beginning of the 18th century by the Swedish Bergkollegium, and at its end by Monnet[123]. It is clear that it was the construction of railways in Europe, making possible the almost universal provision of coal at low prices, which finally permitted the steam engine to move beyond the limits of its earlier restricted palaeotechnical base. On such a view it was railways and steam locomotives which proved to be the solvent of the old sophisticated eotechnic pattern of water control and flow whether for the generation of power or the transport of wood fuel rather than the steam engine as a prime mover and a metallurgy based on mineral fuel. These on their own were quite impotent to disrupt the old order.

NOTES

1. A. Gerschenkron, Economic Backwardness in Historical Perspective, Cambridge (Mass.)1962, Chs. 1 and 2.

2. D.C. Coleman, 'An Innovation and its diffusion: the "New Draperies" ', Economic History Review, 2nd series, Vol. XXII, No. 3, 1969, p.429.

3. Numerous papers have, of course, been devoted to the history of single engines but none has attempted to study the diffusion of the atmospheric steam engine in continental terms. Two studies of particular value are, however, concerned with the subject on a regional basis: Part two of G. Decamps' memoir on coal mining in the Mons region of Imperial Hainaut, 'Mémoire Historique sur l'origine et les développements de l'industrie houillère dans le basin du Couchant de Mons: Depuis l'introduction des premières machines à vapeur jusqu'à nos jours', Mémoires et Publications de la Société des Sciences, des Arts et des Lettres du Hainaut, Vol. 41, 1889, and J. Vozar's study of steam engine building in Slovakia, 'English Mechanic Isaac Potter, constructor of the first fire-engines in Slovakia', Studia VII Historica Slovaca, Slovenskej Akademie Vied, Bratislava 1974.

4. See chapter four of this dissertation passim but especially pp. 266-267.

4.(i) The notion that there really were five hundred horses working the pumps at Griff colliery in 1702 has a venerable history, one long enough in fact for it to have achieved a global distribution. J. Desaguliers, _A Course of Experimental Philosophy_, Vol. 2, London 1744, p.482, states, however that fifty horses costing £900 per annum to maintain were at work there in that year. It was with J. Farey, _A Treatise on the Steam Engine, Historical, Practical and Descriptive_, Vol. 1, London 1827, p.128, misquoting Desaguliers and turning fifty into five hundred (but not the £900 into £9,000!) that the mischief began. Since then the myth of the five hundred has had a brilliant career no doubt because such a number is a highly impressive one to conjure with and has, manifestly, a certain rhetorical value for historians seeking to characterize, in rapid fashion, the crisis situation into which English mine owners were being remorselessly driven. E. Galloway, _History and Progress of the Steam Engine_, London 1831, p.22; D. Lardner, _The Steam Engine Explained and Illustrated_, London 1840, p.65; J. Bourne, _A Treatise on the Steam Engine_, London 1846, p.7, R.H. Thurston, _A History of the Growth of the Steam Engine_, London 1878, p.36; H. Frith, _The Triumph of Steam_, London 1892, p.27; C. Matschoss, _Die Entwicklung der Dampfmaschine_, Vol. 1, Berlin 1908, p.304; S. Lilley, _Men, Machines and History_, London 1948, p.92; D. Landes, 'The Industrial Revolution and After', _The Cambridge Economic_

History, Vol. VI, pt. 1, Cambridge 1965, p.326; and J. Majer, 'Fire and Water Column Engines in European Mining' Acta Historiae Rerum Naturalium necnon Technicarum, Vol. 7, Prague 1973, p.65, note 2, all mention Griff and follow Farey. (L. Beck, Die Geschichte des Eisens in Technischer und Kulturgeschichtlichen Beziehung, Vol. 3, Brunswick 1897, p.104, draws upon Desaguliers directly).

A moment's reflection, however, might have indicated the need for caution since a whole battery of Newcomen engines would have been required to replace such an enormous number of beasts no matter how meagre, and thus rendered a decision by the Griff owner to go over to steam pumping (had the possibility then existed) egregiously unsound. Apart from this, what mine owner in his right mind would ever have dreamt of replacing horses that were really as cheap to use (at £1.8 each) as the figures suggest? Desagulier's actual figure revealing the yearly cost of one horse as £18 compares very closely, it may be noted, with those obtaining at Königsberg (Nova Bana) in Slovakia in c.1724 which work out at nearly £19: sixty-four horses cost £1,215 per annum (10,800 imperial gulden). But see M. Triewald, Short Description of the Atmospheric Engine, Newcomen Society extra publication No. 1, London 1928, pp 30-31, for further details. The Victoria County History, Warwickshire, Vol. 2, London 1908, p.222, notes that at Bedworth Colliery in 1619, sixty-four horses employed in drainage cost £1,000 yearly (nearly £16 each). According to J.F. Lempe, 'Vom Nieder-Ungarischen Berg und Schmelzwesen im Jahre 1692', Magazin für die Bergbaukunde, Vol. 9, Dresden 1792, p.193, horses performed all the hauling and pumping at Schemnitz in 1692. Depending upon whether the horses were used in relays of three or four the numbers involved were 648 or 864. Some 500 were still employed there in the 1720s and it was to eliminate these that five Newcomen engines were built in 1732-38. Lempe, it may be noted, was drawing on an anonymous Probierbuch of 1692.

(ii) T. Savery, The Miner's Friend, London 1702, p.42.

6. The diffusion of the Stangenkunst (or machine hydraulique as it was invariably called) into France can be reasonably well dated: 1750 Poullaouen, 1755 Pontpean (both in Brittany), 1757 Carmaux (near Albi), c.1760 Huelgoat (Brittany) c.1776 Rive de Gier (Lyonnais). The engineers were either Germans or, in the cases of Pontpean and Carmaux, Frenchmen from the northern limits of French speech. The Stangenkunst was introduced into the Almaden mercury mine in Spain after 1775 by the Saxon engineer Hoppensack. The silver/lead mine at

Pouallouen interestingly enough abandoned steam pumping, begun in 1747-8, because of the high price of coal. The machine set up by Christophe Mathieu, director of the coal mines at Fresnes until 1738, worked well but cost 40,000 livres (£2,000) per annum in fuel. It was eventually sold to the duc de Chaulnes and moved to the coal mine at Montrelais (Ingrande) where it began working in 1756. It was of 52 inches and lifted water 600 feet through six repetitions of pumps.

7. A.G. Monnet, Traité de l'Exploitation des Mines, Paris 1773, p.213. It is notable that Monnet devotes only two pages (out of 348) to the "pompe à feu". He comments that its use "...ne peut être avantageux que dans les mines de charbon où l'on a le matière combustible nécessaire à un prix tres modique".

8. M. Rouff, Les Mines de Charbon en France au XVIIIe siècle 1744-1791, Paris 1922, p.333, The quotation comes from Mirabeau's Discours à la Constituante, 1791.

9. See pp.351-55 below where the nature of such portable engines is discussed.

10.(i) A. Barnes, View Book, 1733, archives of North of England Institute of Mining and Mechanical Engineers, Newcastle.

(ii) J. Desaguliers,op. cit., plate 34, fig. 9.

11. Something of the nature of the pattern of exploitation that developed has been indicated already in notes 6 and 7. The experience of steam engine working at Pouallouen no doubt discouraged further attempts to use such engines in mines of metals in France. Very extensive engineering works were undertaken subsequently at Pouallouen, Pontpean and Huelgoat in order to make full use of whatever water was available, thus avoiding dependence on steam engines. The cost of the installations at Pontpean, completed in 1755, amounted to some 600,000 livres (£30,000). It may be worth noting here what Gabriel Jars has to say concerning the abuse of steam engines in England. In Derbyshire he noted with disapproval the use of such engines, at great expense, in places where water was available to drive hydraulic engines cf. Voyages Métallques, Vol. 2, Paris 1780, p.546: "La facilité qu'on a en Angleterre pour la construction des machines à feu fait qu'on abuse communement de son usage, et qu'on les appliquer trop généralement par-tout où l'on a des eaux à élever...". He observes elsewhere that the opposite error was committed in Germany. Often adits were dug and leats were built where steam pumping would have been far cheaper. See Voyages, Vol. 1, Lyon 1774, p.319, for his comments on Dielau. Almaden had a steam engine by 1794 however supplied with coal

brought from the mines at Espiel eleven miles away. For further details see J.M. Hoppensack, Über den Bergbau in Spanien überhaupt und den Queck-Silber Bergbau zu Almaden insbesondere, Weimar 1796, p.98. In France it is notable that outside Hainaut only coal mines situated along the Atlantic coast such as Littry(1749), Chatelaison (c.1753) where there were three, Montrelais (Ingrande) (1756) and Nort (1772) regularly used steam engines. Some, if not all, were imported from England. M. Rouff, op. cit., p.356, "sauf sur les mines du Nord, la machine à vapeur n'était donc pas employé d'une manière courante". His discussion of the reasons for this slow diffusion is most illuminating. See especially pp352-356. At the back of this general continental reluctance to use steam engines, however (except in coal mines) lay the general crisis in fuel supplies caused by depletion of the forests. The 'fuel' needed by hydraulic engines was free. The ecological effects of deforestation were equally a cause of growing concern.

12. J.S. Allen, 'The Introduction of the Newcomen Engine from 1700 to 1733', Transactions of the Newcomen Society, Vol. XLII, 1969-70. Allen lists twenty-five engines built by 1720 with five more noted as probable.

13. A preliminary list would include Potter senior and his sons Isaac, Abraham and John, Thomas Newcomen,

John and Samuel Calley, Martin Triewald, John O'Kelly and his son, Stonier Parrott, Pierre Sabathery, Henry Beighton, George Saunders, Henry Lambton, Thomas Case, George Sparrow and Joseph Hornblower, and might perhaps be extended to include Fischer von Erlach and Jean Desaguliers.

14. M. Triewald, op. cit., pp 4-5, relates the story of the Spanish ambassador's toilsome and fruitless journey to Dudley to see the new machine, presumably in 1712 or shortly thereafter.

15. J. Vozar, op. cit.,(note 3),p.108, note 7.

16. Or so E. Kurzel-Rundscheiner, 'Die Fischer von Erlach'schen Feuermaschinen', _Beiträge zur Geschichte der Technik_, Jahrbuch des Veriens Deutscher Ingenieure, Vol. XIX, 1929, p.73, supposes.

17. E. Gerland (ed.), _Leibnizens und Huygens' Briefwechsel mit Papin, nebst der Biographie Papins_, Berlin 1881, letters 127 and 129.

18. According to J.N.S. Allamand, _Oeuvres Philosophiques et Mathématiques de Mr. G.J. 'sGravesande_, Amsterdam 1774, p.XXIII, note n, Desaguliers recommended Fischer von Erlach to 'sGravesande as "un très bon Méchanicien".

19. The text of the letter is reprinted in D. Hoffmann, 'Die Frühesten Berichte über die Dampfmaschine auf dem Europäischen Kontinent', _Technikgeschichte_, Vol. 41, No. 2, 1974, pp 126-8. The original MS

is in the possession of the Oberbergampt archive in Clausthal.

20. J.N.S. Allamand, op. cit., p.XXIII, note n. He appears to have built only one machine in Germany, a garden engine for the Landgrave of Hesse-Cassel in 1722. But see p.318 below for further details.

21. J. Vozar, op. cit., pp 109-110, establishes this chronology.

22. D. Hoffmann, op. cit., pp 126-130, reproduces the full text of both letters.

23. A suburb of Vienna, outside the walls.

24. For these drawings see D. Hoffmann, op. cit., figs. 4 and 5.

25. It is quite clear that von Erlach handed over a drawing of his own machine in the Schwarzenberg garden with all tell-tale details suppressed. Not only was von Guldenberg deceived but also those historians who have subsequently interested themselves in the matter.

26. Von Guldenberg is here guilty of gross exaggeration. The Königsberg engine cost 16,000 florins and had a 30 inch cylinder. The Schwarzenberg cylinder was of 24 inches. The florin was worth a little over two English shillings.

27. This is the earliest reference to the use of the steam engine for water returning purposes that I have been able to find.

28. Von Erlach's case was no doubt strongly buttressed by the experience of the Ungarische Gewerkschaft at Königsberg. The company, formed in 1723 to exploit the mine, decided to install a horse-driven pump (Ross-Kunst) alongside Potter's steam engine in order to compare their running costs. Horse pumping was found to cost 900 gulden a month (£90) against 400 gulden (£40) for steam pumping. Yet the sixty-four horses, used in four shifts of sixteen, were able to lift only 32 per cent of the quantity raised by the steam engine. Horses, on this showing, proved to be seven times more expensive, cf. M. Triewald, op. cit., pp 30-31, quoting Leopold's report of 1733.

29. Von Erlach's memorandum, delivered to von Guldenberg on 31st July 1725 is printed as appendix I in D. Hoffmann, op. cit., pp 125-6.

30. G. Kortum, 'Ausführliche Beschreibung derjenigen Machine, so zu Königsberg in Ungarn das Wasser aus dem Berg-werck hebet und durch Feuer getrieben wird, nebst einer Nachricht von dasigen Berg-werck', Miscellanea physico-medico-mathematica oder Curiöse Nachrichten von Physical und Medicinischen Geschichten, Breslau 1727, § XVI, p.572. Kortum's plate, p.560, is the first to show the engine with a double beam, absent in earlier illustrations. These are by: (i) J. Leupold, Theatrum Machinarum Generale, Vol. 1, Leipzig

1725, plate XLIV (Leupold had not seen the machine himself and relied on information supplied by von Erlach) and (ii) A.D. von Schönström c. 1724-25.

31. C. le Secondat, Marquis de Montesquieu, Voyages, (ed. A. de Montesquieu) Vol. 2, Bordeaux 1896, p. 256.

32. J. Vozar, op. cit.,(note 3). Vozar, who prints the full text of the Bericht as supplement No. 2, shows in detail the galling nature of Potter's experiences.

33. R.L. Hills, 'A one-third scale working model of the Newcomen engine of 1712', Transactions of the Newcomen Society, Vol. XLIV, 1971-2, pp 63-77.

34. A. Raistrick, 'The steam engine on Tyneside', Transactions of the Newcomen Society, Vol. XVII, 1936-7, p.153. As at Königsberg the horses lifted less than a third of the water raised by the steam engine and cost 20 per cent more to use.

35. Kortum, op. cit., p.571.

36. J. Voda, 'Ohňové stroje na Slovensku vo vývoji parných strojov pred Wattom v 18 storici', Z Dejín Vied a Technicky na Slovensku, Vol. 1, 1962, p.227, is quite wrong in making this assertion. The article is moreover far from secure in other respects.

37. G. Kortum, op. cit., plate facing p.560. It had in fact two safety valves. O'Kelly's drawing of

1725 shows this double system also, something not evident in Beighton's and Barney's engravings.

38. Ibid., § VIII, 2, pp 565-6. However, this alarming phenomenon could scarcely be remarked when the engine was running normally.

39. Ibid., p.566. This is the earliest example I know of where leather was dispensed with.

40. The steam engine at York Buildings retained the buoy pipe (Sutton Nicholls' engraving) which suggests that flame coursing was not a feature of the boiler design. The question of boiler design brings to mind Triewald's assertion that Newcomen was lamentably ignorant on this point and thought that steaming capacity was related to boiler volume and not to boiler shape. Triewald, like von Erlach, was to claim great credit for the 'invention' of flame coursing. Both were deceiving themselves in claiming priority. Savery in 1702 had already clearly described the idea which, as he remarked, was a feature of brewers' kettles. Johann Becher, Närrische Weissheit und Weise Narrheit, Frankfurt 1682, pp 127-130, in his 51st conception (Holzspar Kunst) refers to a book of this title (actually F. Kessler's Holzspar Kunst, Oppenheim 1618) which is concerned with this very matter. Becher's own contribution to the subject was the idea of a diagonal line circular flue "...so wolte ich gar eine Spiral-Linie machen so hoch der Ofen ware".

41. G. Kortum, op. cit., VIII 16, pp 158-9.

42. G. Jars, op. cit., Vol. 2, Paris 1780, pp 158-9.

43. Unequal levers must once have been universal in Europe, that is as the throwing arms of trebuchets. J.C. Höll's Hebelmachines working at the Siglisberg shaft at Windschacht from 1738 to 1742 had unequal arms (3:1). His first such machine was built in 1734 so that it seems fair to conclude that the steam engines themselves could have been so adapted had it seemed advantageous.

44. E. Grar, Histoire de la Recherche, de la Découverte, et de l'Exploitation de la Houille dans le Hainaut français, dans la Flandre française et dans l'Artois, 1716-1791, Vol. 2, Valenciennes, 1848, p.225, note 2.

45. J.G. Keysler, Neueste Reisen durch Deutschland, Böhmen, Ungarn, die Schweiz, Italien und Lothringen, Vol. 2, Hanover 1751, letter LXXXIV, Reise nach den Ober-Ungarischen Bergwerken, p.1277, states that Potter's engine had been able to clear in eight hours all the water accumulating in twenty-four. Keysler visited Königsberg in 1730 after the mine had been abandoned. Like Kortum he stresses the part played by von Erlach in making the machine a success. Potter would scarcely have managed without his help he says: "...wurde es aber ohne Beyhulf

der Kaiserlichen Baumeisters Fischer... schwerlich vollendet haben". The English translation of Keysler's travels, of 1757, softens the tone of this remark.

46. J. Vozar, op. cit., p.128.

47. Fear of a Turkish return was long past, and colonization of what had been largely deserted frontier lands to the south east was proceeding quickly by this time.

48. K. Kurzel-Rundscheiner, op. cit., (note 16), p.77, takes this quotation from the Schwarzenberg office accounts for 1723.

49. <u>Das Merckwürdige Wienn oder Monatliche Unterredungen</u>, 1727, pp.67-82.

50. J.F. Weidler, <u>Tractatus de Machinis Hydraulicis toto terrarum orbe Maximis</u>, Wittenberg 1728, pp 90-91.

51. J.B. Küchelbäcker, <u>Allerneuste Relation vom Rom Kayserl. Hof, nebst einer ausführlichen historischen Beschreibung der Kaiserlichen Residenzstadt Wien und der umliegenden Örter</u>, Hanover 1730, Ch.X, p.772 ff. Küchelbäcker remarks (p.773) that the boiler was like a brewer's kettle, "wie ein Brau-kessel".

52. <u>Das Merckwürdige Wienn...</u>, p.74.

53. Ibid., p.76.

54. The earliest flexible arm ball-cock awaiting its later apotheosis?

The tank was supplied by back pressure from the rising pipe feeding the header tank.

55. Das Merckwürdige Wienn, p.82, and the authors add dutifully, von Erlach's invention of fire coursing. The machine ran for some years but was said to be 'out of action':"ganz verdorben" in 1770. No one could be found to repair it and it was finally scrapped in 1779.

56. It is accepted by C. Matschoss, op. cit., (note 5), p.145, who states that it broke down in 1765 but without citing any sources.

57. J.N.S. Allamand, op. cit., (note 18), p.XXIII, note n. Although Allamand talks of 'sGravesande being familiar with the atmospheric engine, it should be noted that his source, Desaguliers, op. cit., p.484, talks only of the experiments he had made with 'sGravesande in 1716 in improving the Savery engine. Nevertheless it seems highly unlikely that he failed to induct him into the working of the atmospheric engine as well for, as he says, 'sGravesande "...then did me the honour to go through a course of Experimental Philosophy with me".

58. The Oxford English Dictionary, Vol. VI, Oxford 1961, p.568, makes it clear that it was contemporary English usage also to use the word'model' in the sense of 'copy' (i.e. not a small scale model) to which a further word like "small" would have

to be added to yield the latter sense.

59. The search was unsuccessful. J.G. Keysler, op. cit., Vol. 2, Hanover 1751, p.1274, remarked that the country around Schemnitz afforded a kind of mineral-like coal but which was far from being inflammable when laid on other burning coals. This was what poor Potter found and tried to burn but it burst into splinters when put on the fire. The need to find coal was evidently being sharply felt. Keysler earlier notes that though the neighbourhood abounded in wood the mine officials had begun to fear a shortage. Three hundred and fifty loads of charcoal were consumed each week in the furnaces despite the fact that it was already the practice to send the leaner ores to Kremnitz for smelting. Keysler visited Schemnitz in 1730.

60. N. Poda, Kurzgefasste Beschreibung der, bey dem Bergbau zu Schemnitz im Nieder Hungarn, errichteten Maschinen nebst XXII Tafeln zu derselben Berechnung; zum Gebrauch der, bey der Schemnitzer Bergschule, errichteten mechanischen Vorlesungen, Prague 1771. Poda notes, p.36, the historical progression from hand pumps, "...man zahlete mehr als 1000 Kunstzieher" to horse pumps and finally to steam and water pressure engines. The Bergschule was raised to the status of an academy in 1770.

61. J.J. Ferber, Physikalische-Metallurgische

Abhandlungen über die Gebirge und Bergwerke in Ungarn, Berlin/Stettin 1780, pp 68-69, makes a number of interesting observations on the distinctive mining vocabulary employed at Schemnitz (as compared with Saxony). In the Slovakian mines a horizontal gallery leading off a shaft was called a *Kreuzgestänge* even where there was no machine at all. A *Kreuzgestänge* was literally a cross rod, a device for redirecting down the shaft the motion of the horizontal rods reciprocating in the gallery (moved by a water wheel at their far end). The word *Lauf* or *Laufe* was used instead of *Gezeugstrecken* or pump rod gallery.

62. M.C. Lipold, 'Der Bergbau von Schemnitz in Ungarn', *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichanstalt*, Vol. XVII, No. 3, 1867, p.370. The drainage gallery emptied into the Hodritz brook, a tributary of the Gran (Hron) rather over three miles to the west of Windschacht.

63. G. Jars, op. cit., Vol. 2, p.60. He notes that their injection water was drawn from two specially constructed high level reservoirs thus avoiding the loss of power involved in having the machines pump up water for this purpose. Not a trick was missed at Windschacht.

64. Ibid., pp 162-164. The Reichauer dam, a considerable structure some 95½ feet high, and its associated works had cost 821,867 livres (nearly £41,000).

65. The kinematics of this machine are discussed in chapter three, pp.163-64.

66. Its beam, as has been noted, was unequally poised. A detailed description of its modus operandi is given by J.G.Krünitz, Oekonomische, Technologische Encyklopädie, Vol. LV, Berlin 1801, pp 299-300, and figure 3284.

67. These calculations are based on the figures given by N. Poda, op. cit.

68. J.G. Keysler, op. cit., letter LXXXI, p.1226.

69. The text of the letter is printed by P. Delrée, 'À propos de l'introduction des machines à vapeur dans la region Liègeoise', Chronique Archéologique du Pays de Liége, Vol. 53, 1962, pp 114-115.

70. G. Hansotte, 'L'Introduction de la machine à vapeur au pays de Liége (1720)', La Vie Wallonne, Vol. XXIV, 1950, p.51.

71. A considerable feat judged by the experience of the team who built the one-third scale model at Manchester (note 33).

72. G. Hansotte, op. cit., p.49.

73. Péry is some 2,000 metres west of Groumet. Lambert Rorive set up the second Liége engine at the delle Paix pit at Montegnée, only a few yards from Groumet, in September 1738. Water for injection and for the boiler was so scarce that it had to be carted in from neighbouring ponds (flots:étangs). When these were exhausted there was nothing for

it but to use sump water from the mine. This, however, formed such a thick crust in the boiler and the cylinder that the machine had to be stopped every two days in order that they should be chipped clean, a task which took three or four men from twelve to fourteen hours.

74. C. Bjorkbom, 'A proposal to erect an atmospheric engine in Sweden in 1725', Transactions of the Newcomen Society, Vol. XVIII, 1937-8, pp 75-85. F. Kraft de la Saulx, 'Un projet de construction d'une machine à vapeur en Suède en l'an 1725'. Association Française pour l'avancement des sciences, comptes rendu, Liége 1939, pp 1291-1299. Both are translations of Bjorkbom's original Swedish paper, 'Ett projekt att byggn en Ångmaskin i Sverige år 1725', printed in Daedalus: Tekniska Museet Arsbok, Stockholm 1936. The French version is to be preferred since it contains additional material not present in Bjorkbom's English paper, notably the reply of the Swedish Bergkollegium to O'Kelly's proposals.

75. O'Kelly's rules of proportion were based on the numbers seven and nine. These rules, or something like them, lie behind Beighton's table of 1721, and his insistence on the ignorance of most "who pretend to be engineers". What was needed was the skill to reduce the "physico-mechanical part to

numbers when the quantity of weight or motion is given". But see note 78 below.

76. False presumably because such prints as Beighton's, Barney's or Nicholls' showed the by now outmoded buoy pipe. Perhaps also as Bjorkbom suggests, they all contained deliberate ambiguities in order to fox would-be plagiarisers.

77. The original French version of O'Kelly's letter is printed in both the English and French translations of Bjorkbom's article. O'Kelly was, at this time, on the point of leaving Amsterdam for London in order to complete a contract to erect an engine in the Biscay region for the Spanish government.

78. Kraft de la Saulx, op. cit., pp 1296-98. The Bergkollegium's third objection seems well grounded in the light of subsequent experience with steam engines at Dannemora (1728) and Persberg (1767). The Bergkollegium's report throws light also on O'Kelly's rules of proportion. The weight of water and pump rods is divided by nine if the depth is 50 toises (335 feet) and by seven if the depth is 100 toises. One then extracts the square root of the number resulting which will be the diameter of the cylinder requisite for the work.

79. H. Hasquin, Une Mutation: le pays de Charleroi aux XVIIe et XVIIIe siècles, Brussels 1971, p.138.

80. E. Sabbé, 'Les archives de Vedrin et de Marche-

les-Dames', Annales de la Société Archéologique de Namur, Vol. XLII, 1936, pp 65-90. Sabbé drew chiefly on the Arenberg papers which constitute a kind of substitute archive.

81. E. Sabbé, op. cit., p.68.

82. Ibid, p.73.

83. P.L. de Saumery, Les Delices du païs de Liége, Vol. 2, Liége 1740, p.137.

84. G. Jars, op. cit., Vol. 2, p.558. Annual production at the time of Jars' visit in 1765 was running at 600 milliers (289 tons).

85. He was then about sixty years old. In 1737 he had requested the conseil de Namur to grant him a privilege for the construction of water-returning engines in the county of Namur.

86. G. Jars, op. cit., Vol. 1, p.286. "...le nombre en augmentera immanquablement dans la suite, puisqu'il faudra toujours aller chercher les veines les plus inférieures". According to T. Gobert, Liége à travers les âges, Vol. 3, Liége 1926, p. 316, note 3, in 1773 "on comptait pour Liége et les alentours plus d'une douzaine de pompes à feu".

87. L'Encyclopédie, Vol. VI, Paris 1756, p.608.

88. The etymology supposedly derives from bures: pits. Bure originally meant the shed covering the shaft.

89. In 1697 the Intendant of Hainaut (then all French) drew the attention of his government to the problem. The mines near Mons were already over 200

feet deep and the peasants who worked them were too poor to set up adequate pumping machinery. Richer men ought to take a hand in affairs as they did at Liége by financing the construction of hydraulic engines. At Wasmes, where this had been done, the miners had worked without fear of water since 1695.

90. G. Decamps, op. cit., (note 3), pp 8-9.

91. Ibid., p.18.

92. Ibid.,p.22.

93. Ibid., p.22. It pumped water from 45 toises (300 feet).

94. Ibid., p.23. Both pumped water from 50 toises (335 feet). Six societies joined together in making this agreement with Behault.

95. <u>L'Encyclopédie</u>, Vol. VI, Paris 1756, p.608.

96. G. Decamps, op. cit., pp 25-26. H. Hasquin, op. cit., p.142, supplements Decamps' inadequate total for Charleroi but points out that there were still further engines at work outside the administrative boundaries of the pays. He quite rightly warns, however, against taking numbers of engines in isolation as the measure of a region's economic development.

97. J. Monoyer, <u>Les Villages de Houdeng, Geognies, Strépy depuis leurs origines jusqu'à nos jours</u>, Mons 1875, p.19. This was the engine at Houdeng-Geognies. The next was set up in 1779 at Houdeng.

98. R. Darquenne, 'Histoire Économique du départment de Jemappes', Mémoires et publications de la Société de sciences des arts et de lettres du Hainaut, Vol. 79, 1965, p.48. "Cet isolement funeste avait souvent engendré des situations facheuses". Perhaps the most farcical case was that of the aptly named Petit-Profit mine, situated in a suburb of Charleroi, which followed a vein underground into the territory of Liége for "par un aberration de la legislation douanière, ils étaient astreints à payer un droit d'entrée sur leur propre charbon".

99. Condensing engines of the Watt type were not favoured precisely because they demanded a level of technical accomplishment far above what was available in the region.

100. A.E. Musson and E. Robinson, 'The early growth of steam power', Economic History Review, 2nd series, Vol. XI, No. 3, 1958-59, pp 418-439.

101. M. Gillet, 'L'age du charbon et l'essor du bassin houiller du Nord et du Pas-de-Calais', Charbon et sciences humaines, Paris 1966, p.27. The "terrain inexploré" was, of course, the left bank of the Escaut, between Condé and Valenciennes.

102. A. Lequeux, 'Les prospections houillères dans la France du nord et leurs conséquences humaines', Revue du Nord, Vol. XL, 1958, p.323. Lequeux notes, "la frontière est, et c'est infiniment

gênant, une coupure juridique, financière et économique'. He also draws attention to the great contrast in the character of the mining enterprises either side of the frontier: on the Austrian side peasant colliers, on the French, "...avant la lettre, des oeuvriers de la grande industrie moderne sans lien marqué avec le passé, isolés par rapport a leurs employers, detaché dans une large mesure du milieu rural environnant".

103. J.F. Daubuisson, 'Description des houillères d'Anzin', Journal des Mines, Vol. 18, An XIII (1806), pp 119-146, gives an admirable description of the region's geological structure. The veins were mostly vertical and mostly very thin. Although the coal was often of good quality it was very friable, and Daubuisson notes that despite all precautions good sized coals amounted to scarcely a tenth of what was extracted. Veins thinner than twelve inches were not worked.

104. The Fresnes coal was only good enough for use in brick and tile manufacture.

105. E. Grar, op. cit., Vol. 3, p.47, note 3, quotes from Léonard Mathieu's Histoire de l'entreprise, "une veine droite, superbe, appelée la Grande Droiteuse, sur laquelle la fosse avait été par le plus grand hasard le plus heureusement placé". Léonard Mathieu (1746-1805) was the son of

Jacques Mathieu's eldest son Pierre.

106. J.F. Daubuisson, 'Du picotage et du cuvelage des puits dans les houillères d'Anzin', _Journal des Mines_, Vol. 18, An XIII (1806), pp 160-170. The technique of 'square tubbing' is believed to have been invented by Pierre Mathieu (1704-1778).

107. C. Bossut, _Traité Elémentaire d'hydrodynamique_, Paris 1775, p.136, "sans cette circulation... l'eau...ne s'échaufferoit point, suffisament pour produire la grande quantité de vapeur dont on a besoin".

108. E. Grar, op. cit., Vol. 2, p.225, note 1.

109. Ibid., p.225, note 2. It may be significant that this was one of the deepest pits at Anzin. Opened in 1764, it was eventually sunk to over 1200 feet.

110. In English writing the only references to such machines seem to be those given by J. Farey, op. cit., (note 5), Vol. 1, pp 257-262 and pp 299-304.

111. S. Switzer, op. cit., Vol. 2, London 1729, plate 25 and Chapter XXIX, p.335 ff.

112. J. Allen, op. cit., p.15. In 1744 de Gensanne proposed modifications in the Savary engine so as to render it more easily portable.

113. E. Grar, op. cit., Vol. 2, p.225. The Elizabeth Dahiez shafts lay 2,000 metres west of Condé. Grar is here drawing on Pierre Mathieu's MS _Mémoire sur l'établissement de l'entreprise_.

114. Ibid., Vol. 2, p.226, Oisy and St. Pierre lay to the north west of Valenciennes.

115. Reports of the late John Smeaton F.R.S., Vol. I, London 1812, p.227.

116. Ibid., Vol. II, London 1812, p.435.

117. J.F. Daubuisson, op. cit., p.164.

118. Largely the creation of Mathias Höll, Oberkunstmeister at Schemnitz, and his son Joseph Höll (1713 - ?1785), later Oberkunstmeister of the Hungarian mine towns. For a brief biography of J. Höll see C. von Wurzbach, Biographisches Lexikon des Kaiserthums Österreich, Vol. 8, Vienna 1862, pp 261-2.

119. Saxon engineers were in charge of many of the great mines in France and Spain. Denmann and his successors Koenig and Brollmann managed Poullaouen and Huelgoat. Hoppensack was called to Almaden.

120. C.Ballot, L'introduction du machinisme dans l'industrie française, Lille/Paris 1923, p.396.

121. A. Gerschenkron, op. cit., (note 1) chs. 1 and 2 passim.

122. Failures naturally tend to leave few traces but a number of instances may be listed summarily: Dannemora, Sweden (1728); Bernburg, Saxony (1745); Persberg, Sweden (1767); Grisborn, Lorraine (1773); Altenweddingen, Saxony (c.1775); and Hettstedt, Silesia (1785).

123.(i) See p.333 above.

(ii) A.G. Monnet, op. cit., (note 7), p.213,
"...dans un mine métallique...les frais...
de consummation pourraient bientôt ruiner
I'entreprise".

Chapter Six

THE SECTOR AND CHAIN: AN HISTORICAL ENQUIRY

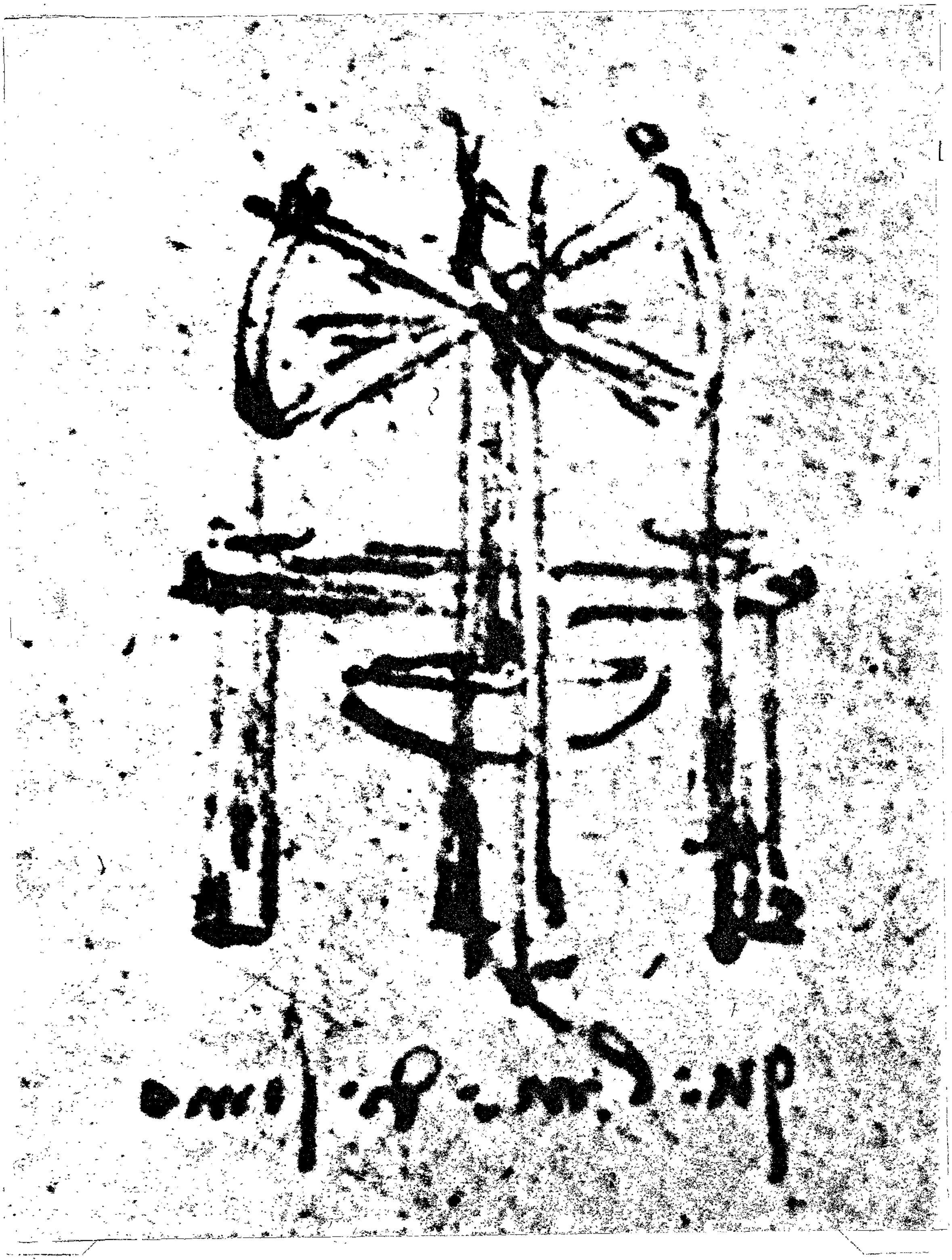
The idea that machines, like genera and species in the natural order, might be subject to processes of change of a quasi-evolutionary nature is scarcely novel and yet very little has been done to throw light on how, when one has divested the question of metaphorical distortion, the process might work itself out, what its significant features might be and its modalities[1]. This is perhaps the more surprising because such an approach, when addressed to the problem of the evolution of tool forms, showed long ago what a rich field was waiting to be exploited[2]. As with tools, so with machines: might not one expect to achieve comparable insights into the nature of invention and the importance of gestalt forms?[3]. Such considerations seemed sufficient reason to pursue the history of a simple yet elegant device, the sector and chain, which was to be exploited in a steadily widening series of applications because of the valuable property it possessed of permitting two different sorts of motions, circular and straight line, to be coupled in a continuously connected kinematic arrangement. An analogous device, the sector and rack, will also be touched upon but no more than lightly since only a separate treatment would permit its own interesting history to be dealt with adequately. It might be as well, at this point, to mention also that the modern term sector and chain is rather anachronistic. Before the period of the

Newcomen engine it would be more accurate to talk of sector and rope: certainly there are no sectors and chains in Leonardo's manuscripts.

It would, however, be of slight interest to consider any transmitting mechanism apart from the motor machine and the mechanized tool associated with it, and in fact the device has a wider interest. It was always associated with a machine type that was, no matter what modifications might be made to it (for the sake of having it run by an inanimate prime mover for instance) always of the balance beam or swape type: and this is as true of the latest manifestation which this enquiry will record, of c.1795, as it is of the earliest. Also as constant a feature, at least until the 18th century, was its employment as a component of pumping machinery. Beyond dispute the kinematic properties of the sector and chain were valuable, and one has only to look at Francesco di Giorgio Martini's earlier approach to the problem[4] to appreciate its economy: but in any case its survival in the inventories of engineers through three centuries is sufficient evidence of that. An interesting question, but one too vast to address here, would be to consider why this means of converting oscillating motion into rectilinear motion should have been preferred before other methods.

The sector and chain device was invented by Leonardo da Vinci, or so much may be said provisionally since I have not been able to find any earlier evidence for the combination. It would appear in addition to be

Fig. 1.

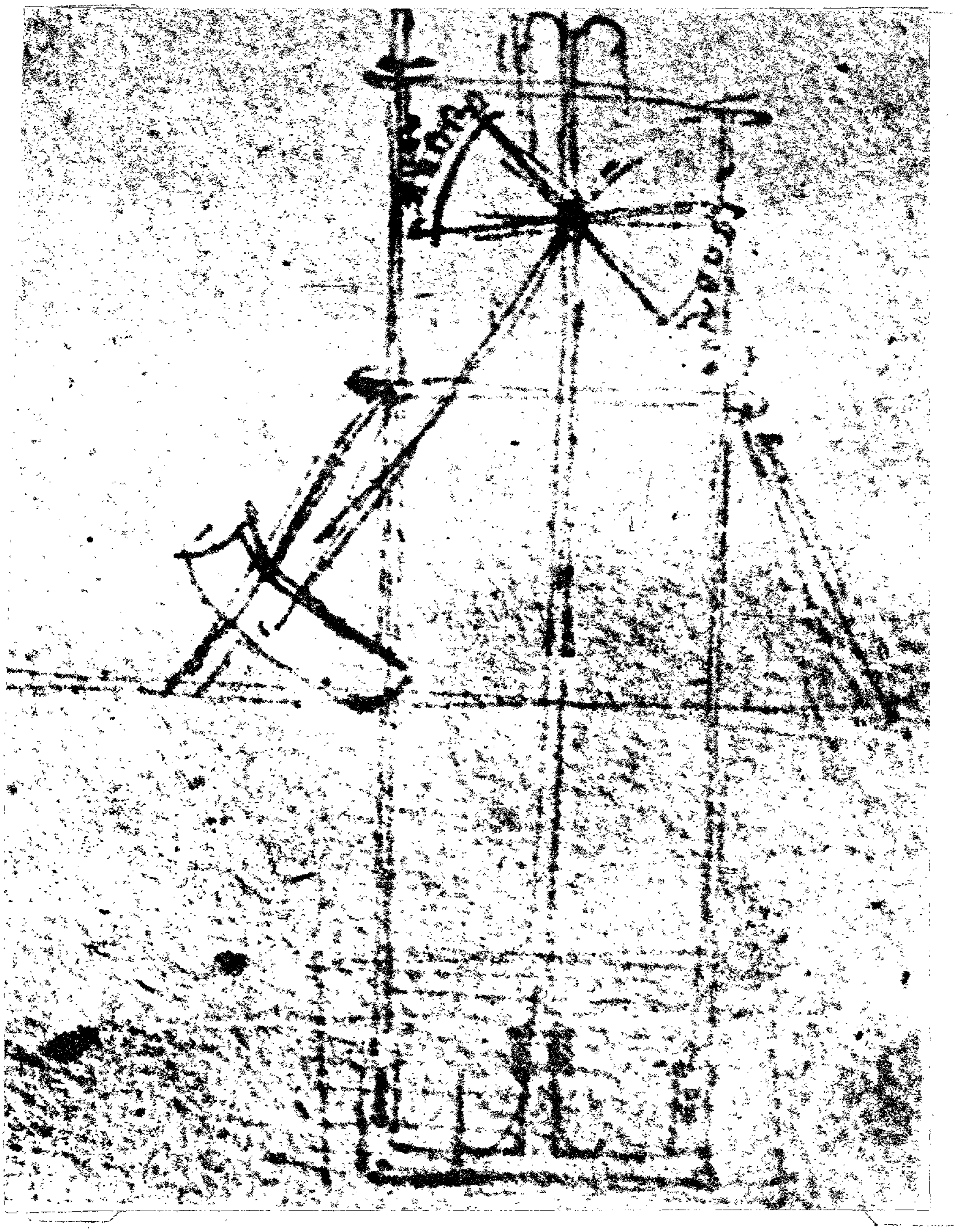


Pendulum pump, 'dalzare acqua'.
Source: L. da Vinci, MSB (1488-89) f54r.

one of the earliest of his inventions that we know of since the device appears in MS.B., of 1488-89, the oldest of the codices which can be dated, although examples do occur in some of the later MSS as well, one of which, f76v in MS.L., it will be instructive to look at in due course. It is scarcely possible, in the nature of the case, to date drawings in the Codex Atlanticus although there are two sketches there which must be considered and which in a sense, as I hope to show below, might be considered as logically prior to part of MS.B. even though this probably cannot be established with certainty in any chronological sense. To have done with citation once and for all the group of Leonardo's drawings that I wish to consider are: MS.B. f6v, f20r, f53v, f54r, f70r, MS.L. f76v, C.A.f16v.c., f57v.a., f392r.b., and Codex Forster f45r.

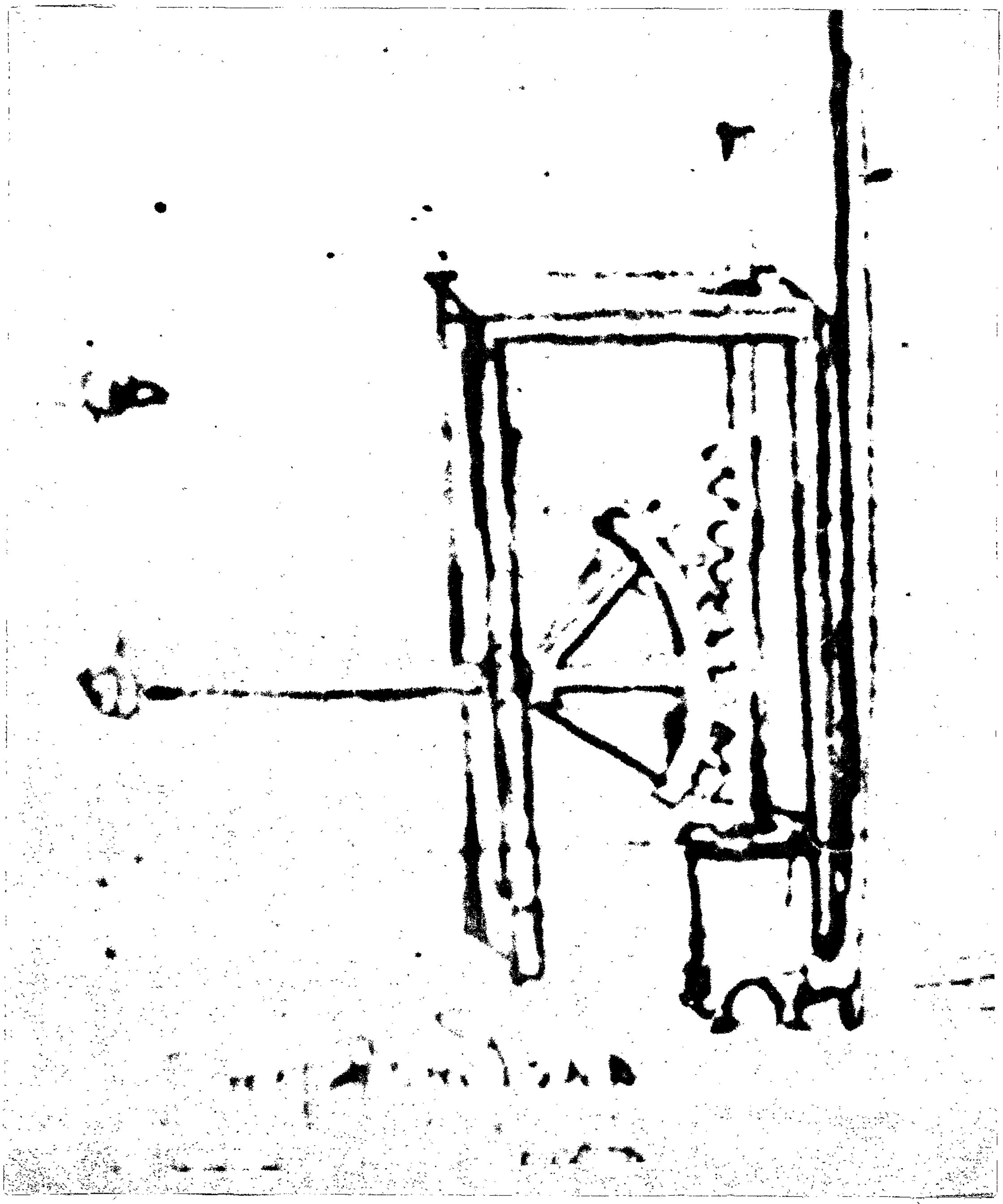
In MS.B. the drawing f54r of a pendulum operated rocking beam, "dalzare acqua", (fig. 1) shows the sector and chain idea very clearly: as each end of the beam, which is really nothing more than two sectors put apex to apex, lifts it raises the piston of a suction pump which, once it has reached the maximum of its upward excursion, falls back under gravity. This may be taken as the classic expression of this sort of pump, and seems to have provided the model which an engineer such as Thomas Newcomen, for example, was to follow some two hundred years after Leonardo's initial statement of it. An earlier drawing, f20r, in the same MS, of a pump, "da

Fig. 2.



Pendulum pump with racks and sectors.
Source: L. da Vinci, MSB (1488-89) f20r.

Fig. 3.

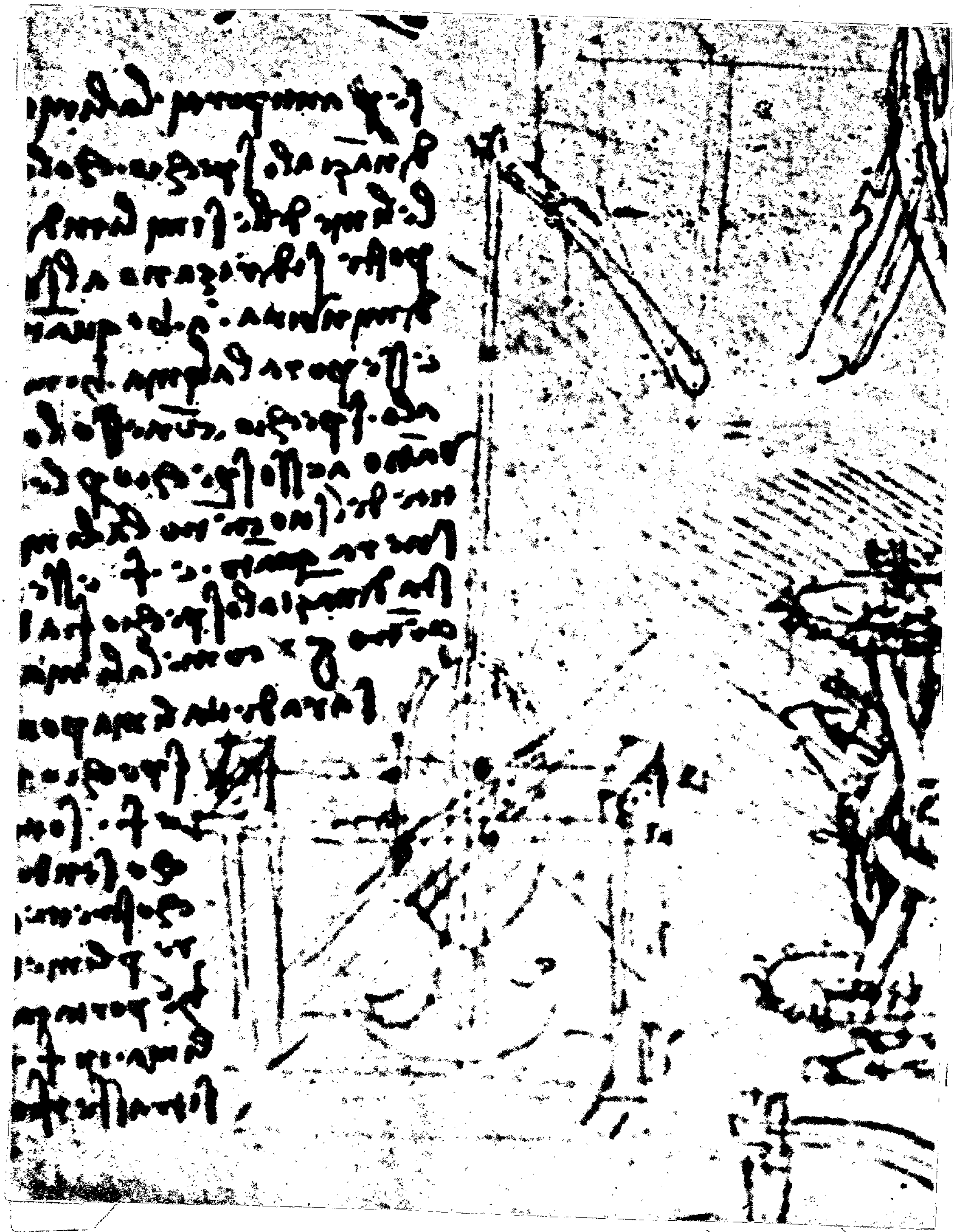


Rack and sector driven force pump, 'E possi fare concorda come con rota dentata'.
Source: L. da Vinci, MSB (1488-89) f53v.

fare montare acqua", (fig.2) shows the form the pump had to take when the pistons were of a Ctesibian valveless type where water was to be forced to a height rather than lifted from a depth. In this situation both excursions of each of the pistons needed to be performed under power, and the attractiveness of this model was to make itself felt as late as 1779 for it was with such racks and sectors that Matthew Wasborough was to experiment and which Watt himself was to employ until 1786[5]. But Leonardo had also sketched in MS.B. f53v a machine with a single rack and sector (fig. 3) and written beside it: "E possi fare con corda come con rota dentata" :"And one can make it with ropes as well as with a toothed wheel". Although it is to anticipate somewhat, it may be noted here that the idea of doubling the rope in the sector and rope/chain device so as to render it capable of pulling in both directions was also to commend itself to engineers after Leonardo's time. Curiously enough, the sources which disclose the continuing employment of the sector and chain reveal also, in two instances, the use of the double rope device[6].

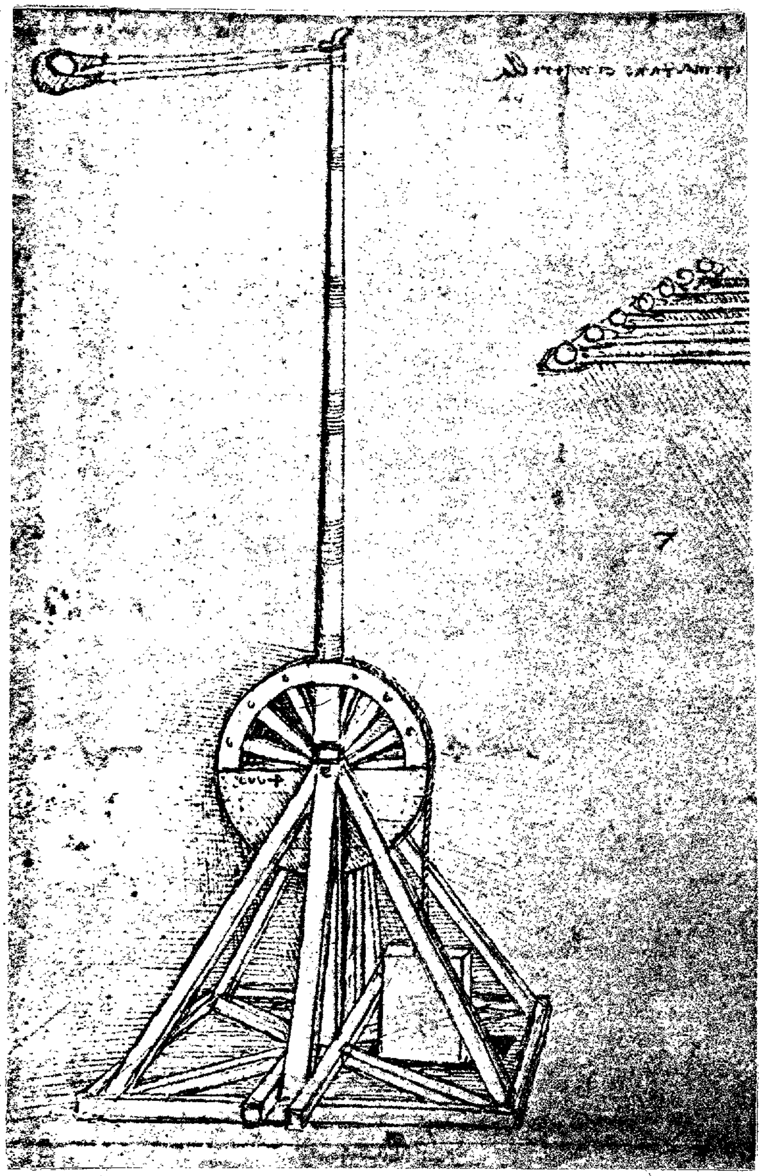
But where had the sector and rope/chain come from? It seems to me that if one is to make any attempt to explain the genesis of B f54r (fig. 1) one has to look at the repertory of machine types with which Leonardo had presumably become familiar in his early years as an engineer. One of these was certainly the manganon, a type of trebuchet such as one finds in the <u>Liber Tertius de Ingeneis...</u> of

Fig. 4.



Manganon of Taccolan type with toothed traction wheel.
Source: L. da Vinci, MSB (1488-89) f6v.

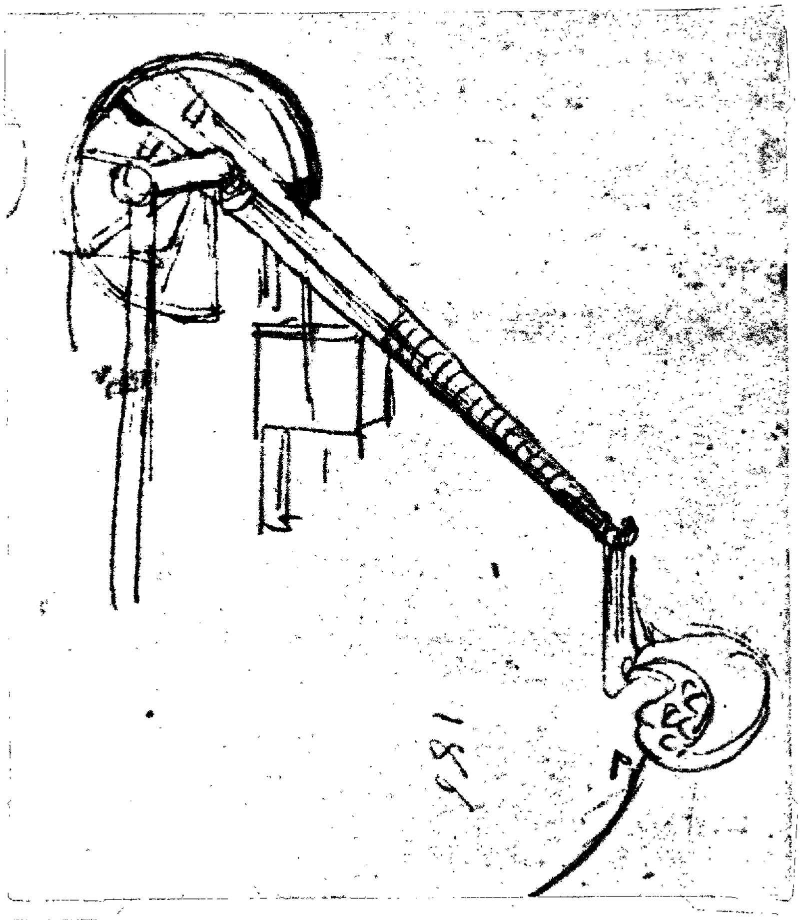
Fig. 5.



Manganon with weighted complete wheel
and counterweight.
Source: L. da Vinci, Codex Atlanticus, f57v(a)
c. ?1488.

Taccola composed about fifty years before Leonardo's time[7]. In such an engine the axle to which the trebuchet arm is fixed was loaded with weights in such a way that at rest the sling arm was in the vertical position and would obviously need to be wound down before the machine could be loaded and fired. All this Taccola shows us clearly enough. In Leonardo's hands, however, the machine was undergoing development. Evidently he was dissatisfied with it. In MS.B. f6v (fig. 4) he provided the throwing arm with a wheel, and although the latter is shown without ropes, such were evidently intended, as is indicated by the pegs protruding from the rim of the wheel. The throwing arm and its weight were to be drawn down into the firing position by tractive effort exerted on the wheel although whether this was to be applied from beneath or from the side is difficult to determine. At least, however, the separate elements of Taccola's machine (the rollers and the winch) had been rationalized (or so it would appear) in Leonardo's wheel manganon. But modification once begun the process could be carried further. Consider the modus operandi of Leonardo's wheel trebuchet in the Codex Atlanticus, f57v.a. (fig. 5). The latter is shown as a complete wheel but with a lower half of solid construction (the previously separate weight). A cord is secured round the rim of the wheel, and its 'free' end, hanging down, is attached to a block which in the drawing is 'frozen' just as it is on the point of disappearing through the trap beneath it. The trebuchet arm

Fig. 6.



Manganon with three-quarter wheel and counterweight.
Source: L. da Vinci, Codex Atlanticus, f16v(c), c.?1488.

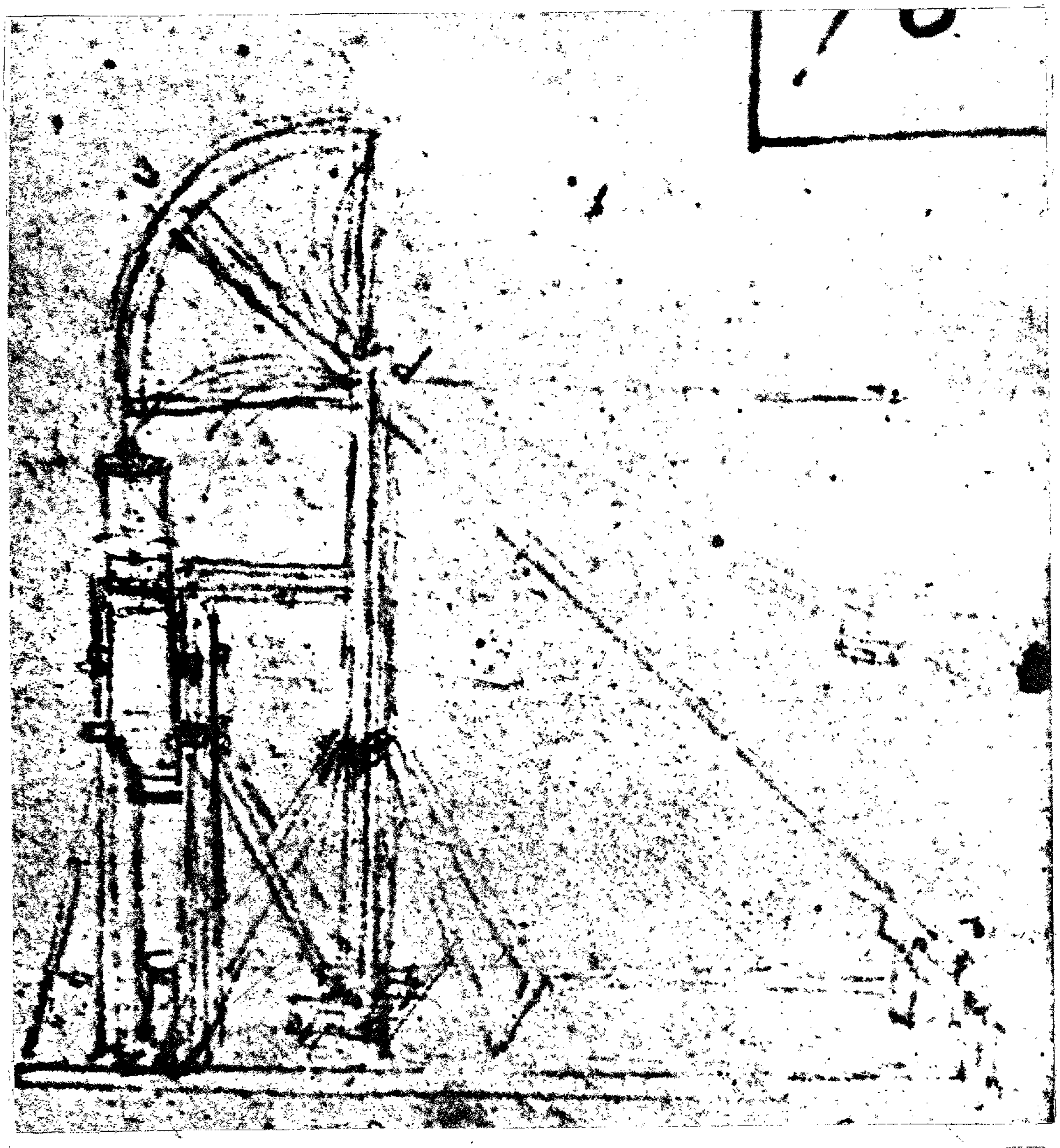
has been jerked violently upward, and its sling cords, pulled out straight behind it, are on the point of discharging the missile. Leonardo does not show how the machine was to be got ready for firing in the first place although it seems reasonable, in view of his other drawings, to suppose that a rope hanging down on the opposite side of the wheel from the weight would be pulled upon by the crew. But did the attached weight, evidently added to increase the firing power of the machine, now make such a solid and bottom heavy wheel unnecessary? Perhaps in fact its construction, once the weight had been hung from it in this way, needed to be made as light as possible since the importance of the wheel would now reside hardly at all in its weight but rather in its function as a <u>rope-carrier</u>. It can scarcely have escaped Leonardo's notice that movement is greatest at the periphery of a wheel and that the largest possible fraction of the counterweight part of the apparatus should be concentrated where the pull, resulting from the sudden release of the block, would be vertically downwards. It is at this point that it becomes important to examine another drawing in the Codex Atlanticus, the trebuchet in f16v.c. (fig. 6). If we pursue the idea of the wheel as a rope-carrier, it is evident that one quarter of its circumference (the quarter missing in f16v.c.) can perform no function at all in this respect so that now there would be every reason to remove it[8]. In the three quarter wheel there was indeed some positive advantage in doing this since it ensured that the attached weight, able to be raised higher, should fall from a greater height. This extra fall was important because Leonardo now planned that the throwing arm should describe an arc about twice as great as that travelled by the arm of the previous machine. The positions of the weight and the sling make it obvious that the arm must move clockwise through something like 180° as the weight falls. In C.A. f16v.c. (fig. 6) the machine is not shown discharged but is either in the cocked position and ready for firing or, more probably, at an instant after release since the counterweight could not be raised very much more before it and the advancing lower edge of the sector began to foul each other. The rope on the pulling side of the wheel would seem to have been previously drawn down from beneath. Nevertheless what we actually see, since Leonardo chose to draw it in this particular position, is a machine that in some respects is like f57v.a. (fig. 5) turned upside down. Even if the new type of trebuchet was never constructed it would not require prolonged inspection of the sketch* to see that the reversal might go further and that the alternate pull on either side of the wheel from beneath by means of cords in order to swing the trebuchet arm might with advantage be put into reverse: why should not the arm be swung to produce an alternating upward pull on the ropes and consequently upon whatever was attached to their ends? In this general post of all the

*Rather indeed a spontaneous flash or moment of eureka.

elements why should not the throwing arm turn into a pendulum, whose movement would cause the wheel to oscillate?(its bag of stones to provide momentum is already there). This movement would cause the cords hanging from its sides to be pulled alternately upwards and thus work, as it might be, suction pumps to which they were attached. Another quarter of the circle becomes redundant, producing the symmetrical shape of B. f54r (fig. 1) while at the same time the protean swape re-emerges from the form in which it had, so to speak, lain concealed in Taccola's and Leonardo's trebuchets. If Truesdell is right in thinking that the essential quality of Leonardo's greatness lay in his unfaltering power of observation and grasp of kinematic relationships, then it might well be the case that changing the characteristics of one machine permitted him to see, unwilled, the form of another emerging when all its essential elements were under his hand. If this is the case then B f54r (fig. 1) follows and so also perhaps do the Madrid codices which according to Reti are a "systematic treatise of practical kinematics"[10].

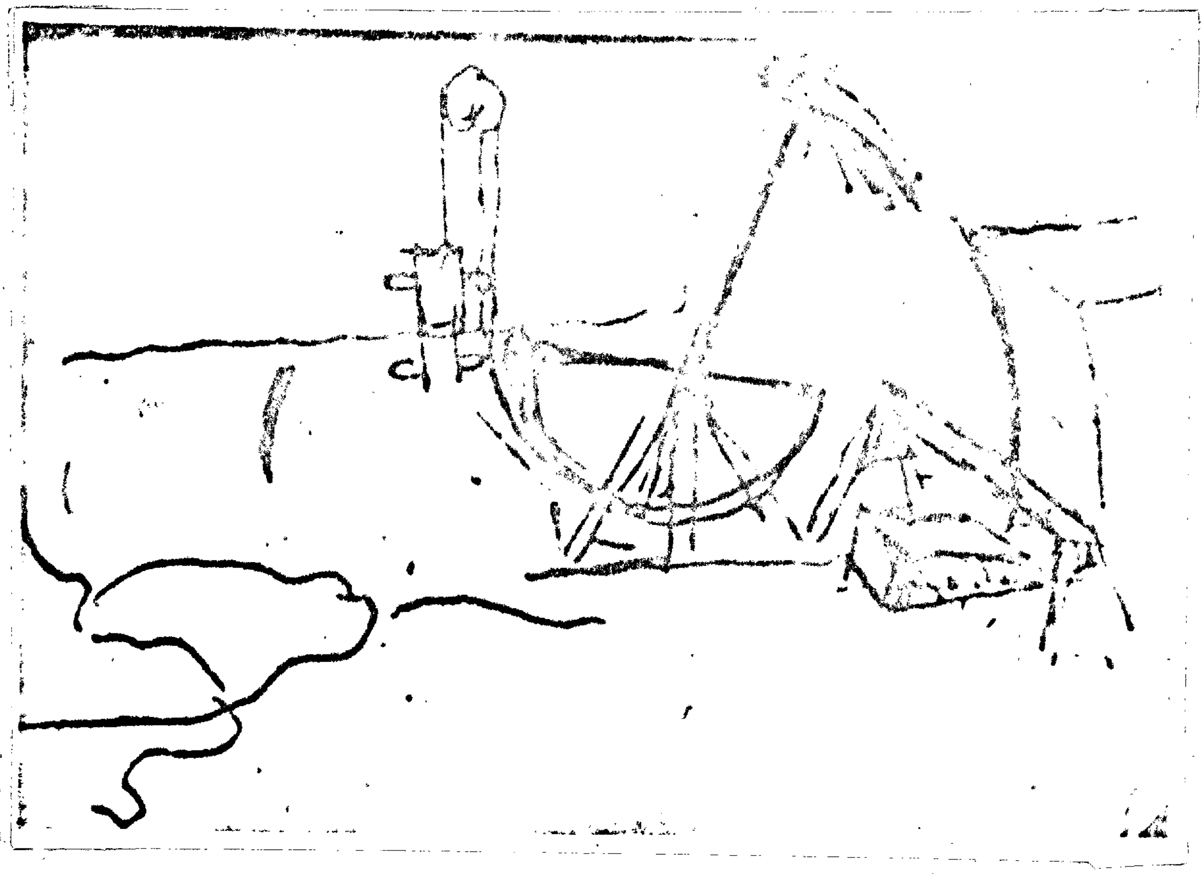
If a new machine had disclosed itself it remained to explore its properties and to see in what situations it might be possible to exploit it. A number of recent studies have rightly emphasized Leonardo's importance as an engineer. It is obvious from the considerable number of sketches to do with the task of pile driving that Leonardo had given much thought to this basic and constantly recurring task. In MS.B. f70r occurs a proposal,

Fig. 7.



Manganon adapted for pile driving, 'da fichare pali a castello'.
Source: L. da Vinci, MSB (1488-89) f70r.

Fig. 8.



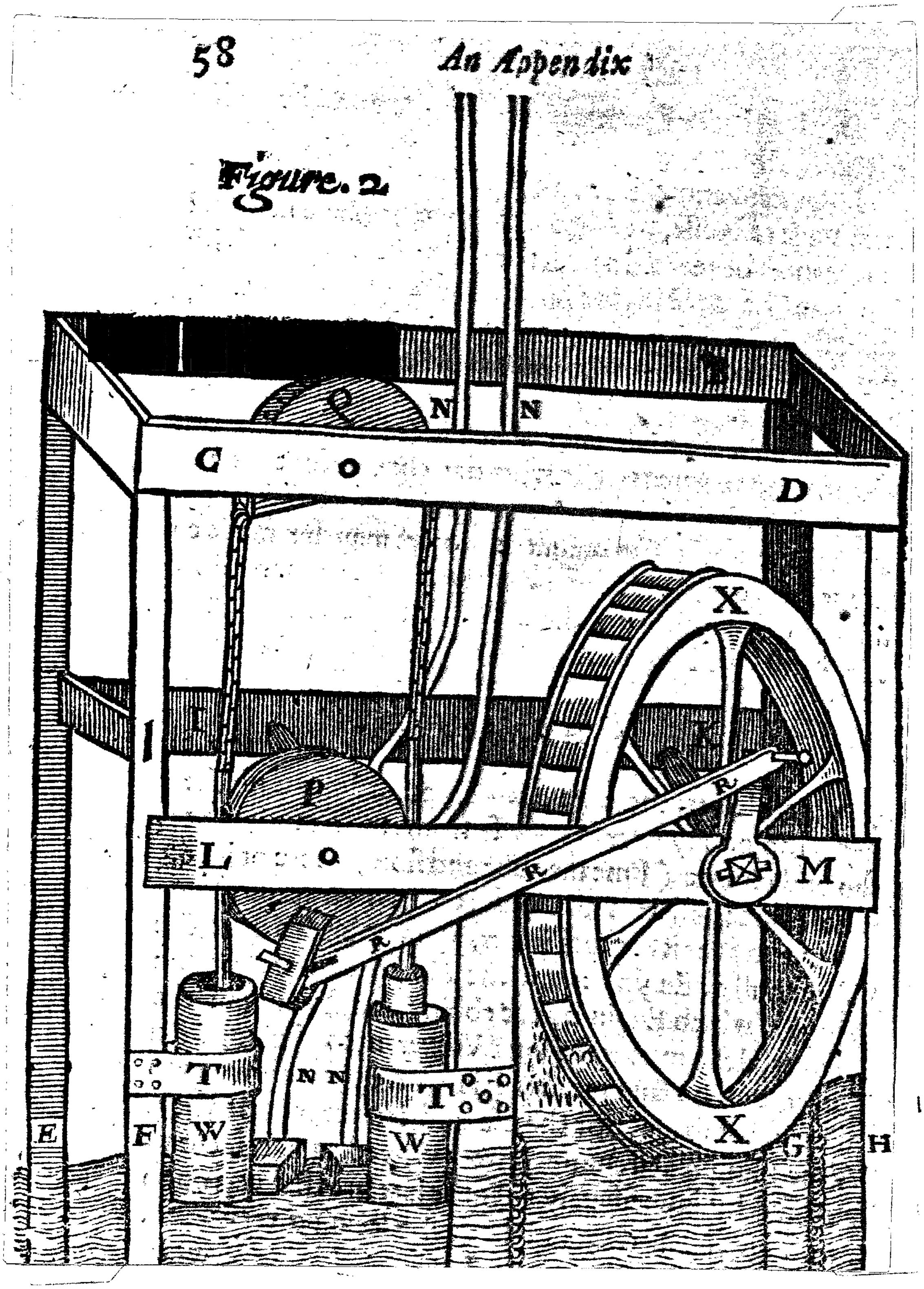
Excavating machine with self-righting cutter.
Source: L. da Vinci MSL (c.1502), f.76v.

"da fichare pali a castello" : "to drive piles at a castle" (fig. 7) involving a sector and chain device that is in every sense intimately related to C.A. f16v.c. (fig. 6). A crank winds down the erstwhile trebuchet arm in a thoroughly Taccolan way and raises the weight, now become a pile driving ram, which hangs from a cord fixed to the quarter circle at its further end. On release no dead donkey is hurled over any city wall: the violent movement following release is channelled through the cross head guides directly downwards on to the head of the stake. Another principal area of activity lay in hydraulic engineering, and, as Reti has shown, it was here that Leonardo gave great thought to the problem of how to handle the removal of earth, particularly in the cutting of canals, in the most economical way[11]. MS.L. f76v (fig. 8) which is directed to this problem probably dates from 1502-3, the period when Leonardo was employed in the Romagna in the service of Cesare Borgia. The excavating device he now sketched is another variation on the sector and chain idea, and comparison with MS.B. f70r (fig. 7) is well worth while because like the pile driver it throws light on the sort of device with which Leonardo probably began his trebuchet experiments, that is to say the bottom heavy Taccolan type in which the throwing arm is in a vertical position when the machine is discharged or at rest. Compared to the pile driver the flow of energy through the elements of the excavating machine is exactly reversed. Work is put in at the pile driver end, now become a device with rings upon which a team of men pull, with the result that the sector rope or chain is pulled violently upwards. The cutting head of the excavating tool swings down and takes a slice from the face of the cutting and tumbles the spoil into the basket placed at its foot. The cut completed, the cutting head returns by itself to its vertical at-rest position at the same time hauling the pulling weight back up in readiness for the next heave upon it. When Reti quotes Leonardo's words describing the ideal situation, "...the soil removed would jump by itself quickly on the instrument that will transport it", one feels that Leonardo would have been entitled to add... and the tool which performs the labour will swing back by itself ready to work again[12]. Such seems to have been the way Leonardo came to recognize this new gestalt form and proceeded to exploit it. If the first step is difficult, the subsequent ones are easy: "difficile est invenire, facile autem inventis addere".

One can only speculate as to the manner in which Leonardo's ideas were disseminated: that they had begun to make their way in some measure even from the earliest period into the inventories of other engineers need not be doubted. Like any other engineer of his time Leonardo learned his business from current practice, from contact with his fellow engineers, and from manuscript literature. The ideas that he gathered from these sources were subjected, as I have tried to show, to vigorous scrutiny and re-formulation. The new ideas and forms that resulted, insofar as they were incorporated into machines actually built, were there for all to see. Even if they were only discussed, they would, in another sense, become public. For a Renaissance engineer could not practise behind closed doors like a Benjamin Huntsman or a Samuel Crompton presenting the world with a finished product whose acquisition even by a purchaser with a professional interest in the mystery would reveal nothing worthwhile about its fabrication. If an engineer were to show his superiority at all then he could not confine himself to the pages of his notebook; he could hardly avoid divulging his arts in some fashion to the interested gaze of his fellows, whose attention would be drawn in proportion to the success which a new device achieved. We do not know, of course, which ideas were exploited and which remained paper schemes, but it is becoming increasingly obvious that even if one were to take an extreme case, that is, to suppose that nothing was constructed at all, we should still be wrong to think that his ideas remained locked up and inaccessible in his notebooks. A number of formal parallels have been shown to exist between Leonardo's sketches and certain of Ramelli's machines, to whose number I hope to add another example presently, which make it appear almost certain that Ramelli had been able to study Leonardo's manuscripts himself. But why should one, in any case, imagine so absurd a situation as that of an engineer who never engineered anything? Probably whatever he did was incorporated almost immediately in the inventories of other engineers just as he had freely absorbed other people's ideas himself. In fact, as far as the question of diffusion is concerned, Reti has put the matter as plainly as possible, "Leonardo did not work in a vacuum but in close contact with fellow engineers, artisans and helpers"[13].

From the last quarter of the 16th century evidence survives which shows, I think, not only that at least three of the group of machine sketches which I have listed had survived very much as Leonardo had formulated them and were in circulation, in several senses of the word, in France, Germany and England, but also, for such is the nature of the evidence, that far from being content to repeat the Leonardian schemes, a new generation of engineers was seeking to adapt them to more exacting situations in order to get more work out of them. Why they were doing this, or rather why they continued so much more vigorously and successfully in these endeavours than other societies is not a question that has received any very satisfactory answer but concretely it could not but result in a continuous evolution of machine types. Pressed to the limit some device would cease to be serviceable save in a new formulation involving familiar elements, or unless out of some creative metamorphosis, such as would seem to have produced the sector and chain, a new superior form became available. Nevertheless it should not be thought that any machine or device, however

Fig. 9.



Morris' London Bridge 'wheel pump' of 1582.
Source: J. Bate, The mysteries of nature and art, London 1635, appendix fig. 2.

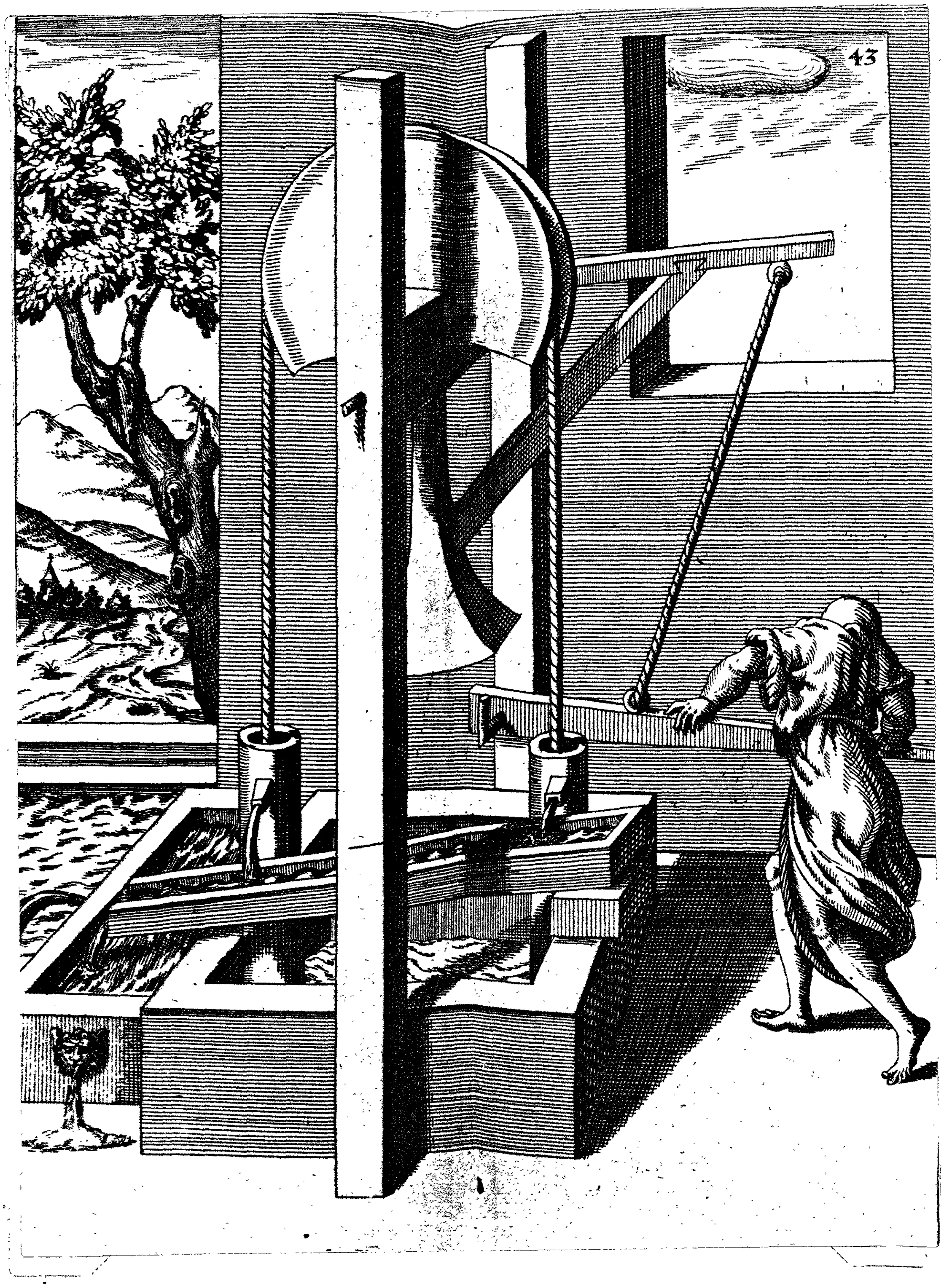
simple, would need necessarily to disappear because a superior device had in some situations superseded it. An ecological niche for it would continue to exist wherever an unexacting situation continued to exist: the swapes of the slate quarries of Angers, the source of Joachim du Bellay's "ardoise fine", co-exist in the pages of the Encyclopédie with the fire engine at the Bois de Bossu. Indeed, this is to put the matter almost the wrong way round: there must at that time have been hundreds, if not thousands, of swapes for every atmospheric steam engine.

On 23rd February 1633 a fire on London Bridge, above the first arch on the north side, destroyed some of the houses and laid open to view the pumping engine which had been installed in the arch over fifty years previously. It was observed by John Bate who published an account and a drawing of the machine in 1635 in the second edition of his Mysteries of Nature and Art. After mentioning that it pumped water into a tower whence distribution pipes supplied an area two miles across, he tells us how he got to see it, "Which engine I circumspectively viewed as I accidentally passed by immediately after the late fire that was upon the bridge Anno 1633, and the device seeming very good when I came home I drew a modell thereof and have here represented it to the view" (fig. 9). Either in 1575 or 1577 Sir Christopher Hatton was petitioning the Crown that a patent for an engine, "to draw and raise up water higher then nature of yt selfe only serveth" should be granted to his follow-wer, Peter Morris[14]. The patent, granted on the 24th January 1578, spoke of this, "new kynde and manner of engynes...not nowe or heretofore as we are informed...made, practized or used by any other within this our realm of England...wythin memorie of any man". But construction did not then begin. Financial difficulties of various sorts ensued even after Morris had secured a contract in 1580 for supplying Thames water to Leadenhall, and the engine only finally began to pump late in December 1582. It is most probable that this engine was mounted on a boat since Bate shows no arrangement for adjusting the wheel to the state of the tide. It was Rhys Jenkins' belief that certain tubes, four inches long, recovered from the site when excavation for a new bridge were begun in 1828, were the machine's sucking pipes. Fynes Moryson, writing in 1591, may well provide the answer if his remarks apply to Morris' work. In that year Moryson was in Dresden and noted the "water mills swimming upon boats and removed from place to place the like whereof was since made at London by a Dutchman* but became unprofitable by the ebbing and flowing"[15].

However, it is the actual constitution of the engine which is of interest here, and several of its features demand inspection. Its mode of operation may be stated quite simply. The tidal flow of the Thames served to move the water wheel (X) in either direction which motion the connecting rod (R) communicated to the small

*Morris was, of course, a Dutch (or Deutsch) man.

Fig. 10.



Pendulum pump of Leonardian form.
Source: J. de Strada, Kunstliche Abriss..., Frankfurt 1617, fig. 43.

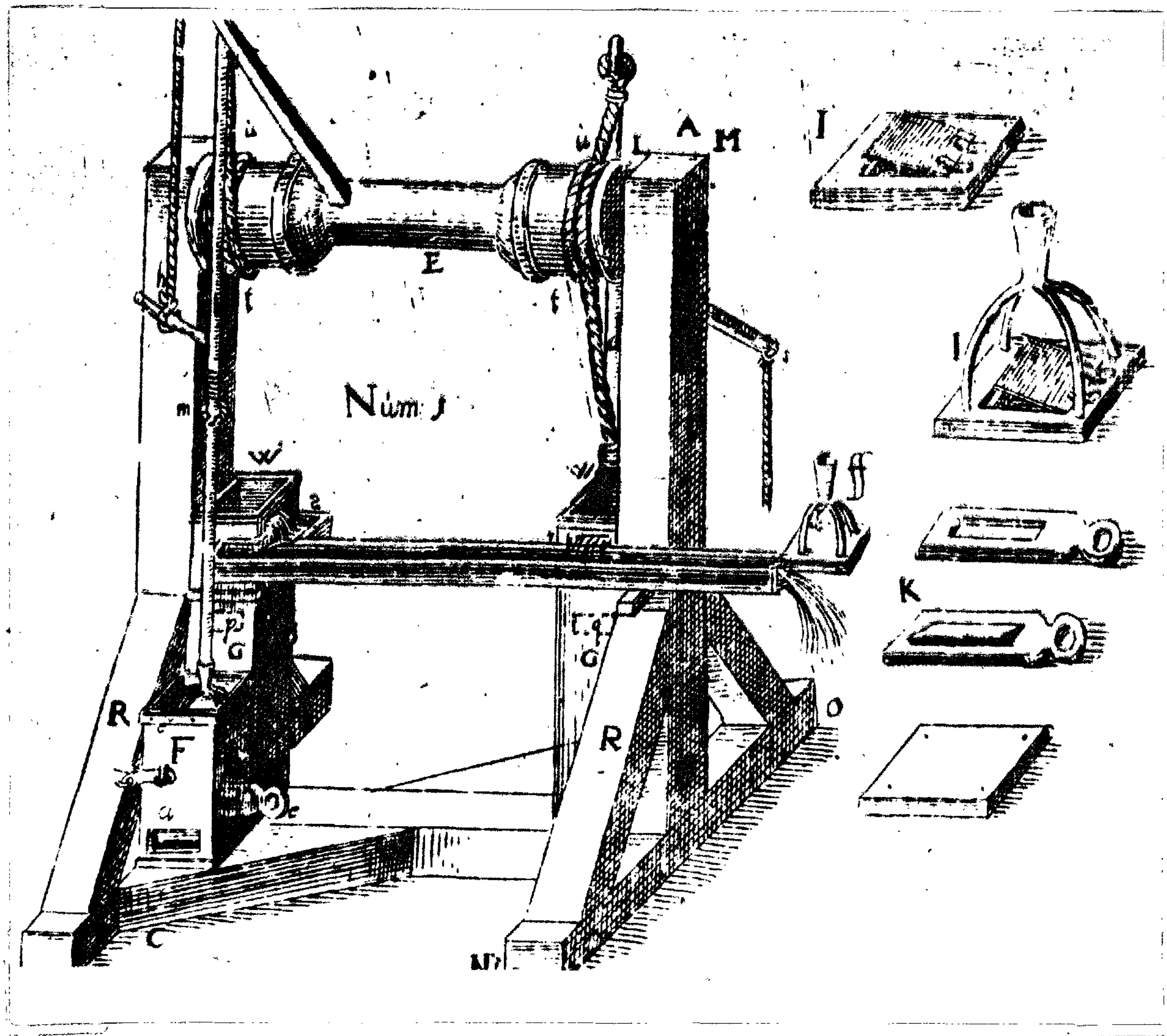
wheel (P). P was required only to oscillate, and the necessary intermittent motion is likely to have been achieved in the following manner. If, as appears to be the case, the water wheel (X) is intended to be shown revolving in a clockwise direction (and how else should the water be spilling from it?) then the connecting rod (R), secured by a pin, between the fork pieces fastened to the bottom of the small wheel (P) will pull it round in an anti-clockwise direction until the fork has described an arc of about 90° from its starting point. By that time the forcer (embolus) in the pump nearest the wheel (X) will have been drawn up to its fullest extent in preparation for its forcing stroke which, of course, the other plunger will have just completed. The small wheel will then be forced backwards in a clockwise direction to repeat the sequence of events in reverse order. The function of sector Q and its chains above the small wheel was to locate the pump rods and keep them perpendicular. I hope it will not seem like a labouring of the obvious to say that Morris' arrangements, once he or some precursor took the decision to dispense with the pendulum of the pump in MS.B. f54r (fig. 1), follow as a logical consequence. In order to get the work done by a rather more powerful prime mover than, for instance, the poor fellow we see (fig. 10) operating Strada's version of Leonardo's machine[16] it was necessary to find a combination of mechanisms which would yield the two basic motions of the manually worked device: reciprocatory (the thrust of the worker on the pendulum) and oscillatory (the sectors moving about their centre). The connecting rod and small wheel reproduce these motions so exactly that it is difficult not to see the simple progenitor haunting this altered form like a ghost. Morris' particular choice of means to transform the pendulum pump into a waterwheel driven affair was, of course, far from being the only one by which this might have been achieved. Philip Skippon sketched a machine at Augsburg in 1663 (one of a number, he says) in which mutilated gears on the axle of the water wheel worked directly on the racks with which the pump rods were fitted[17]. Leonardo himself, in Codex Forster III, f54r, had figured, long before, an inordinately complicated arrangement by means of which a pendulum pump could be worked by animals*. It has to be said, however, that the scheme was his only project for such a conversion so that it would appear to be the case that the adaptation of the pump to animal or water power was to be the achievement of others working after Leonardo's time rather than of Leonardo himself. A further complication faced by Morris was the need to force water to a height of over one hundred feet. Previous descriptions of this engine have, however, faltered somewhat when the moment came to decide how the oscillating motion of P was transferred to the force pumps disposed either side of it. It is possible, for instance, that partial sets of gear teeth, although they are not indicated, engaged with pins on the pump rods.

* The sketch has been noticed already in chapter three, fig. 4.

On balance, this seems a little unlikely since Bate does not show the morticed ends one would expect to see on P if it had half-lanterns. Indeed, the simpler layout of Skippon's Augsburg machine would seem to be a form in which they would more naturally find a place. It seems unlikely also that the pump rods could have had teeth or pegs since Bate tells us that they were only two inches thick. One is forced therefore to envisage, although there is no hint dropped about it in either text or drawing, that an arrangement of chains, one running under P and one above it, linked P to the tops and bottoms of the piston rods rather like a double sector and chain, a counterpart to the single one which appears marked as Q above P. Leonardo had noted beside MS.B. f53v that ropes could do the work of toothed sectors (fig. 3) so that Morris' machine appears on this argument still more Leonardian in inspiration. The rack and sector idea of MS.B. f20r (fig. 2) was still available, as I hope to show, but more probably it was easier and cheaper to adapt the double sector and chain idea to wheel P although in the nature of the case no part of P could be cut away. Bate talks of "two chains of iron which must be linked straight up to the two ends of an iron band that must compasse the circumference of the uppermost wheel". Their function was to assist in pulling up the piston rods alternately while the oscillations of wheel P, acting in an opposed sense, would cause the chains running over and

* This sketch has been already noticed in chapter three.

Fig. 11.

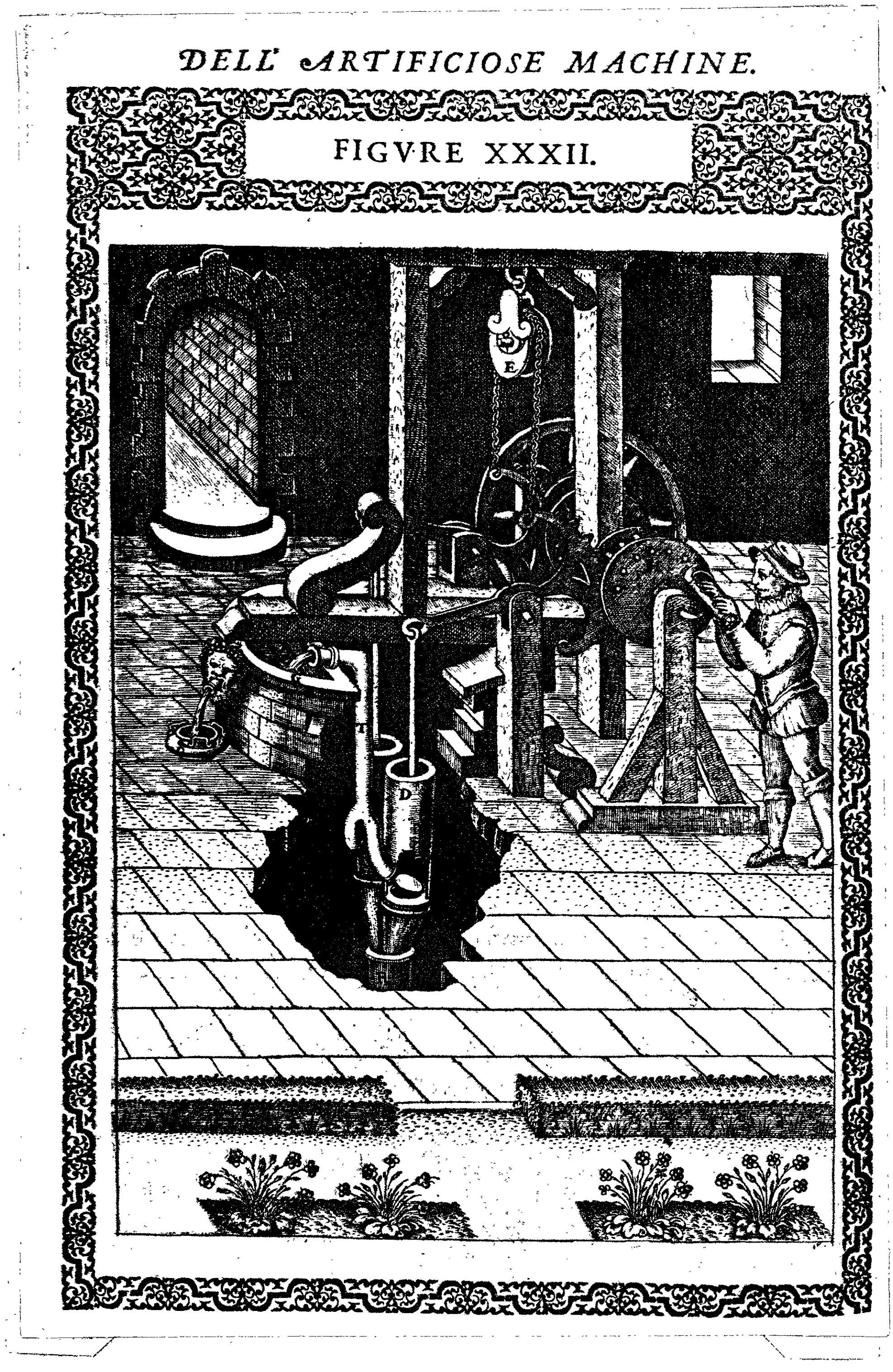


Ship's pump employing Leonardian doubled ropes in place of racks and sectors.
Source: W. Schildknecht, Beschreibung Festungen..., Stettin 1652, plate Z, fig. 1.

under the wheel each to pull down one piston and force up another alternately[18].

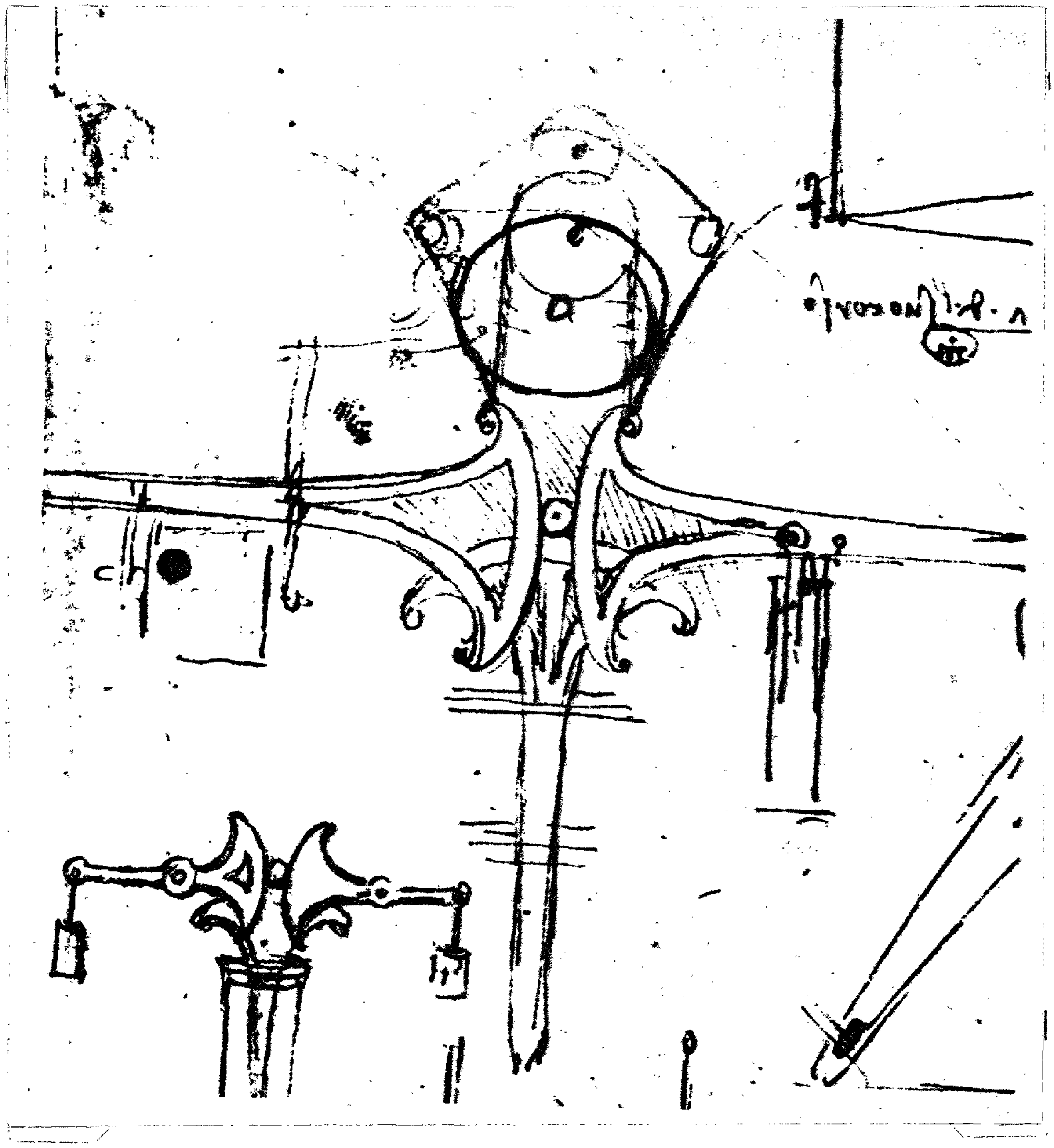
A drawing of a pump (fig. 11) published in 1652 by Wendelin Schildknecht[19] the constructional details of which, he explains, had been shown by him by a boat builder (Bootsknecht)he had met in Holland worked exactly on this double pull chain principle although since it was a light, portable machine, ropes were used, and the two wheels, P and Q of Morris' machine, are nowhere visible since they are subsumed in the rocking roller (bell crank) arrangement at the top of the assembly. This roller, which was pulled in see-saw fashion by two men, imparted the necessary reciprocating motion to the pumps. Each pump was attached at top and bottom to a single rope which passed in a loop around the roller. Since the machine delivered power on both excursions of the pistons it is no surprise to find Schildknecht commenting that it could be made to work both suction and force pumps. His charming simile is worth quoting: "Es kan beydes in ein Truck und Zugwerck transferiret werdē/als ein Strohut/der für die Sonn und Regē fut"[20]: "It can be adapted for both force and suction work just as a straw hat is good for sunshine and shower alike". It might seem that a drawback of MS.B. f54r (fig. 1), in view of all this, would lie in its dependence on gravity for its downward excursion but this would be to miss the attraction that its elegance and economy had for engineers

Fig. 12.



Pumps set in motion by toothed sectors and half lanterns.
Source: A. Ramelli, Le diverse et artificiose machine, Paris 1588, fig. XXXII.

Fig. 13.



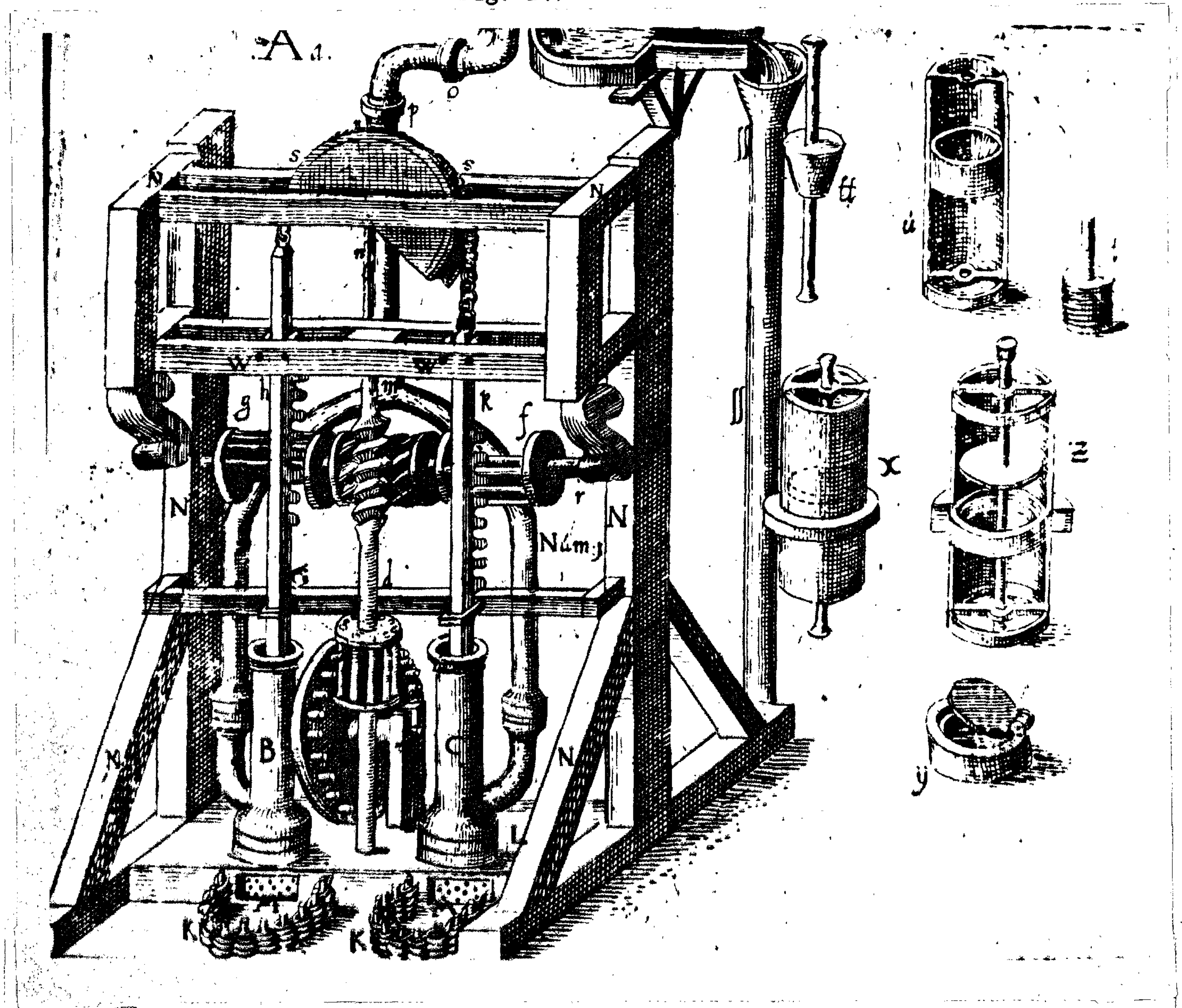
Pumps set in motion by linked sectors and pendulum drive.
Source: L. da Vinci, Codex Atlanticus, f392r(b), c.?1489.

after Leonardo's time. Only a slight loading of the piston would presumably be necessary to iron out any hesitancy in return even in a small light version of the machine, and the fact that the most distinguished engineers in Europe and England were later to exploit the idea would seem to indicate that the machine was still then in use. In the Newcomen engine of 1712, of course, or Mathias Höll's Stangenkünste of 1711, the weight of the pump rods was sufficient to ensure their prompt return after each lift[21]. Where, as at London Bridge, force pumps were necessary it is interesting to see the Leonardian model preserved by duplicating its chain action.

If the Leonardian background to Morris' work be accepted it still remains to draw on further late 16th century evidence to show that yet another of Leonardo's schemes was in circulation. Agostino Ramelli's machine number 32 (fig. 12) has some affinity with Morris' engine as will now appear but derives its morphology and its kinematics primarily from Codex Atlanticus f392r (fig. 13) rather than from MS.B. f54r (fig. 1)[22]. When the handle of machine number 32 is turned, the half lantern marked H begins to engage the toothed sector S, forcing it downwards and so causing its other end to lift the piston in suction pump D. The chain to which the top of the descending sector is fastened is pulled down and this serves to raise the further sector to which its other end is fastened. This sector is shown on the point of disengaging from its half lantern. As the further sector is raised, so its other end is forced down and depresses the piston in P, the water beneath the piston being forced through T into the receiving basin G. On the face of it Morris' machine appears more economical in its use of elements, since all its motions are in the same plane, while Ramelli's requires a change of direction of motion through 90^{o}. Morris' lower wheel in effect does the work of Ramelli's two sectors but any lengthy comparison of the two machines would scarcely be profitable since they are, so to speak, only distantly related. The true parent of Ramelli's machine is, I suggest, the pump in C.A. f392r.b. (fig. 13), and what Ramelli has done in effect has been to get rid of the pendulum drive, using for this purpose the very obvious solution of crank and axle. Although only a lad turns the wheel the arrangement discloses that a more powerful prime mover could be employed at will. But as is often the way, one thing leads to another. Unless the operator is continually to change the direction of his cranking (and presumably it was this to-ing and fro-ing which was objected to in the pendulum drive and impelled Ramelli to abandon it in the first place) it was impossible to retain either Leonardo's friction roller, the end of which appears in the drawing at the top of the pendulum, or the two swape beams facing and linked to each other by a chain passing over a freely revolving upper wheel. The inelegancies of Ramelli's machine, unless it metamorphose still further, now emerge as an inevitable result of the change. The swapes, with two sectors, must now be placed side by side, for only so could two half lantern wheels be made to work them if the cranking were to be performed unidirectionally, although a bonus was to result from this arrangement in that a common rising pipe was now an easy matter to arrange since the two suction pumps were disposed side by side. Observe, however, another effect of all this on the ropes, or, as here, the chains. They will be pulled awkwardly out of alignment once the machine begins to work. It is little wonder that Ramelli does not show this, or that he leaves the upper wheel hanging freely so that it may turn with the slantwise pulls upon it. Such deformations, although present in Leonardo's machine, would have been less troublesome since they were at least confined to the same plane of motion as the wheel. As a final parallel the close resemblance between the open work form of Ramelli's sectors and their curled loops, "en forme de l'ancre" as he says in the text, to which the chain/rope is attached, to those of Leonardo might even suggest that Ramelli himself had seen Leonardo's drawing, unless all sectors were by then so shaped.

By the early 17th century there is the evidence of Strada, already glanced at, to demonstrate that the pendulum pump formula was still alive but the sort of enlargement of the idea which men like Morris had achieved was far from being played out. In 1652 the German engineer Schildknecht, already referred to, a citizen of Stettin,

Fig. 14.



Pumping engine with sector and chains locating the pump rods.
Source: W. Schildknecht, <u>Beschreibung Festungen...</u>, Stettin 1652, plate A.

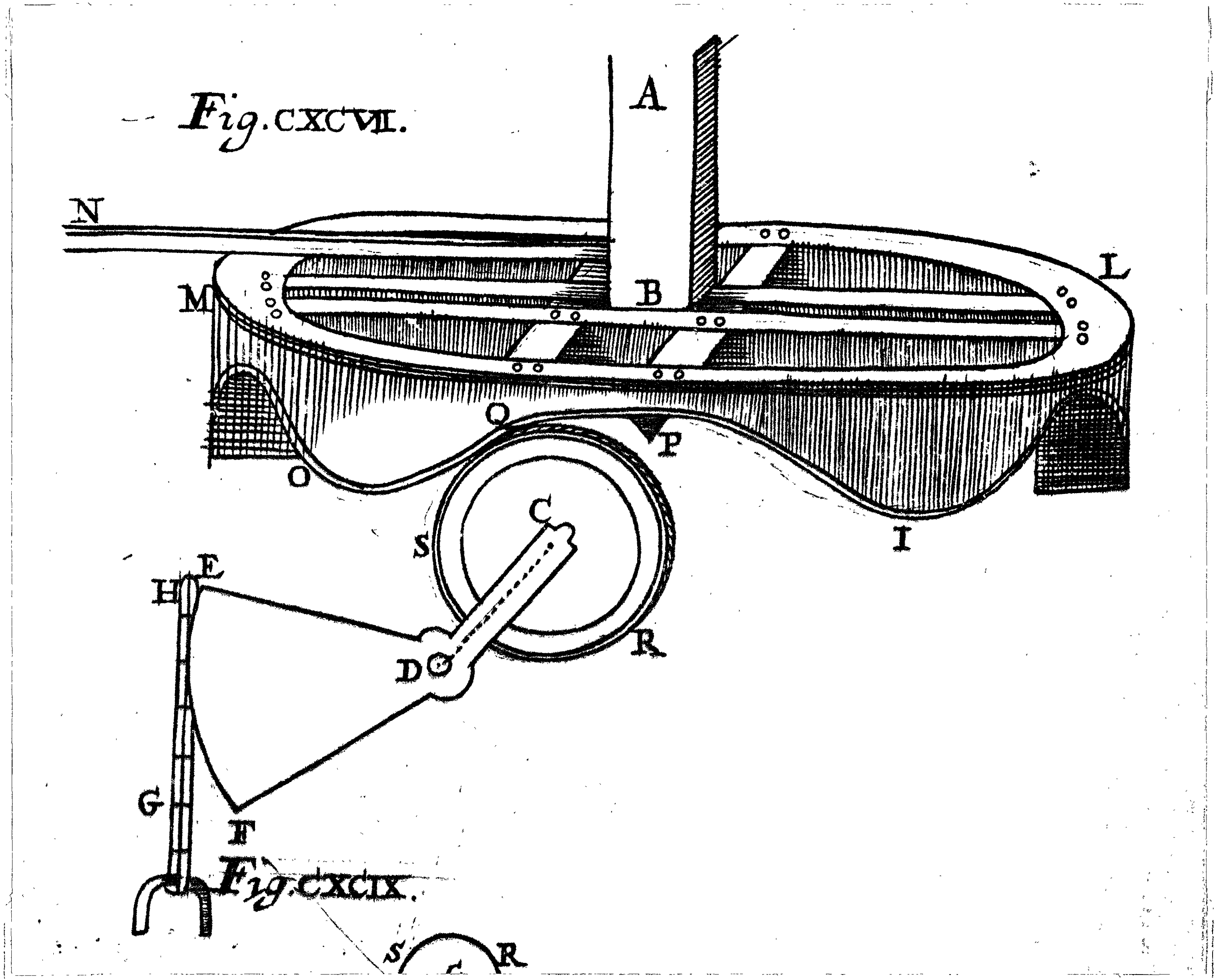
published a book largely concerned with the techniques of military engineering[23]. However, chapter 11 of the third part of his book is concerned with pumps of various sorts,and what is even more to the point, and worth pages of Fraktur, is that it is embellished with two pages of copper plates. He writes with some wit and lets drop many hints of his travels: this pump was shown him in Holland, that one he saw in Padua when he was travelling in the Venetian terra firma; and probably a close reading of his book would reveal a great deal more of his experience and travels. He was a reading man and refers approvingly to several of Ramelli's designs. The second of the copper plates in chapter 11 shows a pump (fig. 14) profitable (according to Schildknecht) to a ruler or magistrate who wants a water pumping appliance which is strong, shows skill in construction and is efficient. The central vertical shaft is driven through its lantern by wheel A which here would be worked by a crank. The endless screw on the shaft transmits this movement to the horizontal shaft with which it engages. This shaft has half lanterns at each of its ends which engage alternately with the toothed sections of the piston rods working in the pump barrels B and C. The racks of the pistons are kept in close contact with the lanterns by their upper parts being caused to pass between guide beams provided with anti-friction rollers. The downward power stroke resulting from the meshing of lantern and piston rod serves to pull the other rod up: this is secured by the chains to which the ends of both piston rods are connected being linked up over the top of the sector above them, a feature the machine shares with Morris'. The Leonardian kinematics which the latter so slavishly imitated are here handled differently, though whether with any gain in efficiency may be doubted. It has already been pointed out that Morris' device could easily have been adapted to suction work. Schildknecht also shows us a pair of force pumps but indicates that they too could easily be adapted. It is also of some interest to note that although his drawing shows the sort of arrangement that would be needed were the prime mover to be a man, he makes it quite clear that the machine could readily be modified. If there were a river with a strong current available, he says, the crank, pin wheel and lantern on the central drive could be replaced by a rimless, horizontal waterwheel. If, on the other hand, water power was not to be had, but a large delivery of water was required so that syrens, Neptunes and water snakes spouting freely might provide a heart-easing spectacle for promenaders in a pleasure garden, then again a horizontal wheel worked by men or animals was the solution. The employment of a horizontal wheel, however powered, to work the pumps is an interesting development. If Morris' scheme was transparently the offspring of its Leonardian parent, it is no longer possible to say as much for Schildknecht's, neither the morphology nor the kinematics of which distinctly recalls those of the prototype to mind.

If the prototype had by this time ceased to exist as a machine in everyday use, the problem presented by the next development to be considered would be simple indeed, for the sort of evolution, or as it may rather appear, saltation, for which Schildknecht's machine is evidence, would have left any engineer wishing to effect improvements with one basic problem only: how best to reconcile the rotary motion of the wheel with the reciprocating motion of the pumps it was to operate[24]. It would, after all, be difficult to suppose that Schildknecht's arrangements represented the last word on the subject. But in fact the prototype continued in existence alongside a variety of machines owing something to it and it might well be that some process of synthesis is what we have now to inspect. At about the very time probably when Schildknecht, home from his travels, was arranging his book a French contemporary, Girard Desargues, engineer and mathematician, was constructing a machine at the chateau of Beaulieu about twenty miles outside Paris whose elegance and simplicity would make the German pump with its lanterns, racks and endless screw look decidedly mannered. It is most unfortunate that Desargues' career as an engineer is, except in this one instance, completely veiled from us despite the fact that it was probably in this field, rather than as an architect, that he was mostly in demand[25]. It is to a mere accident that we owe the earliest description of this machine. On the 22nd September 1671 Christiaan

Huygens wrote to his brother Lodewijk, mentioning Beaulieu but saying almost nothing about the pumping machinery there[26]. Apparently this letter never arrived, or was somehow delayed, because on the 29th of October 1671 Christiaan was writing again to Lodewijk and refers to its non-arrival. He proceeded to describe again his trip to Beaulieu and Viry. This time, however, the pumping machinery at the former house is the subject of a sketch and a careful explanatory note: "Pour des fontaines il n'y en a point, que par les moyens de pompes, qui vont par une belle machine de fabrique de M. des Argues. Un mulet y fait tourner une grande roue, qui par le bas, est taillé on ondes, qui en passant sur un rouleau de font baisser et hausser, et en mesme temps le bras auquel est attaché le piston de la pompe"[27]. Its upkeep will cost very little, he says, because not a single toothed wheel is needed, and he goes on to suggest that if Monsieur le Prince (the future William III of England) had not yet built his machine at Honselerdijck he would do well to take that of Beaulieu for model. Huygens, much impressed by the waved wheel, makes it abundantly clear that Desargues, not Römer, was the first to use an epicycloidal wheel. Huygens does not bother with many other details but does indicate that a sector was used on the pump end of the balance beam. Quite when Desargues constructed the machine it is impossible to say. He was in Paris from 1624, and more or less uninterruptedly so from 1630 until

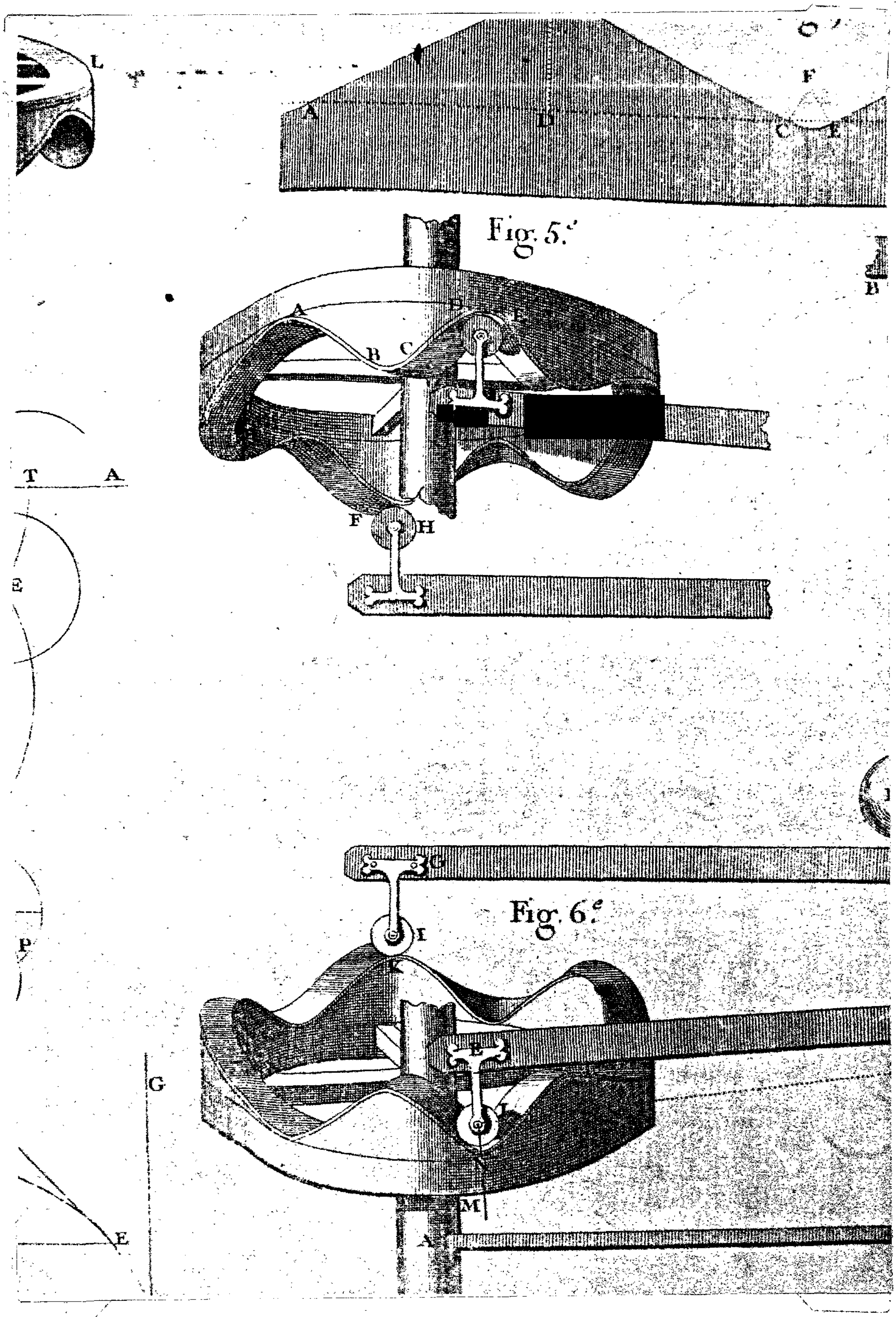
Fig. 15.

Pumping engine constructed by La Hire as a replacement for Desargues' machine of c.1640.
Source: Traité des epicycloides, Paris 1694, fig.CXCVII.



shortly after 1648. It seems almost certain that the work belongs to this period. Although he was in Paris again in 1657 and 1658 he had not then long to live[28]. It was only later that an exact idea of its arrangements (fig. 15) emerges from Philippe de La Hire's Traité des épicycloïdes et de leurs usages dans les méchaniques of 1694[29]. It is later still that we learn from Belidor something of its dimensions[30]. In the preface La Hire says, a propos of the usefulness of geometry in mechanics, that because it was his fortune to build a wheel at Beaulieu, "à la place d'une autre semblable qui y avoit été autrefois construite par M. Desargues et qui étoit entirement ruinée" and because so far as he knew that excellent geometer had only worked out the epicycloidal properties of the wheel mechanically, this was a matter he intended to deal with formally under Proposition IX[31]. Within two years the work had been translated into English and presented unblushingly, as if it were theirs, by Venterus Mandey and James Moxon, although it was tucked away as Book 10, along with other materials in a book tricked out with the catchpenny title, Mechanick Powers, or the Mysteries of Nature and Art Unvail'd[32]. La Hire is the earliest writer to comment explicitly on the usefulness of the sector and chain (the quotation is from Mandey's translation) "Tis easily seen that the chain which is fastened to the portion of the circle serves to raise the pestle always perpendicular which is a very good use in these sorts of pumps; for otherwise if the handle which

Fig. 16.



Top and bottom waved wheels as employed in Desargues' and La Hire's machines.
Source: B.F. de Belidor, Architecture hydraulique, Paris 1739, Vol. 2, Ch. 4, plate 7.

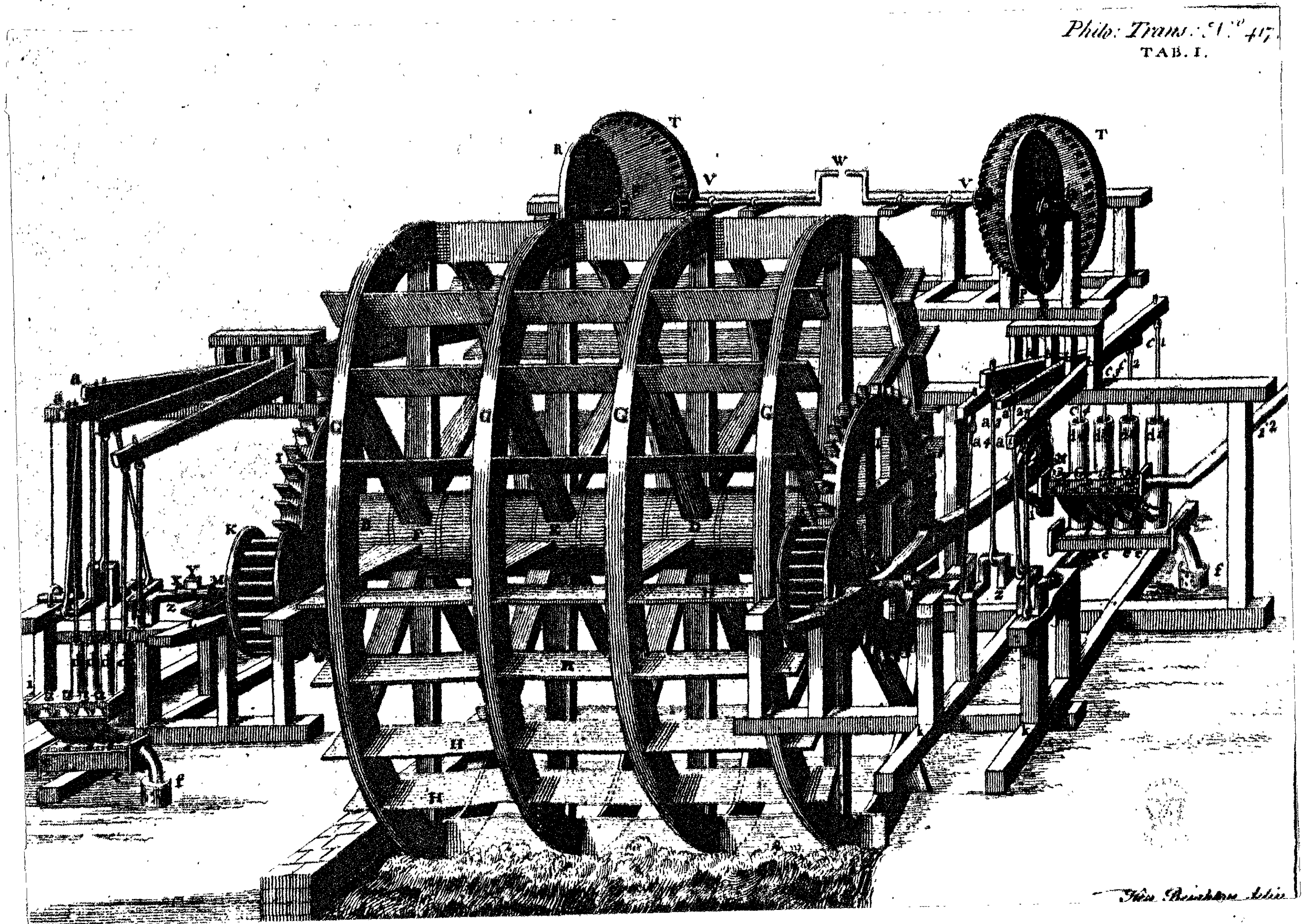
carries the pestle be only fastened to a leaver movable about an axis as D in this engine, it will happen that the pestle will be drawn sometimes to one side and sometimes to the other, and wear unequaly in the body of the pump in working which will destroy it in a third part of the time, as I have observed in some rencounters"[33]. The engraving of the machine taken by Mandey from La Hire's book along with the text is not as explicit as one would wish about the arrangements of the parts. The revolving wheel or cam follower which the waved wheel depresses is in fact attached by a bracket to one end of a swape beam centrally pivoted, at whose other end is the sector and chain. Across the waved wheel another cam follower works in an opposed sense, that is, it will always be at the top of a wave when the other is at the bottom. Belidor shows this much more clearly (fig. 16), gives dimensions and constructional details, as well as showing both bottom waved and top waved wheels[34].

The enquiry up to this point has been concerned only with the fortunes of certain Leonardian pump forms employing the sector and chain idea from their first appearance in the note books. The existence of both in association has so far been traced to the close of the 17th century but Leonardo, as we have seen, recognized the value of sector and chain in other applications quite distinct from their use as an element of pumping machines, and there is some reason for supposing that this part of his legacy had survived also and was indeed by the close of the 17th century on the verge of an incredibly rapid extension. Reti has already drawn attention to Leonardo's sketch of a mill wheel which might be adjusted by means of screws so as to be always in an optimum position in relation to the water which moved it. Ramelli has several designs for such wheels and a brief paragraph in Scamozzi shows quite clearly that these were not paper schemes[35]. The idea had achieved by Scamozzi's time a remarkable geographical extension for he mentions a mill at Noyon in Champagne where the wheel and mill sluices could be lifted more than twenty feet, another at Strasbourg, and others on Lake Lucerne and south of the Alps on a tributary of the Piave. It is clear, however, that by Scamozzi's time a new feature had crept into the design of some of these mills. At a mill on the river Deman near Lucerne he talks of great screws that lift the whole body of the wheel by moving a balance to which the wheel is attached. Scamozzi's word <u>bilancia</u>, meaning swape beam, is something new in this context. There is nothing in Leonardo's drawing or Ramelli's designs which could possibly have called for such a word since they notably lack pivoted beams. As is nearly always the case with verbal descriptions, one is left in a state of uncomfortable doubt as to what the thing being described actually looked like. However, what may have been the nature of the arrangement begins to emerge when the first information comes to hand of adjustable wheels in England.

The first definitive evidence is in the patent

Fig. 17.

Sorocold's London Bridge machine of 1701 with Hadley's patent adjustable wheel.
Source: H. Beighton, Philosophical Transactions, 1731, Vo.. 37, plate 1.



secured by John Hadley of Worcester, No. 613 of 1693, for "raising and letting down vertical wheels so as to render them useful at all heights of the water...". Worcester, where Hadley is said by Dickinson to have first employed the device, would certainly be a place where such adjustment would be extremely useful since the river Severn is subject to great and rapidly occurring variations of level. Quite when Hadley began work with another engineer, George Sorocold of Derby, is uncertain, although it seems that Sorocold had used Hadley's device, even before it was patented, for the mill work he had completed at Derby in 1692. Celia Fiennes, who visited Derby in 1692, and who had always an eye for money-getting schemes, was impressed by "the rising and falling wheel" at Sorocold's works, and explained, "...at this engine they can grind if it is ever so high a flood which hinders all the others from working...they are quite choaked up"[36]. George Sorocold's greatest work was, however, to come in 1701 when the new proprietors of the London Bridge Waterworks commissioned him to build two great wheels in the fourth arch of the bridge. Once again Hadley's patent device was used, and when Henry Beighton drew the machine in 1731 we finally see what it was (fig.17) or at least the particular form it took in this application. It is only by looking through a small thicket of pipes, beams and connecting rods that one is able to see what was involved. Beighton's description is very precise[37]. There are..."two great levers (L,N)...The wheel (G) is, by these levers, made to rise and fall with the Tide". Then follows a formal exposition of the lettered members (the levers are sixteen feet long) before he concludes: "One man, with the two windlasses (W), raises or lets down the wheel as there is occasion...By means of this machine the Strength of an ordinary man will raise about fifty Ton weight". But was it all worth while? "The machine for raising and falling the wheels is very good, though but seldom used as they tell me; for they (the wheels) will go at almost any depth of water, and as the tide turns the wheels go the same way with it".

Dickinson thought that perhaps Beighton was being told the tale by smooth operators who had found the changing times of tides too monstrously variable to live with and who were quite prepared to let the wheel take its chances. It is also possible that Sorocold and Hadley had produced an over-sophisticated machine and that the men were giving an honest account. Whatever the truth of the matter it would certainly have been dangerous beyond words to have attempted to lower or raise the wheel unless it was equipped with a sluice gate which could be lowered to shut off the current from the wheel. Even so, unless there was also some sort of locking device to hold the wheel in place, whatever its position, there was a clear risk that it could become in effect locomotive and begin to climb the rundle or spur wheel or else pull on the capstans and revolve them like circular saws. But in fact Beighton's drawing omits so many features that the machine must have had, quite apart from those omitted for purposes of exposition, that any lengthy discussion of it would be quite otiose.

If we now recall the equation between Sorocold's lever and Scamozzi's bilancia the possibility is at least raised that Hadley was not the first in the field and that possibly one of his precursors was the anonymous engineer of the mill on the river Deman. Scamozzi talks of, and Ramelli shows, the whole body of a mill being moved up its legs by the force of screws, an extravagant waste of effort when the advantage it yielded could be secured by moving the waterwheel alone, a labour easily performed, as we gather from Beighton, if it were counterweighted.

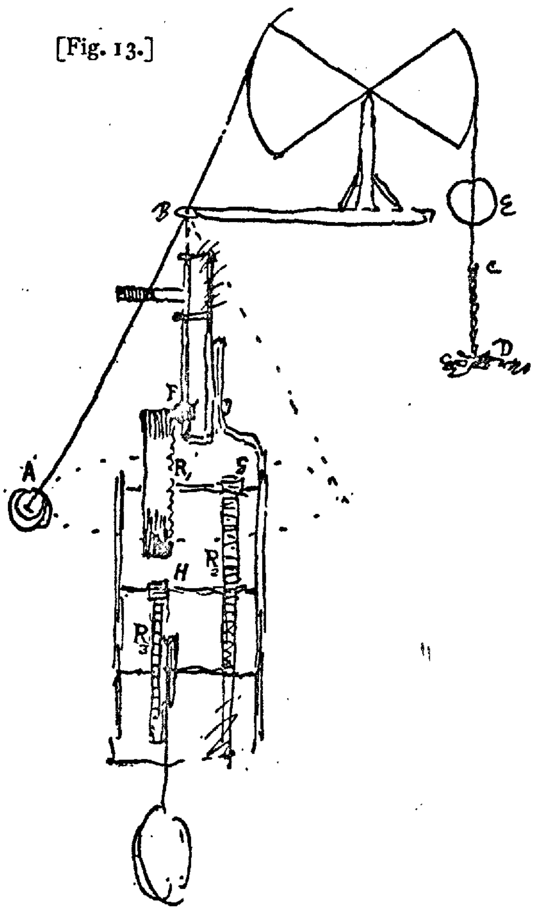
Although the evidence for the use of sector and chain in this particular application is sketchy and late, there is rather more coherence in the case to be considered next. Ironically, it is one at some remove from the world of actual practice. Christiaan Huygens' Projet de 1659 d'une horloge à pendule conique, and indeed the other projects having to do with chronometry with which he was occupied as late as 1693, reveal that sectors and chains, both with and without racks, deployed in a variety of ways, played an important role in his schemes[38]. I do not intend here to enter into the complexities presented by these materials except to observe that the presence of these elements in Huygens' work almost certainly indicates that

Fig. 18.

PROJET DE 1659 D'UNE HORLOGE À PENDULE CONIQUE.

Inventum die 5 Oct. 1659 [1])

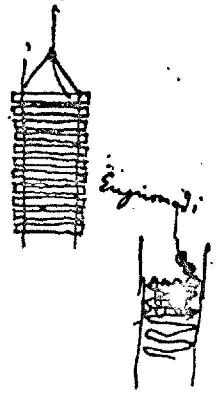
[Fig. 13.]



cum globus A [Fig 13] perpendiculariter pendet absque vertigine oportet filum a centro ejus ad foramen B æquale eſſe parti catenæ CD [2]), quæ tantundem pendit atque pondus E una cum particula catenæ quæ elevata eſt cum globus ita perpendiculariter pendet [3]).

Ideo cum minuitur longitudo BA, tantum gravitatis et globo A et ponderi E ſingulis eſt adjiciendum quantum pendet [4]) particula catenæ æqualis longitudine ei particulæ quâ fili longitudo diminuta eſt [5]). Vel

[Fig. 14.]



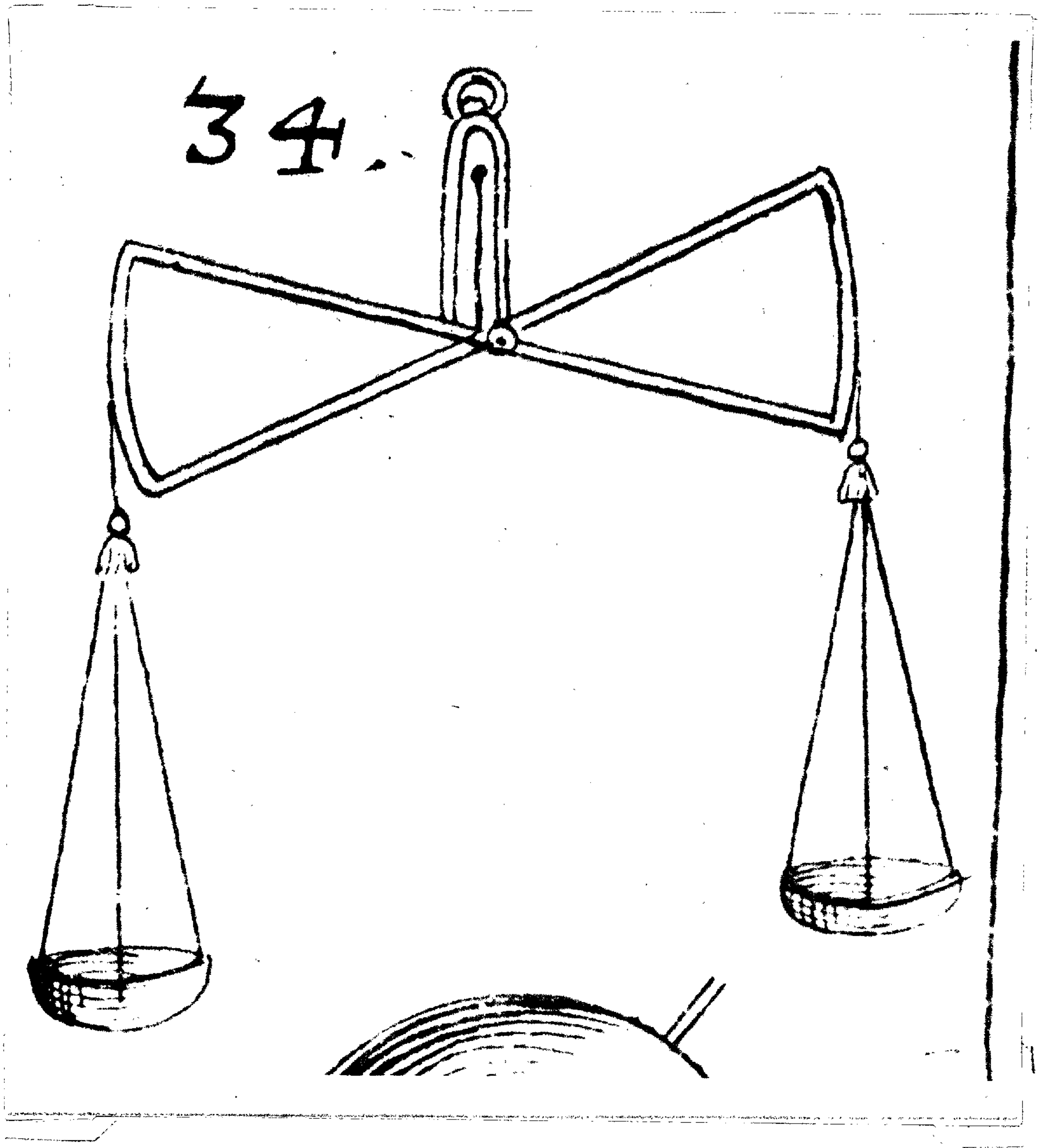
[Fig. 15.]

tantum hac eadem longitudine diminuenda eſt diſtantia inter C caput catenæ et pondus E [6]). catenula hujusmodi [Fig. 14].

Pro catena ſit cylindrus cum hydrargyro [Fig. 15] in quem alter tenuior hydrargyro plenus dimittatur [7]). bilance explora quantum ponderet pars certa cylindri ſupra marginem P extracta.

Balance device to compensate for fluctuations in atmospheric pressure.
Source: C. Huygens, <u>Projet de 1659...</u>, fig. 13.

Fig. 19.



The common balance, 'libra communis'.
Source: J.A. Schmidt, Theatrum naturae et artis, Helmstadt ?1710, plate 3, fig. 34.

devices or machines in common use were the sources from which they were derived. If one were to take, for instance, the sketch accompanying the Projet of 1659 (fig. 18) it is immediately apparent that its central feature is a sector device of exactly the form of MS.B. f54r[39]. It serves, however, merely as a balance. But did balances of this type then exist? The answer might well seem to be supplied by J.A. Schmidt in a small book published in Helmstadt about 1710 entitled Theatrum naturae et artis. In a section devoted to weighing devices a balance like that used by Huygens in 1659 is described as libra communis (fig. 19)[40]. Huygens was to use the 'common scale' in 1675 and again in 1693 in his balancier marin parfait, features of which schemes reappear later in the work of chronometer makers such as Henry Sully and John Harrison. Huygens' correspondence also affords, as it happens, one other piece of evidence which suggests that sector and chain devices were, despite the paucity of direct evidence, in wide employment in the second half of the 17th century. Charles Perrault, writing to Huygens from Viry in October 1669, referred to a water clock they had discussed which he evidently proposed to install in his grotto. He had decided, he says, to supply it with a pendulum as Huygens had suggested. The clock's balance beam which he sketched in his letter has at one end a weight hanging from a sector and chain[41]. Had the libra communis again supplied the model or should one look rather to some form of pendulum pump?

References to sectors, however, hard to come by before about 1700, become a veritable torrent in the 18th century and figure in an enormous number of mechanical ensembles. Altogether they offer a prospect of the 18th century's love of mechanical gadgetry which is both intrinsically interesting and of service as evidence that in respect of the pendulum pump and its derivatives Europeans were daily in Leonardo's debt whether as scientists using precision instruments, as artisans plying their trades, or as housewives preparing their country messes. Some of these uses will be looked at presently but as a preliminary it may be remarked that since they are so varied and wide-ranging in nature, it is hard to believe that they are all as genuinely late, from c.1710 to c.1775, in their adoption as on strictly chronological grounds they must appear to be[42]. Chance survival of evidence has no doubt played a large part in distorting the picture, but even so the nature of the evidence makes it possible to draw certain distinctions. It may well be the case that the employment of the sector and chain as an element in the construction of scientific instruments projected and actually built really is a late development, a function of the search for greater precision in measurement that characterized this field very noticeably from the later decades of the 17th century. It is, however, difficult to find any factor which will explain its late appearance in more prosaic situations unless it is that lack of direct evidence is distorting one's view of things.

In 1721 Henry Sully, a maker of chronometers, English by birth but who spent most of his life in France, began work on a marine time-keeper which he finally presented to the Académie des Sciences in 1724. As a controller Sully used a version of the sector and chain. A weighted lever, acting as a sort of horizontal pendulum, was equipped with a sector to whose lower end was attached the flexible cord which played between two curved cheeks. Two years later he published an account of it which contains an engraving of the arrangement with the inscription, 'Nouvelle Pendule à Levier approuvé par l'Académie Royal des Sciences 1724'[43]. In the same year as Sully's book appeared, Jacob Leupold published the third part of his Theatrum Machinarum in which he described various automatic recording machines which would trace continuous records, hour by hour, of variations in temperature and in barometric pressure, in both of which situations one finds balance beams with sectors and chains. There is also another machine in which a variant of the device acts like a *fusée*[44]. The use of the balance barometer with sectors and chains later spread to England where perhaps other instrument makers than Watt had read Leupold's work. J.H. de Magellan, writing in 1779, claimed that he had himself made improvements in barometers of this type and that he had seen two such instruments, one by Adams, made, possibly in 1760, for George III; the other begun by Jonathan Sisson (d.1760) which he had himself improved[45].

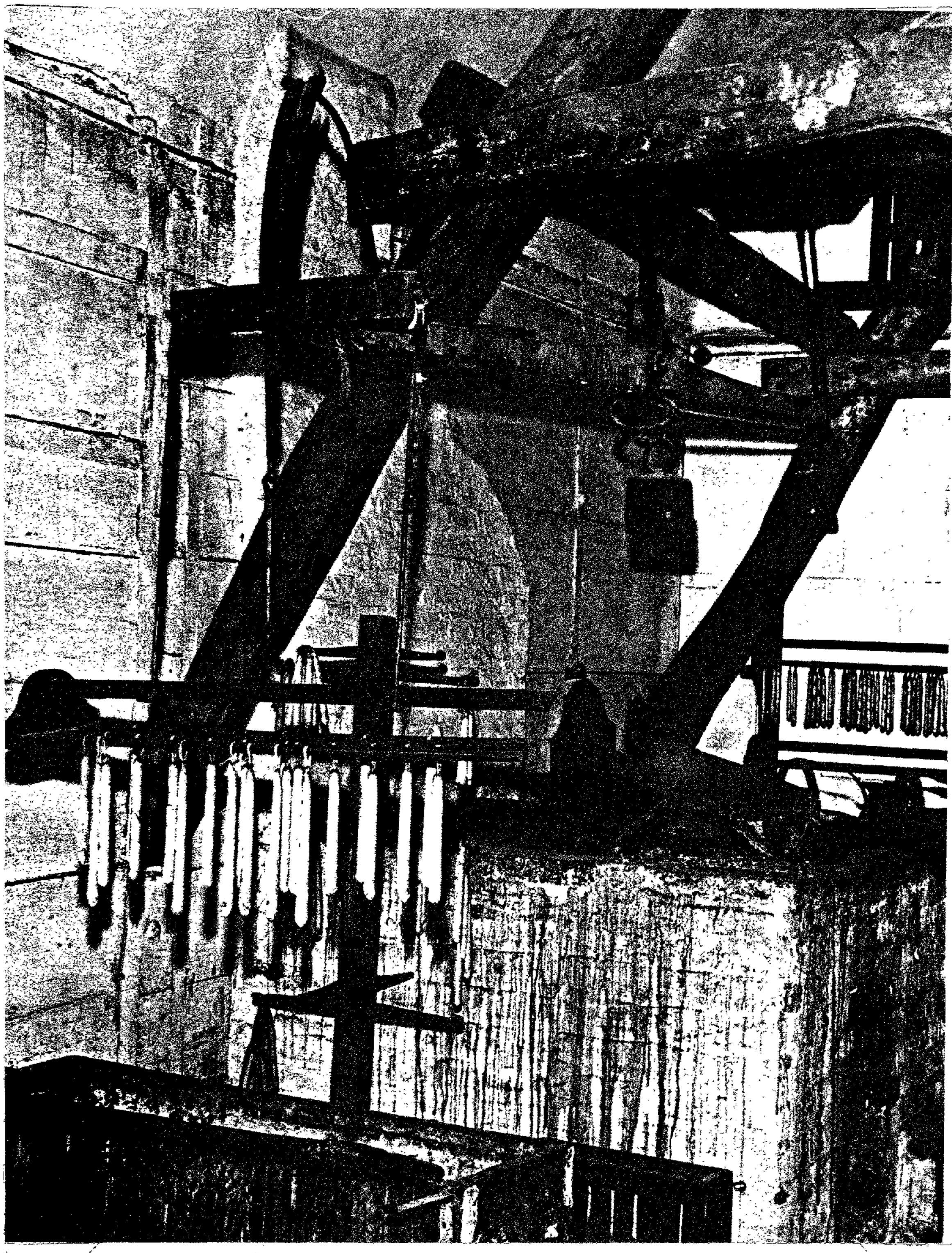
By the 1780s the balance beam, four feet long, with sectors and chains, appears in yet another role, as part of the gasometer constructed for Lavoisier by Mégnié following Meusnier's plans in 1783, and again in a later type constructed in 1787. The first of these gasometers had a chain, said wrongly by Daumas[46] to have been invented by Vaucanson, of a special type supposed not to be subject to elongation under tension. The shape of each individual link can best be imagined as being like that of a lyre with hooked ends (by which it hangs from the lyre above). Such a chain may well not have stretched but another desideratum is that the chain should lay itself flatly on the sector as the beam end rises and pay out smoothly from it as it descends. The pitch chain, (or chaine anglaise as it was sometimes called in France), might well seem a better type for use in precision situations*..

Such are the uses of the device in laboratory work but no less diverse a picture is presented when one looks at the situation as far as the tasks of everyday life are concerned. I pass over its use, recorded in the Encyclopédie,[47] for the ringing of small bells, although, no doubt, it could join that select collection of devices, the fly-ball governor, the vertical axle revolving book-case, the hot air turbine and Villard de Honnecourt's

* In German Uhrkette (clock chain).

turning angel, that have assisted in what Lynn White has called the technology of prayer. I wish instead to draw attention to another use, also illustrated in the Encyclopédie, that is in the preparation of lead sheet[48]. Attached to the preliminary forming table on to which the liquid lead is to be run is a trough holding about 3,500 pounds of metal. The forward lip of the trough is hinged to the top of the table so that when the back of the container is lifted by chains it spills its contents evenly over the casting bed. The success of the operation lay not only in establishing a level surface for the lead to flow over but also in precision of pouring, especially important since the metal, when poured, was not at its most fluid, having been allowed to cool to the point where a paper held over the metal would only turn brown. The sectors and chains of the counterweight beams ensured a uniform flow of lead over the lip of the trough since the pull would be immaculately vertical. Yet it would appear that the procedure, including the final rolling of the cast lead sheet, had been modelled on that in use in England since the beginning of the 18th century[49]. In fact a company had been formed in London to produce rolled lead as early as 1678. In England the sector and chain was later used about 1775 to ensure that candlewicks should be plunged with precision into tallow[50]. This ensured an equal build up of material around the wick and consequently a candle that would burn uniformly and without waste. From the end of the chain hung a horizontal rod with a row of

Fig. 20.



Candle dipping machine from the candle factory at Boroughbridge, Yorkshire, probably of about 1850.
Source: the collections of the Castle Museum, York.

hooks over which were placed the loops of the cotton wicks. The wicks would already have been well primed with tallow so that one must imagine them hanging down straight like rods (fig. 20). The operator standing next to the trough full of tallow, which like the lead would be on the point of losing its fluidity, pulled on the beams which, swinging down, allowed the wicks to receive their coating of tallow. After a brief immersion the operator released the beam which swung smoothly back, lifting the wicks clear of the trough where they would drip off and harden in the air and thus be ready for their next coating. Nothing like this is to be seen in Duhamel de Monceau's 'L'Art du Chandelier'[51] for there everything is done by hand, but the superior speed and ease of the English method of production would not have been gained at the expense of quality; rather the reverse.

The English iron industry also was to exploit the sector and chain. Isaac Wilkinson's third patent, No. 713 of 1757, for "a machine or bellows to be wrought by water or fire-engines" proposed its use in a cylinder blowing machine for blast furnaces in place of the cuneate form of bellows then almost universal. The arrangement overall is reminiscent of the Newcomen engine, except that air was to be pumped instead of water. Isaac hoped to retrieve his own fortunes with the idea and may well have succeeded, for a cylinder blowing engine was in use at Walker's ironworks in Rotherham by 1762 and was the

Fig. 21.

A farmhouse three movement chimney crane from the north Yorkshire moors, probably of the late 18th century. Source: the collections of the Castle Museum, York.

type the Carron directors insisted on (in the face of Smeaton's desire to design his own) when the time came to build blast furnaces Nos. 3 and 4[52]. William Wilkinson installed steam-driven cylinder blowers in 1785 at the Mont Cenis ironworks in Burgundy. Johann Ferber, a good judge, was staggered at their enormous force when he visited the works in 1788.

Perhaps one would hardly expect the sector and chain device, pervasive though it has now been shown to be, to have invaded even the kitchen parlours of the 18th century, but such was the case. The open fire of the domestic hearth was, of course, where food was prepared and the wrought iron accoutrements that were so necessary a part of its furniture have a long and fascinating history. The andirons, cats and spits deserve description, but I wish to draw attention to the chimney cranes which were a universal feature of English, and no doubt European, hearths at this time (fig. 21). A housewife tending her pot needed always to be able to adjust its position in three ways. The first movement the crane had to be capable of was to turn on its vertical axle and thus bring the horizontal arm and everything hanging from it clear of the fire so that the housewife could perform her offices. Next she had to be able to adjust the rate of cooking by varying the height of the pot above the fire, and finally, when all was ready and the stew needed only to be kept nicely warm until dinner time, a horizontal movement was necessary that would bring the pot to the side of the hearth. Any blacksmith in 18th century England would have quickly made a crane which would perform the first movement, but generally speaking the others would be left to the cook to manage with her bare hands, with a certainty of soot and a good chance of being burnt as well. The sophisticated three-movement crane took these horrors out of cooking. A balance beam mounted on a travelling carriage permitted motions two and three to be given to the pot from a safe distance[53].

It remains to say something about the Newcomen engine of 1712 which perhaps more than any other of the machines that have been considered would appear to have been influenced by its Leonardian antecedents. In 1963, in honour of the tercentenary of Thomas Newcomen's birth, Dr. Joseph Needham presented a paper to the Newcomen Society called 'The Pre-Natal History of the Steam Engine'[54] and revealed the complexities of the currents of design that lay behind, to use Usher's words, "the greatest single act of synthesis" in the development of steam power. In many ways the metaphorical colouring of Needham's title is appropriate because a succession of commentators ever since 1725, when the author of the poem 'The Prize Enigma' presented his version of the engine's ancestry, have described the engine in a curiously anthropomorphic and anatomical fashion:

> "I now can raise my hand above my head;
> And now, at last, I by myself am fed.
> On mighty arms alternately I bear
> Prodigious weights of water and of air"[55].

But Needham's anatomising neglected to mention, if it is permissible to continue the trope, the arms and shoulder blades of the machine, for he had nothing to say of the sectors and chains nor indeed of the swape beam itself. In another sense too his analysis was, I think, incomplete, if not actually misleading. All the elements are presented, as it were, in a heap much as a cook might assemble all her ingredients, but the situation Newcomen faced about 1698, or whenever it was precisely that he began work on his machine, was obviously far different. Beyond doubt all of the many ingredients were already gathered together in other syntheses such as this survey has already considered. If, as appears overwhelmingly likely to have been the case, Newcomen knew at least of the working principle of Papin's engine of 1690, and the review of Papin's Recueil which appeared in Volume XIX (1697) of the Philosophical Transactions would have acquainted him with its essential features, he would have sought for a machine which could be adapted in such a way as to permit the weight of the atmosphere to be exploited. He had no need to conjure up a whole machine for this purpose ex nihilo. Consider the Leonardian machine of MS.B. f54r (fig. 1) which was the starting point of this enquiry. Is it really possible to believe that Newcomen had not seen English versions of it at work in Devon? This is almost a rhetorical question, for English colonists in North America had already taken the machine with them across the Atlantic. The issue for June 1755 of the Gentleman's Magazine[56] contained an article acquainting the English public with the equipment needed and the procedures followed by the planters of the southern colonies in processing their crops of indigo. The engraving reproduced by G. Terry Sharrer in his article in Technology and Culture on 'The indigo bonanza in South Carolina' shows that the installation was all very simple, nothing more than a pump and some vats for steeping the plants in[57]. But what a pump, and of all conceivable pumps what an astonishing one to find in use in South Carolina in 1755. Two and a half centuries after Leonardo had first sketched his pendulum pump its exact replica makes its appearance in an English magazine. It is, of course, possible that Newcomen, searching for a machine on to which he might graft the new idea, sought other models. Perhaps he had seen the sort of pump that Desargues and La Hire (and Mandey) had made familiar, and I suppose it is not impossible that if Watt had had his kettle, Newcomen could be supposed to have had a three-movement chimney crane. To mention such possibilities is to see at once that they lead nowhere. It might seem rather that the marriage of Papin's cylinder and Leonardo's pendulum pump lies at the heart of his engine, and everything else, snifting valve, cataract and so on, the technical problems included, takes its place within the context of this first basic synthesis. Once the possibility of obtaining power from an active piston was available, the pendulum would naturally disappear. The one stroke nature of the device would necessitate the loading of the pumping end of the machine and thus far one would guess that Newcomen found his progress gratifyingly rapid. Thereafter, if Triewald's account of the accidental discovery of internal water injection is correct, a long period followed while Newcomen cast about for a method by means of which a speeding up of the cycle might be induced, and thus finally bring Papin's idea to a practical delivery. Here, however, the world of technics had nothing much to offer either immediately or via any conceivable process of gradual evolution.

Now that these remarks on Newcomen's engine have permitted a resumption of the development of pumping engines, one further example ought to be considered before it is brought to a close. In 1711 Mathias Höll began construction of six Stangenkünste at Windschacht all of which embodied the sector and chain. His work and its context has already been considered earlier in this study, so here it will suffice to say that his complex arrangement was very probably modelled on a simpler system used in rod engines working single lines of field rods.

What appears to be a sudden efflorescence in the use of the sector and chain device as the 18th century advances may be no more than an accident of survival of evidence, while if it is not, it might be held to reveal something perhaps, of the accelerating pace in the development of engineering skills which would accord well with the orthodox view of the relatively rapid onset of industrialization in the second half of the century. Although it would be inappropriate to discuss such larger issues here, it will not do to suppose that the 16th and 17th centuries saw little enlargement of the inventories of engineers. Perhaps the question is less whether the evidence for 18th century development has survived than whether that for the previous two centuries has been to a very large extent lost. A fairly recent survey of the historiography of the Industrial Revolution rejects the idea of a starting point or discontinuity some time after 1750 and prefers to think of that period instead as "the culmination of a most unspectacular process, the consequence of a long period of economic growth[58]. If this non-heroic view of the matter is somewhere near the truth then it seems not unreasonable to suppose that a parallel growth, either as cause or effect, was taking place in the field of mechanical engineering. The machine books, however unequal in value and however plagiarising they might sometimes be, indicate something of this development, and the growing realization of what machines had permitted to be done and might yet permit: a feeling of <u>vivitur ingenio</u>. Machine histories, as far as they can be recovered, provide the concrete evidence which shows such optimism to have been well founded.

Chronology of sector and rope/chain devices

(a) Double sectors

1488	L. da Vinci	pendulum pump
1582	P. Morris	component of pumping engine
1617	J. de Strada	pendulum pump
1652	W. Schildknecht	component of pumping engine
1659	C. Huygens	chronometer balance
1662	J. Böckler	pendulum pump
1675	C. Huygens	chronometer balance
1693	C. Huygens	chronometer balance
?1710	J. Schmidt	libra communis
1712	T. Newcomen	Dudley Castle engine
1726	J. Leupold	meterological instruments
1734	J. Höll	Hebelmaschine
1756	Anon	pendulum pump
1760	J. Sisson	balance barometer

(b) Single sectors

1488	L. da Vinci	pile driver
1502	L. da Vinci	excavating device
?1615	V. Scamozzi	adjustable water wheel
c1640	G. Desargues	pumping engine
1669	C. Perrault	balance bob
1693	J. Hadley	adjustable water wheel
1694	P. de La Hire	pumping engine
1701	G. Sorocold	adjustable wheel
c1708	Anon	vat tilting device
1711	M. Höll	T. bobs
1724	H. Sully	chronometer balance
1730	G. Gerves	pumping machine
1733	A. Barnes	T. bobs
c1750	Anon	chimney cranes
1771	W. Henry	register for stoves
c1775	Anon	candle dipping

(c) Double ropes in place of rack and sector

1488	L. da Vinci	pumping machine
1582	P. Morris	pumping machine
1652	W. Schildknecht	pumping machine
c1700	Anon	ships' tillers
1712	T. Newcomen	plug rod drive
1721-5	R. Newsham	pumping machine
1767	J. Smeaton	pumping engine

NOTES

1. The locus classicus is, of course, a footnote in Vol. 1 of Karl Marx's Capital where a plea for a history of the productive organs of man in society is prefaced by reference to Darwin's work on what Marx called 'the history of natural technology'. Capital (Everyman ed.) Vol. 1, London 1957, p.392, note 2.

2. R.U. Sayce, Primitive arts and crafts. An introduction to the study of material culture. Cambridge 1933 (rev. ed. New York 1963). His object, as he says in the preface to the second edition, "was to introduce...some of the principles that can be seen to operate in the invention, diffusion and general evolution of human artifacts".

3. Sayce's remarks (op. cit.) on this subject are very revealing especially those concerned with the phenomenon of retention of redundant features in an artifact because they seem to the maker to constitute part of its essential being, so powerful is the hold of the prototype. He gives examples of skeuomorphs from various cultures. L. Reti, 'Francesco di Giorgio Martini's treatise on Engineering and its plagiarists', Technology and Culture, Vol. 4, 1963, pp 287-98, has drawn attention to a similar sort of situation in art, and one long familiar to art historians, and has suggested that certain 'images' in technology may well have

had a similar compelling force on the imaginations of engineers.

4. C. Maltese and L.M. Grassi (eds.), Trattati di Architettura, Ingegneria e Arte Militare, Vol. 1, Milan 1967, f45v. Martini's pierced piston rods fitted with anti-friction rollers to accommodate the circular motion of the swape beam did permit force to be exerted on both strokes of the piston. However, a more exact comparison would be with Leonardo's design MS.B., f20r. As far as I know Francesco's device, if it was his, did not survive beyond the 16th century.

5. Watt's parallel motion device was first used at the Albion Mill, Blackfriars Bridge, London, when the mill began working in March 1786. No drawing exists as far as I know of Wasborough's first engine erected in Bristol in 1779. Since it was his second, built for Pickard at Snowhill, Birmingham, that had a rack removed in 1780 in favour of a crank and connecting rod (on the non-engine end) and since Watt only solved the question of positive linkage for the engine end some time later, it is conceivable that Wasborough's first engine may have borne as strong a resemblance to MS.B. f20r as Newcomen's does to MS.B. f54r.

6. An almost certain example dates from 1582 but the device was definitely in use well before 1652.

7. Cf f40 and f41, op. cit. (ed. J.H. Beck), Milan 1969. Taccola's devices were certainly common property by Leonardo's time among Italian engineers. Taccola's special form of scaling ladder working in the same way as the manganon appears in Leonardo in modified form in Codex Forster, II, f46v.

8. This becomes evident if one sketches the machine in its positions before and after firing. Two quarters are to have rope paid out from them, one quarter has the rope secured to it.

9. C. Truesdell, Essays in the History of Mechanics, Berlin, Heidelberg, New York, 1968, p.20, "Like no one else could he see", and p.62, "He shows us motions".

10. L. Reti, 'The Leonardo da Vinci Codices in the Biblioteca Nacional of Madrid', Technology and Culture, Vol. 8, 1967, pp 437-445. Leonardo's experiences with machine design would seem to demand a sober practical assessment of their value set against an analysis of existing procedures.

11. L. Reti, 'The Problem of Prime Movers', Leonardo's Legacy, ed. C. O'Malley, Berkeley 1969. But see more particularly pp 83-86. I must differ, however, with Reti's interpretation of MS.L. f76v as my reading of the excavator's action will indicate.

12. Ibid., p.85.

13. L. Reti, 'Leonardo and Ramelli', Technology and Culture, Vol. 13, 1972, p.605.

14. Morris' name is variously spelt: Morice (Stow), Moris (Patent).

15. Fynes Moryson, Itineraries, London 1617, p.11. In Part iii, p.91, Moryson explains that the name Dutchman was applied indifferently to both Germans and Hollanders because their language and manners were so similar.

16. J. de Strada, Künstliche Abriss, Vol. 1, Frankfurt, 1617, fig. 43. The caption runs: Ein machina durch hülff eines Menschen und eines Gewichts und zwei Pompen das Wasser in die höhe zuheben. The advantage of Strada's form of the machine is presumably constructional (I refer to the uncut top of the wheel). If, as in Morris' upper wheel, the top were not cut away, a band of iron could be placed round the upper part of the curve and thus provide a good anchorage for the end links of both the pump chains. G.A. Böckler, Theatrum Machinarum, Cologne 1662, takes his figure 102 directly from Strada.

17. P. Skippon, An Account of a Journey made thro' part of the Low Countries, Germany, Italy and France, p.464, in J. Churchill, A Collection of Voyages and Travels, Vol. VI, London 1732. Skippon was in Germany in June 1663.

18. A feature that makes one suppose Morris' model may have resembled Strada's pump. As for the double or reverse chain, it remained long in use. Barney's engraving, published in 1719, of the Dudley Castle engine (Newcomen's first engine of 1712) shows the plug rod given a positive downward drive in this way. John Smeaton used it for his Borough Wheel (London Bridge) pumping engine of 1767.

19. W. Schildknecht, Harmonia in Fortaliciis, construendis, defendendis et oppugnandis. Das ist: Beschreibung Festungen zu Cawen, Part III, Stettin 1652, p.116, plate Z, No. 1.

20. Ibid., Part III, p.117.

21. See below, p.428 for further remarks on this engineer.

22. A. Ramelli, Le Artificiose et Diverse Machine, Paris 1588. There are other variations on this theme but No. 32 may stand for the type.

23. W. Schildknecht, op. cit. Three pumps are shown, two in plate Z, p.117, one on plate A, p.120. Little appears to be known of Schildknecht's biography. The title page of his book speaks of him as one time engineer to the Prince (Fürst) of Pomerania and as still engineer, ordnance master and surveyor to the city of Stettin where his book was published. J.H. Zedler, Grösses Universal Lexicon, Vol. 34, Halle and Leipzig

1742, p.1545, has little to add to this except to misquote the title of his book. However, Zedler's separate entry for Wendelin's son Christian (1626-1679), successively major and colonel in the private guard of the Duke (Herzog) Gustav Adolphe of Mecklenburg-Gustrow, helps perhaps to establish some idea of Schildknecht senior's floruit.

24. Sir Edward Ford's machine at Somerset House, London, sketched by B. de Monconys in 1663 and published in his Journal de Voyages, Vol. 2, Lyon 1666, p.29, fig. 3, hardly solved the problem of how best to do this but shows what an amateur was likely to come up with. The evolution and history of the face wheel has not so far as I know been attempted but what would be elements in such a history spring readily to mind: Besson's water driven face cam working a swape, of 1579, reappears turned upside down and driven, not driving, in James Watt's first proposal of 1781 for converting the reciprocating action of the steam engine into rotary motion. Obviously the idea remained in circulation between these two dates to offer Ford a hint.

25. R. Taton, L'Oeuvre Mathématique de Girard Desargues, Paris 1951, p.64. Although nothing is known of what he communicated, it was Desargues' lifelong habit to give free instruction

to tradesmen and craftsmen with whom he would also share his ideas. Desargues believed that by contributing to technical progress he would do most to ameliorate the lot of the poor.

26. Christiaan Huygens, Oeuvres Complètes, Vol. 7, Correspondence (1670-75), The Hague 1897, Letter No. 1844, 22 Sept. 1671.

27. Ibid. Letter No.1850, 29 Oct. 1671.

28. His presence in Paris in 1658 has been established from a will he made in that year, cf J. Balteau, Dictionnaire de Biographie Française, Vol. 10, Paris 1962, pp 1183-84.

29. His Traité de Mécanique, Paris 1695, Proposition CXV, pp368-374, contains the same description.

30. B.F. de Belidor, Architecture Hydraulique, Vol.2, Paris 1739, Part 1, Ch.4, p.161, mentions that the swape beams are 30 feet long, the rollers 8 inches and the waved wheel 7 feet in diameter. Such a pump would lift water 150 feet at the rate of over 1250 gallons an hour (my rendering of Belidor's 5,500 pintes or 19½ muids per hour).

31. Traité des Épicycloïdes, Paris 1694, Proposition IX, pp 68-72: "Construction d'une machine pour élever de l'eau sur la forme précédente". A necessary work, Le Hire explains, because "...je n'ay point sçu que cet excellent Géomètre eut jamais rien expliqué de sa construction...je crois

qu'il en avoir seulement determiné la figure méchaniquement".

32. Op. cit. Book 10 of epicycloids and their use in mechanics.

33. Ibid., p.297.

34. Op. cit., plate 7, figs. 1, 5, 6 and 8.

35. V. Scamozzi, L'Idea della Architettura Universale, Vol. 2, Venice 1615, p.370. L. Reti, in 'The Problem of Prime Movers', traced the diffusion of the idea from Leonardo. Juanelo Turriano appears to have used such a wheel at Toledo in 1569; at least, the words used of the wheel there, that "la creciente del rio no puede impedirlo", seem to suggest this. See L. Reti, El Artificio de Juanelo en Toledo, Toledo 1967, p.19, quoting Zuccaro. The use of screws to lift wheels continued after Scamozzi's time but in the two examples known to me they were provided only in case the wheel got damaged and needed to be lifted clear of the water for repair. Belidor, op. cit., Vol. 1, Part 1, Ch. 1, plate 3, shows an engraving of such a mill at Mont-Royal on the Moselle. His description will be found on p.296. The wheel of Laurent's pumping machine at Pontpean, Brittany, built in 1755, could also be lifted by screws in case of damage. A full description is given in the Encyclopédie, Vol. 13, Paris 1765, p.10, under "pompes". Perhaps Leonardo

had intended nothing more in the first place.

36. Celia Fiennes, Journeys, London 1888, p.140 (London 1948, p.170). The best short account of George Sorocold's career is by F. Williamson in Derbyshire Archaeological and Natural History Society, N.S. Vol. X, 1936. Sorocold died of his injuries c.1717 after falling into the wheel-race at Cotchet's Silk Mill, Derby.

37. Philosophical Transactions, Vol. 37, 1731, No. 417, pp 5-12 and plate 1.

38. C. Huygens, Oeuvres Complètes, Amsterdam 1967, Vol. 17, p.88ff (scheme of 1659) and Vol. 18, p.501ff (schemes of 1665 to 1693).

39. Ibid., Vol. 17, p.88, fig. 13.

40. The title pages of both editions of the book are undated. The author, signing himself I.A.S.D., has been identified as Johann A. Schmidt. The British Museum catalogue tentatively gives the date of publication of both editions as 1710. It might here be noticed also that John O'Kelly in his letter of 1725 was to speak of the beam and sectors of the Newcomen engine as being exactly like an ordinary balance.

41. C. Huygens, Oeuvres Complètes, Vol. 6, Correspondence (1666-1669), The Hague 1895, Letter No. 1769, 28 Oct. 1669.

42. Not discussed here are double ropes as an aid

to the steering of men-of-war which came into use almost simultaneously in the English and French navies soon after 1700; double chains employed by Richard Newsham in his fire-fighting pumps of 1721 and 1725, the single sector and chain used by George Gerves in his pumping machine of c.1730,and by William Henry in his sentinal register stove of 1771. After 1771 references become even more abundant.

43. The plate is reproduced in R.T. Gould, The Marine Chronometer, London 1960, pp 35-36.

44. Jacob Leupold's meteorological recording devices of 1726 exemplify very well a rapidly developing expertise: Theatrum statici universalis, sive Theatrum aero-staticum..., Leipzig 1726, plate XXIII, figs. II, III and IV. For a description of Leupold's machines and reproductions of these engravings see H.E. Hoff and L.A. Geddes, 'The Beginnings of Graphic Recording', Isis, Vol. 53, 1962, pp 287-324.

45. Magellan's balance barometer is figured in W.E.K. Middleton, History of the Barometer, Baltimore 1964, p.103, fig. 6.9.

46. M. Daumas, Lavoisier: Théoreticien et Expérimentateur, Paris 1955, Ch. VI, p.146. His fig.5, plate III, does not show the chain clearly but it is distinctly shown in J.B.M. Meusnier,

Description d'un appareil propre manoeuvrier differentes espèces d'airs, Vol. 2, Strasbourg 1787, p.432. J. Leupold, Theatrum Machinarum Hydraulicarum, Vol. 1, Leipzig 1724, p.52, shows three types of chains including the lyre-shaped variety. Vaucanson (b.1709) was then fifteen years old. But in any case they are to be seen in G. Agricola, De Re Metallica, Basel 1556, bk VI.

47. Recueil de Planches, Vol. 5, Paris 1767, plate VIII, fig. 9, of Fonte des Cloches.

48. Ibid., Vol. VIII, Laminage de Plomb, plates 2 and 4. For a description of the process see Encyclopédie, Vol. IX, Paris 1765, p.230.

49. P. Rémond de Saint-Albine, Mémoire sur le laminage de plomb, Paris 1731, p.45 (Query No. 1).

50. The Castle Museum, York, has preserved an entire tallow candle maker's shop. The candle dipping machine is so beautifully counter-weighted that an exquisite degree of control is possible. More importantly its use eased the operative's work while permitting production to be increased by over sixty per cent. A. Rees, The Cyclopaedia, Vol. VI, London 1819, sub Candles, making of dipped, states, somewhat vaguely, that such machines had been introduced "within 15 or 20 years past". The section in question is, however, likely to have been written as early as 1795. For

Rees' machine see Plates, Vol, II, 1820, Candle Making, figs. I and II.

51. Duhamel de Monceau, 'L'Art du Chandelier', Description des Arts et Metiers, Vol. 1, Paris 1764. Producing chandelles plongées was an extremely unpleasant job, especially the last part which involved forcing their bases against a hotplate so as to ensure that they would stand upright.

52. H.W. Dickinson reproduces a drawing of the machine in John Wilkinson, Ironmaster, Ulverston 1914. The layout, reduced to two cranks, and wrongly ascribed to John Wilkinson, is diagrammatically represented in J. Needham, Science and Civilization of China, Vol. 4, Cambridge 1965, Part 2, p.380.

53. The Ironwork Gallery in the Victoria and Albert Museum, London, has one extremely elegant example and the remains of another. The example in the Castle Museum, York, is decidedly a heavy duty type, as will be evident from the photograph. L.A. Shuffrey, The English Fireplace and its Accessories, London 1912, p.62, fig. 69, shows the type reduced to essentials. See my article 'Sophisticated Cranes', The Connoisseur, 1974 (June) for further details.

54. The Transactions of the Newcomen Society, Vol. XXXV, 1962-63, pp 3-58. Also reprinted in

Clerks and Craftsmen in China and the West, Cambridge 1970, pp 136-202.

55. Originally printed in *The Ladies Diary*, London 1725, but quoted in L.T.C. Rolt, *The Pre-History of the Steam Engine*, London 1963, p.6.

56. Op. cit., Vol. 25, p.259. The caption to the engraving merely records 'Two pumps in a frame worked by a pendulum'. A carpenter would be needed, the writer adds. Altogether it would seem that Note 1, pp 172-3 of Lynn White's *Mediaeval Technology and Social Change*, Oxford 1963, stands in need of revision.

57. See *Technology and Culture*, Vol. 12, 1971, p.451, fig. 1.

58. R.M. Hartwell, 'The Causes of the Industrial Revolution: an essay in methodology', *Economic History Review*, 2nd Series, Vol. 18, 1965, p.180. An *obiter dictum* of Alfred Marshall quoted by Hartwell is equally apposite, "economic evolution is gradual and continuous in each of its numberless routes".

Chapter Seven CONCLUSION

The literature of the history of technology concerned with the early modern period of European history is scarcely distinguished by its abundance, least of all in work attempting to view the period as a whole. The period has, in short, languished as something of a terra incognita lying between a medieval Europe seen increasingly as highly receptive of new technical ideas and making significant advances as a result of its readiness (however engendered) to explore and exploit their potential for increased production, and the further and more familiar frontier of the industrial revolution of the late 18th century concerning which there is again general agreement that the pace of technical change was subject to a renewed, and indeed unparalleled, acceleration. The implication is obvious. The result of such a perspective has been a marked disposition to think of the interval of roughly three centuries lying between these two dynamic episodes as having been by contrast a period of technical consolidation, or even stasis, in Western Europe rather than one of sustained development. And this despite the eloquent insistence of a great many commentators* over the last hundred years that technical change is essentially evolutionary in its nature, that every item seems in the last analysis to be linked to every other item in a series of endless and interlocking sequences, and that to think of it as taking place in

* Notably John Nef, whose work certainly called for a revision of thinking on the conventional timing of the industrial revolution.

discrete stages is simply to ignore the real complexity of events[1]. This latter notion inevitably falsifies the history of techniques (and of technology generally) for by denying perpetual movement it leads directly to a further conceptual difficulty. If evolution is denied, then plainly technical advance can be seen only as proceeding via a series of 'revolutions' which, thus brought arbitrarily into existence, have then to be explained, in heroic terms, of great inventors and epoch-making inventions[2].

It was exactly this manner of conceiving the history of technology that Endrei sought to combat in his study of the European textile industry. He sought to show specifically that the generally accepted notion of immobilism in spinning and weaving techniques in the period from the late middle ages to the time of Hargreaves and Arkwright was false. The discovery of evidence of progress in this period would serve to 'combler ainsi la lacune énorme'. In surveying his findings he concluded that it was indeed wrong to think of those techniques as having been arrested in their development with renewed advance awaiting a great epoch or an outstanding personality: "Quel que soit le domaine particulier, ou l'époque que nous examinons, nous y trouvons le mouvement compliqué des méthodes de production - nouvelles, perimées ou fossiles - la lutte de l'ancien et du nouveau. Il est donc tout à fait faux de limiter cette lutte à quelques époques revolutionnaires"[3].

The objective of the present thesis has been not dissimilar and has sought in particular to illustrate some aspects of the development of machine design. I have traced some of what I take to have been the major features of development in this area which took place in the three centuries separating the middle ages from the modern period of western European history. What emerges is a picture of continuous evolution in the application of mechanical ideas in new combinations to new uses in innumerable branches of industry. Such a picture is, needless to say, quite incompatible with any notion of discrete stages in the history of technical development as far as machine design is concerned, an area of activity which by any reckoning is one of crucial importance.

What is perhaps the most surprising feature of the current persistence of the idea that the period from c.1450 to c.1750 was a static interval between two dynamic stages is that it ignores a wealth of evidence surviving from those very centuries of a nature clearly incompatible with any such conception. From the publication of Polydore Vergil's De inventoribus rerum onwards there was never any doubt in the minds of contemporary writers that new inventions and especially new machines had changed the world. The passages in which Cardano and Dee, Bacon and Sprat, Huygens and Leibniz speak of machines convey in the most lively fashion the intellectual excitement they felt at the prospect that ingenuity (in every sense of that word) and the exercise of mind was disclosing. And what are the machine books of Besson, Errard, Ramelli, and their imitators, if not the honeymoon of the Europeans and their machines with the longer and more sober experience to follow? The mood was one almost of exultation. The essence of what all such commentators have to say is much as Defoe expressed it in 1727: "As the most glorious empires in the world had their beginnings in the little adventures of single men or the small undertakings of a few; so the most flourishing arts, the most useful discoveries, and the most advantageous improvements which the world now boasts of had their foundations in small things; and from thence have increased and been brought to their present perfection...we have infinite advantages beyond what the ancients could pretend to...for we stand upon the shoulders of three thousand years application". And the rate of change had accelerated: "...to look back a little between the years 1400 and 1600 almost all the greatest and most illustrious improvements...have been found out; or at least extended in these parts of the world"[4].

"These parts of the world" as Poppe judged the situation in 1807 were certain of the western nations in which craftsmanship and technical development had notably flourished: "In Teutschland, England, Frankreich, Italien und in den Niederlandern blühten freylich die Handwerke und Künste am meisten", although in the 17th and 18th centuries the lead over all others had been taken by

England and France: "besonders gewannen England und Frankreich herein vor ellen übrigen Ländern die Oberhand"[5]. Poppe was surely right to think of these developments as long term and as taking place in a broad European setting, for the process of technical change which the western nations had experienced extended over many centuries. It had brought them each, severally, by the middle of the 18th century to advanced (if not identical) stages of development. But the flow of new techniques (to say nothing of cultural exchanges)passing by innumerable channels between them had ensured that all had shared, in large measure, in what was in fact a common material culture even if transfer of ideas was not perhaps as perfect as Montesquieu (tout se communique) writing in 1728 supposed it to be.

There were obvious reasons why some technologies did not diffuse, for not all were suitable for transfer. Then again, the variety of natural endowments and of climates imposed their own constraints in terms of which a range of specialized technologies found their place: the Dutch were the experts in land reclamation, the Germans in mining, and so on. Danger lies, however, in overstressing such differences. Recent historical writing indicates very clearly in particular that the more that is discovered about the history of economic development in Europe the harder it becomes to define the precise differences between the English and the other 18th century economies. But if this is so, how may such a conclusion be reconciled with the notable tendency of historians of the Anglo-Saxon world to see the distinctive features of the English economy and the technology on which it was based, as the norm, the yardstick against which the continental nations were to be measured (inevitably to their disadvantage)?[6]. It is here that an idea I have sought to develop in this thesis may appear to be of some utility in correcting the distortion of historical perspective which has caused English technological advance to appear as the developmental norm. It would seem rather that there were two models of development - the English and the German - which, proceeding in certain essentials quite separately during the 16th and 17th centuries, had permitted both these nations to achieve a sustained expansion of their industrial activities. The English model was, of course, based on a mineral fuel technology to which a new prime mover was added in the 18th century. The German model based on traditional fuels was able by reason of a vast endowment of forests rendered exploitable by a sophisticated float-flume technology to sustain a continuous development of its many industries. Pierre Grignon was not dealing in empty rhetoric when even so late as 1775 he could apostrophize Germany as "la patrie des machines"[7].

Both models exemplify perfectly the truth of von Born's remark that "wants and climates going hand in hand are the first teachers of men"[8]. By the middle of the 18th century there was indeed the growing reality of a third model, in essence a synthesis arising in almost Hegelian fashion from those of England and Germany. By that time English and German technology alike were being exploited in France as local conditions warranted, the choice of one or the other being made on purely rational grounds. It is not without significance that it was a Frenchman, Gabriel Jars, who was able to see that such an eclecticism was not to be found in England and Germany. The English, he noted, commonly abused the steam engine (and, he might have added, the use of coal) by neglecting to exploit water power, while German engineers committed the opposite error and failed to behave in an economically rational manner by reason of their commitment to hydraulic engines. It would, however, be foolish to refuse to recognize that even within the tight limits imposed by the then state of technological development the English model possessed more potential for growth than any other. How could it be otherwise, when England supplied its needs for heat and energy from sources accumulated over millions of years? The increments afforded by the annual rhythm of vegetable growth were not inconsiderable but must pale into insignificance when set beside the capital resources afforded by geological time. There is no doubt that the point had been clearly taken in France and Prussia long before 1780: conventionally the beginning of the industrial revolution. But equally evident is the fact that until a technology had been developed for the transportation of coal in bulk at low prices, the sets of conditions which had brought the regional responses, or models, into existence in the first place would remain substantially unaltered. The totally new power that technology was soon to exhibit in transcending such obstacles is what is finally impressive. The real revolution (if the word is to be used at all) in Europe, and in England as well, was brought about by the development of steam locomotion and the building of the great networks of railways. It was then and only then that the possibility of the English model sweeping aside other modes of development and assuming, for a time, universal (or at least pan-European) dimensions, expanding so as to draw all regions into a technological ecumene became a practical possibility. Waterloo may not have been won on the playing fields of Eton but a great deal was settled in October 1829 on Rainhill level.

I have sought to demonetarize the currency that sets a high value on the notion of revolution, of outstanding inventors, and of men of genius snatching their ideas out of nowhere. It is important, however, to understand that to argue for an evolutionary approach is not to subscribe to any notion of 'vast impersonal forces' before which the individual is powerless and by which men in general are swept along, but rather simply to insist on the evidence and in so doing restore a more human scale to events[9]. The stereotype of inspired genius, the artefact of ignorance, denies both. The necessity of choice and the need to choose among a variety of possibilities is not denied by technical development but is largely a product of it. But one cannot 'choose' everything, or, having chosen to travel a particular route, very readily reverse or wish to reverse the logic of that choice, still less deny the fundamental axioms, that is the values, which underlie that logic. John Bell of Antermony, travelling through the Eurasian steppes in 1719, recorded that the worst curse one Kalmuck could hurl at another was that he might "live in one place and work like a Russian"[10]. On their side, the Europeans might dream of the noble savage and lament the damage done to human nature by the forms of their society, but more telling is the manner in which Robinson Crusoe, presented with something like Defoe's 'universal blank', set about recreating his lost world with all the resourcefulness he was able to muster. But in neither case should these responses be seen as inevitable, predestined or in any other way beyond human control. It was as Vico remarked in the Scienza Nuova in his final statement on all human striving: "That which did all this was mind because men did it with intelligence, it was not fate because they did it by choice"[11].

NOTES

1. There can be little doubt of the importance of Darwin's work in the crystallization of such ideas. Karl Marx explicitly acknowledged the debt in a footnote of volume one of Capital (see ch. 6, note 1): technology shaped human society just as natural technology shaped the animal world. Parallels to Marx's comment that "a critical history of technology would show how little any of the inventions of the 18th century were the work of one single individual" may be found in the writing of V.E.P. Chasles (Le Progrès, Paris 1864) and Samuel Smiles (Industrial biography, London 1863.

2. The abuse of the word 'revolution' in the writing of economic hstorians scarcely requires documentation. One should look for an explanation perhaps in the influence on their thinking of analogies drawn from political economy. The absence of an adequately developed history of technology is doubtless also responsible for a certain naivety in the approach of economic historians to technical problems.

3. W. Endrei, L'évolution des techniques du filage et du tissage du moyen âge à la révolution industrielle, Paris 1968, p.8.

4. D. Defoe, *The history of the principal discoveries and improvements in the several arts and sciences*, London 1727, preface.

5. J.H.M. Poppe, *Geschichte der Technologie...bis an das Ende des Achtzehnten Jahrhunderts*, Göttingen 1807, Vol. 1, pp 23 and 31.

6. A. Millward and S.B. Saul, *Economic history of continental Europe*, London 1973, Vol. 1, pp 30-40, provide an excellent critique of such supposed differences. Lewis Mumford characterized the stressing of differences as a "British provincialism".

7. P. Grignon, *Mémoire de physique sur l'art de fabriquer le fer*, Paris 1775, p.199, note (a).

8. I. von Born, *Travels through the Bannat of Tesmeswar, Transylvania and Hungary in the year 1770* (trans. R.E. Raspe), London 1777, preface,p.vii.

9. The phrase is T.S. Eliot's. See also I. Berlin, *Historical inevitability*, London 1954, for a refutation of teleological theories including Marx's technological teleology.

10. J. Bell (of Antermony), *Travels from St. Petersburg in Russia to diverse parts of Asia*, Vol. 1, London 1763, p.33.

11. T.G. Bergin and M.H. Fisch, *The new science of Giambattista Vico*, New York 1948, p.382.

APPENDIX

Wood Transport on flumes and floatways

(i) Historical outline

I have suggested earlier in this thesis that the growth of population and the decisive steps taken in the 11th and 12th centuries towards the mechanization of the basic industries through the development of water powered, cam-driven devices led to a growing pressure on fuel supplies in Europe. The drive for increased production was accompanied by a growing capitalistic or entrepreneurial spirit whose origins, along with much else, have been divined by some to have resided in the coercive attitude towards nature of western Christianity in general, and by others in the institutions of western monasticism[1]. If this was so, then thus early did such values as the work ethic and the profit motive begin to produce their train of spiritual and material sequelae[2]. However this may be, the growth of centres of concentrated fuel consumption, whether cities, salt works, mines or smelters, could not but lead to problems of fuel supply as stands of timber available in the immediate vicinities of those centres were cut and consumed[3]. In such circumstances, as the radius of provisionment of each inexorably widened, the ordinary means of land transport became increasingly uneconomical and then quite unable to cope physically with the quantities of timber it was necessary to haul[4]. The only response possible (other than passively accepting the situation) was to begin using rivers and streams for the floating of wood. By this means distant and hitherto unexploited reserves of timber could be brought at small cost to the places of consumption[5]. Such floats might consist either of long, steerable trains or rafts of bound logs or loose billets swimming freely with the current. Inland transport of wood by means of ships was also resorted to but seems, judging by documentary evidence, to have been later coming into use than either of the other methods[6].

The earliest direct references to the rafting of timber on the Elbe for the service of the mines of the Saxon Erzgebirge, although scarcely numerous, indicate that the river carried significant quantities of timber as early as 1325, while indirect references permit the history of this traffic to be traced back to 1292 and with rather less certainty to 1177[7]. As for the smaller rivers and streams flowing northward from the Bohemian frontier such as the Zwickau Mulde, the Weisseritz, the Freiberg Mulde and the Floha, it seems likely that all were in use as free floating streams by the 14th century, although it is only through references to it for Zwickau (in 1316 and 1348) that free floating may be traced back so far. However the Rotengraben (an artificial water course) serving Freiberg was certainly in use before 1400[8]. Thereafter the network of artificial channels (Graben) was steadily extended to supplement the ever more ambitious schemes of management to which the natural streams were subjected. What these might entail is best illustrated by reference to the Zwickauer Bildrolle of 1570[9]. This document, a colour washed drawing measuring 60 cms by 618 cms, was made as a result of a lawsuit brought against the town council of Zwickau by the commune of Scheweditz following the expiration of agreements concerning the boundaries of meadow land. On it are shown the river engineering works along the river Mulde from Zwickau itself to the Kainsdorf weir, that is, the main weir at Zwickau, the rake-works (Rechen), structures for arresting floating timber, on the Mulde and the Muhlgraben, flood diversion channels and bank revetments. Many of the constructional details of these structures shown in the drawing (a unique source of reference for the period) are of the highest interest. One might mention as an example the use of wooden cribs (Steinkasten) packed with stones (and presumably also with clay) which served to buttress the banks of the overflow channels and to secure the wooden planking of their flood beds[10].

But Saxony was but one of a great number of regions whose economic life (in this case largely based on mines and smelters) was sustained by the enormous masses of timber borne to them on rivers, streams and flumes. The great salt works which boiled down the brine of such places as Hall, Hallein and Bad Reichenhall in the Tirol and Bavaria were consumers of wood on a scale which eclipsed even the demands of mining and metal working. At Hallein on the Salzach a rake-work existed already in 1204, a structure which was enlarged and improved in 1494. The fuel needed for the salt pans was derived from forests totalling some 100,000 hectares (250,000 acres) whose annual yield, floated as free-swimming billets along innumerable streams, amounted to something in the region of 140,000 to 160,000 cubic metres: equivalent in thermal value to something like 40,000 tons of coal[11]. At Hall on the Inn likewise a large rake-work existed in 1307 and was called, significantly enough, the "work" (Werch)[12]. By no later than 1400 a similar construction caught the wood carried down by the Saalach to Bad Reichenhall. Here, however, the forest reserves became unequal to the needs of the salt works when a new brine spring was discovered in 1613 whose salt content was nearly as high as that of the old Edelquelle (noble spring)[13]. At first an attempt was made to avoid the need for extra fuel (which was in any case unobtainable) by building, in 1615, a graduation house (Strohkunst, Leckwerk) in order to concentrate the brine before boiling. The graduation technique, in itself evidence of fuel shortage, had by then been in use for something like fifty years in other regions of Germany[14]. At Bad Reichenhall, however, it was not a success and it was in these circumstances that an idea mooted as early as 1613 was taken up in earnest. This was to pump part of the brine over the mountains to Siegsdorf where adequate reserves of fuel were available. Work was begun on the pipeline in 1617 but it now became part of the plan to continue the line beyond Siegsdorf to Traunstein, lying 31 km to the north west of Bad Reichenhall. Seven pumping stations (some worked by Stangenkünste, some by horses: Ross Künste) forced the brine up to a height of nearly 900 feet to Lettenklausen near Inzell whence it ran by gravity to Traunstein. The construction was pushed through with such speed that by August 1619 the salt pans at Traunstein were boiling down the first supplies of brine delivered through the pipeline. The daily rate of discharge approached 25,000 gallons[15]. The great city of Augsburg with its multiplicity of industries came to depend for its life-line at a very early date on the innumerable streams and floatways all of which fed the Lech and the Wertach at whose confluence the city stood. The quickest way to reduce the city to submission in war was in fact to intercept its flow of building timber (Zimmerholz) and firewood (Brennholz), a tactic employed by Duke Albrecht of Bavaria in his struggle with the Augsburgers in 1468. But its dependence (via the Lech) on the high forests of Aschau and Reutte in the Tirol had begun long before that as the guilds of float workers in existence in the 13th century testify. As for the Wertach the right of Augsburg to use the stream for floats unhindered and in perpetuity was granted to the city by Abbot Heinrich of Irsee in 1304. On both rivers the floating season began in March and lasted until November or December[16].

With the passage of time more and more regions came to depend on water transport systems for the conveyance of wood, so that by the 16th century what had certainly been originally German techniques (most probably first developed in Styria, the Tirol and the Salzkammergut) were in use virtually throughout Europe. Paris began to be supplied with fuel by such means when the headwaters of the Yonne downstream to Cravant were adapted for free floating in 1549. Later the Saulx and Ornain, tributaries of the Marne, were also engineered to fit them to deliver _bois perdu_[17]. At much the same time Juanello Turriano in a section of book XV of his _Viente y uno libros_ of c.1560 entitled 'De Los Arboles' reveals the already extensive use of such floats in Spain although the fact that he found it worthwhile to suggest ways of improving the courses of natural waterways would seem to indicate an imperfectly understood technique[18]. Edward Browne noted in 1669 that the Venetian glass houses of Murano drew their supplies of fuel from the Alps floated along a conduit of masonry called the Brentella which ran from Spilimbergo on the Tagliamento south westwards to the lagoon[19]. In eastern Europe the important mines of central Slovakia possessed extensively developed water transport systems long before the one thousand two hundred yard long rake-work across the Gran (Hron) at Neusohl (Banska Bystrica) was constructed by experts from Styria in 1547[20].

Europe continued to depend ever more heavily on its forests for fuel until well into the 19th century except for certain restricted regions where coal mining was well developed[21]. Large scale engineering works continued to be undertaken to relieve the fuel shortage. As an example of the magnitude which such work might attain during this final period of Europe's eotechnic phase (c.1790-1830) one might take Joseph Rosenauer's scheme to bring the Urwald of southern Bohemia, a terrain of some 700,000 acres of hitherto unexploited primeval forest, into active exploitation. Vienna, some 250 km to the east and perenially short of fuel, was the market he sought to supply. In 1758 Rosenauer entered the service of Prince Johann Adam Schwarzenberg who soon recognized his talent as an engineer. In 1770 he was appointed forest engineer of the Krumau (Krumlov) forest, a portion of the Schwarzenberg domains. During 1774-75 he made an exact survey of the line along which a flume 49 km long might be constructed, beginning at 925 metres on the northern slopes of the Dreissesselberg and falling at 790 metres into the Zwettlbach, at Rosenhugel. His plan was then to use the already canalized courses of the Zwettlbach (of 7.6 km) and the Grosser Mühl (38.5 km) into which the former flowed, to convey timber to the rake-work at Partenstein, a little above the confluence of the Mühl and the Danube. Work was begun in 1789 on what came to be called the <u>alter Kanal</u>, a stretch 31.6 km long running from Rosenhugel to Seebach. This was completed and in use by 1791. The upper stretch from Lichtwasser to Seebach was completed long after Rosenauer's death. Rosenauer's original plan for this section of 17 km was to route the flume along the 900 metre contour, but when work began in 1820 it was decided to shorten the line by driving a tunnel through the Flosselberg. This cut over 7 km from the length of the flume by avoiding Rosenauer's projected contour line round the Jokesberg. The tunnel, 419 metres long, was driven through solid granite in the winters of 1821 and 1822 and by 1824 the neuen Kanal (new flume) 9.7 km in length was linked to the already existing section at Seebach/Hirschforst. Until 1870 the annual delivery of wood along the route averaged well over 100,000 cubic metres (or in coal equivalent 25,000 tons). Even in 1880 an impressively large work force in military style uniform (the Schwarzenbergischen Grenadiere as they were called) operated the installations. Two hundred and sixty signallers armed with discs mounted on long poles, six hundred and fifty throwers-in of logs and three hundred and twenty auxiliaries formed the permanent work force on the canal[22].

(ii) The technology of wood transport.

As with virtually every aspect of the history of technology the problem of vocabulary in relation to the techniques of hydraulic engineering as applied to the transport of wood has to be resolved in some degree if the source materials are to be correctly understood. Its nomenclature was in fact always highly variable, and according to Neweklowsky such variability is to be found in the records of even the earliest period of wood floating[23]. The word Trift, for instance, (from treiben: to drive) which in more modern usage came to signify free floating wood was often used interchangeably with Flotzen or Fletzen (from fliessen: to float) whose modern equivalents Flösse and Flösserei refer more correctly to the rafting of timber. Then again as far as free floating was concerned a distinction was sometimes drawn between wood floated on natural watercourses (Holztrift) and that conveyed along flumes (Holzschwemme: swim wood) although here again both Trift and Schwemm were used interchangeably at an early period.

As far as water transport of timber is concerned it is clear that there were three principal modes in use: that conveyed (a) in ships (Schiffahrt), (b) in rafts (Flösserei) and (c) as free swimming timber (Trift). But before the wood actually reached the water it had usually to be transported some distance to it from higher ground. This was done by means of (1) shoots or slide-ways (Riesen) where the slope was sufficient for the wood to be able to deliver itself or (2) wooden tracks of gentle gradient (Winterbahnen, Schmierwege) on which it was necessary to apply some tractive effort to the timber. Although whole tree trunks (Bau-Lang oder Zimmerholz: building or long wood) were usually rafted, this was not invariably the case. Most fuel timber (Brennholz) was, however, floated as free swimming billets for at least part of its journey.

It is obvious that only large rivers could in general be used for Flösserei, and the principal works necessary to ensure the passage of trains of timber were specially constructed glide-ways or flow paths (Flosgasse) in the regulating weirs along the rivers which bore such traffic. There were, of course, a variety of techniques for the lashing together of the raft timbers, to say nothing of the special procedures to be followed when woods of different species (and different floating characteristics) were to be floated together.

As for the smaller streams, although these might occasionally provide a sustained flow sufficient for Trift work, it was usually only at the time of spring snow melt or after heavy rains that most could be exploited. It should be noted here, in anticipation of section (iii) which examines the situation in more detail, that the heavy cutting of timber in the catchment area of any stream would begin almost at once to affect its regime adversely. Large scale cutting accelerated the rate of run-off of rain or melting snow and led consequently to a much attenuated flow after the flush had passed and to a greatly shortened floating period. For this reason it was usually necessary to construct catchment reservoirs (Floss-teichen) to regularize stream flow after the initial flush was finished. Sometimes indeed a whole series of temporary structures more like flash locks or sluices (Klausen) would be built step-wise at intervals of a mile or so up a valley lacking any sufficient natural stream. These would be opened in succession to flush stocks of cut timber down to a lower point where a stream existed along which they might be floated further[24].

Trift streams (Triftwasser) even if they flowed with sufficient strength, were, unlike raftable rivers, seldom usable in their natural state. A good deal of engineering was usually necessary to bring them into exploitation. Rocks were the worst danger to floating wood and led to a high rate of loss through the splintering of billets. But sand banks were also very troublesome, as were sin-uosities in the water course. All had to be remedied. Nor could the stream at low water carry more than 60 to 100 centimetres of water since otherwise the Senkholzer (sunk logs) lying on the bottom could not be recovered. These might amount, according to the buoyancy of the type of wood being floated, from 4 per cent to 12 per cent of the total swim[25]. By degrees as a stream's bed was paved with planks, or its banks reveted with timber, as its course was furnished with cut-offs to eliminate meanders and with floating guide booms to direct billets away from sand banks, it became almost as much a work of art as a completely artificial flume (Graben, Schwemmkanal) fed by streams and reservoirs. Networks of such flumes draining an entire collection region (Sammelgebiet) were often switched from watershed to watershed and linked together in arterial ways leading to the points of assembly (Holzplatze). Such were the systems described by Delius in 1773 which served the copper smelters at Neusohl: Nebenfluder (ancillary flumes) ran into the Hauptfluder (principal flumes). These discharged their loads of timber into the Gran (Hron) which bore the whole mass down to the Rechen at Neusohl itself[26]. A similar system in use at Hall was described by Feigenpuz in 1707: "...Oenus, in que ope rivulorum miro artificio e montibus in unum torrentem collectorum, et per ligneos alveos subjectos ex una valle in aliam derivatorum haec ligna deportantur, suo tergo subvectat": "...the Inn, into which river this wood is conveyed by the help of mountain streams. These are joined by wonderful works into one torrent which diverted from one valley to another through a wooden flume carries (the wood for the salt pans) on its back"[27].

At the end of its course, whether along stream or flume or river, the floating timber had to be collected. For this it was necessary to construct a rake-work (Rechen). These were of various forms ranging from a simple row of vertical posts held by top and bottom rails to the massive and elaborate structures necessary on the great rivers. A Rechen was usually built at 45° to the direction of flow so as to present a longer collecting length to the stream and prevent any undue accumulation of billets. It was also necessary to select a point where the current slackened so as to reduce the impact of floating wood on the rake. The best rake position of all was behind a curve so that the river itself would tend to drive much of the timber towards the bank and thus lessen the dangerous work of pulling it off the rake itself. Wood delivered in this way was called variously Scheitholz (split wood), Klafterholz (cord wood Kurzholz (short wood) and Brennholz (fuel wood). Trift work was not exclusively concerned with fuel timber, however. The Schwarzenberg Holzschwemmkanal, for instance, was eventually modified to carry logs (Langholz) of up to 24 metres[28].

It remains finally to consider the various slide systems which served to convey timber cut on the higher slopes down to the valley floors and the water courses which flowed along them. As mentioned earlier, such slides took two principal forms. The first variety were those in which the gradient (usually about 1:8) was sufficient for the billet's own weight to carry it down to the end of the run. They were built of timbers and were given a U-shaped section. At the end of the 'pipe' the timbers were given an upward tilt so as to throw the billets well clear of the point of discharge[29]. These slides went under a variety of names such as Riese, Holzriese, Riesel, Rutsche and Holzglitsche, and were used mostly in winter when a coating of ice or compacted snow on the slide path timbers added greatly to their efficiency. Some indeed could only be used when they had acquired such a glazing. Others again could be operated only when lubricated with water. This was necessary to prevent the sliding logs from beginning to burn through friction.

As concerns the second type, those having only slight gradients, it is necessary to distinguish, following the sources, between those used only in winter and those used in summer. The former were called Winterbahnen (winter roads). The track consisted of 'sleepers' set at intervals of ten to twelve inches rather in the manner of a corduroy road with compacted snow filling the spaces. The 'sleepers' were round logs two-thirds buried with the bark peeled from the exposed surfaces standing two inches or so above the soil. Baulks of timber or 'rails' were secured lengthwise to the sleepers which thus had the appearance of a railway. But the rails were simply to prevent the sledges (Schlitten) running between them from leaving the track. Normally these sledges carried a cubic Klafter (rather over two cubic metres) of split wood (Scheitholz). Krunitz (in 1778) describes how, if such slides became mushy during the day, the work was carried on instead at night by moonlight or by the light of torches. Tracks for summer use (no doubt also winter roads in another season) were called Schmierwege (smear ways). The intervals between the sleepers were filled with tree-loppings while the tops of the sleepers were smeared liberally with fat or grease, replenished after each run[30]. As with regular railways, track junctions were equipped with points.

The decline of all these modes of wood transport set in about the middle of the 19th century with the introduction of railways and steam locomotives. The use of coal instead of timber went hand in hand with railway construction. Vienna, for instance, which had consumed 720,000 cubic metres of wood fuel in 1815, was burning only 187,000 by the late 1880s[31]. Rather more slowly the rafting of timber also lost ground to the railways[32]. But there is a curious final twist in the story. As coal replaced wood fuel and as all over Europe demand for fuel rose far above the levels the forests could have sustained, the demand for timber remained colossal. In the form of pit-props the abundance of wood was a primordial necessity for the exploitation of coal. Every ton of coal extracted 'cost' one cubic foot of timber[33].

(iii) The ecological consequences of deforestation.

The treeless devastated landscapes depicted by the illustrators of Agricola's De Re Metallica were no artistic licence and it is clear that the continually intensifying exploitation of the European forests could not but affect the hydrological balance of whole regions. The devastating effects of the technique, described in section (ii), for sluicing timber down mountain valleys can well be imagined but would be as nothing to the results following the scouring away of top soil left exposed by deforestation. Despite the great interest the subject possesses it is not one which any historian has yet attempted to trace. It is easy to see that such a study presents enormous difficulties since the evidence would, no doubt, be of a highly scattered and incoherent nature. Materials exist, however, which make it evident that by about 1700 at latest records of river behaviour were being kept. The recorders were concerned in particular with such matters as flood heights and with the ever decreasing volumes of water flowing along rivers in summer.

The secular effects that inspired such record keeping were not insignificant. It was observed that the frequency of devastatingly high floods was greater than it had been in the past, and yet, paradoxically, although this seemed (to the recorders) to constitute evidence that more rain fell than formerly, the fact remained that in summer the rivers sank to lower and lower levels, hindering traffic and sometimes preventing it altogether. These were serious consequences, for it was the major rivers which were under observation and seen to present increasingly disturbed regimes. But what was the cause? Although there was much evidence to suggest that deforestation was responsible, it was not until the second half of the 19th century that any serious experimental study was carried out which attempted to quantify the effects on a watershed of a large scale clearance of timber. In 1860, however, F. Jeandel, J.B. Cantegril and L. Bellaud published in the Comptes-Rendus of the Académie royale des sciences their Études expérimentales sur les inondations. Despite the severe criticisms levelled against its methodological shortcomings, J. Vaillant's report to the Academie on the Études expérimentales was far from unfavourable. It was clear to Vaillant that a most important area of scientific research had been opened up which, taken further, would lead by degrees to a clear understanding of how the important task of regulating water flow was to be handled. What the authors of the Études had been concerned to demonstrate, however, was that forests exerted a considerable damping effect on stream flow: that the flood crests of the forest streams in their experimental control area had been lower than those of streams in the cleared zone which they had studied. Their response to Vaillant's criticism, which indicated that for him this finding had still to be regarded as an open question, contains a number of interesting remarks*. They noted first that their study had shown beyond question that the duration of run-off of rain from their forested area was double that of the cleared zone, while in times of flood the streams of the cleared zone had more than doubled in volume compared with the forest streams. They concluded that forests had the effect of reducing by half the danger of violent flooding action from streams[34]. In support of their experimental findings they appealed to observable facts. They cited the well known case of the commune of Labrugnière (Tarn). Before the Revolution it had possessed some one thousand eight hundred and

* The Études, Vaillant's report and an appendix by the authors replying to his criticisms were published together in 1862.

thirty-four hectares of forest. Following the revolutionary legislation which removed the penalties attaching to unauthorized cutting of timber the forest had been so devastated by 1840 that it was capable of producing only trifling quantities of brushwood[35]. As the forest had disappeared violent floods had become more and more frequent, forcing the mills to stop working, while in summer the briefest dry spell reduced stream flow to such an extent that the mills were once more repeatedly forced to stop work. Remedial action, that is reafforestation, had begun in 1840, and although one hundred and fifty hectares were still waste, experience had shown that pari passu with the replanting of forest it had become possible to work the mills more regularly and that sudden violent floods had gradually ceased to occur. It had been noted that water levels in the Caunan began to rise only some six to eight hours after the beginning of rain and that their flood crests followed a regular pattern in coming to and declining from their peaks. They concluded: "Cette exemple est remarquable en ce sens que, toutes les autres circonstances etant restees les memes, on ne peut attribuer qu'an reboisement des changements survenus dans la régime du cours d'eau, changements qui peuvent se resumer en deux mots:

(1) attenuation de la crue au moment des pluies

(2) augmentation du debit en temps ordinaire.

On comprendra, d'apres l'exemple qui precede, le role capital que sont appelées à jouer les montagnes couvertes de forêts. En retardant l'écoulement d'une partie les eaux au moment des pluies, elles diminuent les chances d'inondation. En augmentant le debit des cours d'eau en temps ordinaires, elle peuvait rendre de grands services au point de vue de l'agriculture et de l'industrie.. A ces avantages, déjà si precieux, il faut ajouter encore celui d'un accroissement notable de production de combustible". But in any case, the authors concluded, travellers of such authority as Humboldt, Boussingault and Becquerel had recognized that wherever clearances had taken place on a large scale, whether in Europe, Asia or America, the normal volume of flow in water courses had diminished, that it built up again with reafforestation, and lastly that there had been no such variations before the forest cover had been disturbed[36].

The difficulty of setting up experiments of the kind that Jeandel, Cantegril and Bellaud had carried out are obvious enough. How easily can one find two catchment areas as nearly comparable as possible, both of which should initially be forested but one of which, after the first series of recordings, should be cleared of timber so as to permit a second series to be carried out?

After the Études expérimentales of 1860 it appears that only two further experimental studies have been published, that of A. Engler in 1919 on the Emmenthal in Switzerland, and that of C.G. Bates and A.J. Henry in 1928 on Wagon Wheel Gap, Colorado. The final report of Bates' and Henry's study, The forest and stream flow experiment at Wagon Wheel Gap, summarized the results of an exhaustive series of recordings extending from 1911 to 1926[37]. The two basins they had studied presented virtually identical features. Records were kept of basin A and basin B from 1911 to 1918 when both were forested and then again from 1919 to 1926 after B had been almost totally cleared. The watersheds of both were of two hundred acres. The mean air temperature of B rose from 34° to 35.3° (Fahrenheit), maximum readings were up to 2.1° warmer and minimum 0.7° colder. Soil temperature rose by up to 3.4° at a depth of twelve inches. Mean wind speed increased by 2.6 metres per second, and humidity dropped. What is of the greatest interest, however, was that a very large alteration took place in the speed of run-off. Despite the fact that the soil was coarse and had a high natural capacity for storage, flood discharge at snow melt increased by over 25 per cent, total discharge went up by 15 per cent and the ratio of peak flow to low increased from 12:1 to 17:1. Flood crests in basin B, formerly only 6 per cent greater than in A, rose on average to 64 per cent after clearance. The rapid flush of water in April and May meant that water was lost which later in the year might have served for irrigation. The "deux mots" of the Études expérimentales apply almost perfectly. As regards scouring of the terrain the nature of the soil in basin B precluded any possibility of destructive erosion, yet even so the amount of silt carried by its streams rose by eight and a half times, and, if periods of flood peak were taken alone, by twelve times. Dams were therefore not an attractive proposition. The loss of soil per acre per annum rose from 2.8 pounds before clearance to 16.7 pounds afterwards. The authors remark that these findings were untypical. Geological surveys of other cleared areas of the United States had shown that flow ratios of 50:1 were not uncommon and that readings as high as 150:1 had been known to occur, with correspondingly augmented levels of erosion.

What such studies indicate is that the eotechnic phase of European development must, without question, have been increasingly destructive of the environment, a fact which has indeed been scarcely recognized but which can have been no less damaging in its effects than those accompanying the use of coal. The scouring away of top soil, the conversion of streams into torrents, the rapid silting up of reservoirs, to say nothing of the reduced possibilities for transport and industry and the general devastation caused by floods, were the penalties attaching to an exclusive dependence on wood fuel. The patient recension of local histories would surely reveal in intricate detail the pattern of these events[38].

NOTES

1. (i) L. White, Machina ex Deo. Essays in the dynamism of western culture, Cambridge (Mass.) 1968, p.72, "...to those who search out 'why it happened', it is part of the history of religion".

(ii) L. Mumford, Technics and civilization, London 1962, p.13, "It was...in the monasteries of the West that the desire for order and power...first manifested itself".

2. St. Thomas Aquinas (1225-1274) may be regarded as a classic representative of developed medieval thought. In his writings the state is largely governed by the economic motive. The basic features of bourgeois values have become clearer still in Duns Scotus (1266-1308) who establishes the principle of the freedom of contract and in Buridan (1300-1358) in whose work the doctrine appears that a morally good man who cared for the common weal ought not to be hindered from growing rich since he brought benefits to the community.

3. The role of population growth in the rapid destruction of forests was no doubt vastly greater at first. According to G. Huffel, Économie Forestière, Paris 1920, Vol. 1, pt. 2, p.141, "...le recul de la forêt devant le cultivateur ne fut aussi general et aussi rapide que durant les deux ou trois siècles qui ont precedé la guerre de cent ans. Au commencement du XIVe siècle on ne voyait plus en France, comme au temps de Charlemagne, d'immenses zones forestières, traversant le pays d'une frontière a l'autre". What was left could be, and was, measured "en arpents, en bonniers, en acres".

4. As late as the 18th century land haulage grew ruinously expensive even for manufactured products beyond a very few miles: cf P. Mathias, The brewing industry in England 1700-1830, Cambridge 1959, p.xxxii, "With the high overland transport charges of the pre-railway age ordinary strong beer in the 18th century had an economic marketing area, by land carriage, of only four to six miles".

5. It is precisely the nature of the choices the West made and the sustained character of its determination to overcome obstacles to action that make it meaningful to speak of the dynamism of Western culture, whatever may have been the system of values, the 'calculus' which inspired it.

6. E. Neweklowsky, Die Schiffahrt und Flösserei im Raume der Oberen Donau, Linz 1964, p.235.

7. H. Wilsdorf, W. Herrmann, K. Löffler, Bergbau: Wald: Flösse, Berlin 1960, p.112.

8. Ibid., p.107. The Mulden Flösse (Graben), also serving Freiberg, was constructed in 1438. Altenberg was served before 1464 by the Aschergraben. Many more works of this sort were undertaken in Saxony in the 16th and 17th centuries. As the 17th century wore on, however, the demands of the mines for water for hydraulic engines became so great as to cut short further flume development for fuel transport.

9. The drawing is preserved in the city archives, Zwickau. Portions of it are reproduced in colour by K. Löffler, 'Die Geschichte der Freiberger Muldenflösse...', in H. Wilsdorf et al, op. cit. See especially p.81, fig. 29 and p.83, fig. 31.

10. See also C.T. Delius, Anleitung zu der Bergbaukunst nach

<u>ihrer theorie und Ausübung nebst einer Abhandlung von den Grundsätzen der Berg-Kammeralwissenschaft....</u>, Vienna 1773, p.514 and plate XXIV fig. 1. Where a Rechen was of some length Steinkasten were to be set at intervals along it. A. Solzhenitsyn, <u>Gulag Archipelago</u>, London 1976, Vol. 2, p.86, recounts that wooden cribs of this sort, up to fifty feet high, were built to support the lock chambers on the Belomor (White Sea) canal in 1931-33.

11. E. Neweklowsky, op. cit., pp 538-39. The Rechen at Hallein was one of the largest in Europe.

12. Ibid., p.538.

13. M. Flurl, 'Ältere Geschichte der Saline Reichenhall vorzüglich in technischer Hinsicht bis zur Erbauung der Hülfs-Saline Traunstein', <u>Denkschrift der königlichen Akademie der Wissenschaften</u>, Munich 1811, Vol. 2, p. 183. The new spring called the Plattenfluss (silver fountain) delivered something over 400 gallons a minute. About 4.5% of this was being pumped twenty miles to Traunstein by 1619.

14. The idea was to accelerate evaporation of weak brine by passing it repeatedly through layers of straw (Stroh) or, later, brushwood.. The earliest reference to the technique occurs in 1559 when Caspar Seeler, mint master at Augsburg, made an offer to Duke Albert V of Bavaria to set up at his own expense a work which would greatly reduce the amount of fuel needed to boil down brine. As in the case of the rag and chain pump proposal of 1437 (see chapter two, p.102), this seems to me a sure sign that the device he had in mind was then in its experimental stage. According to Virgil Hoffer,

controller of the Bad Reichenhall salt works at that time, Seeler's plan was to build a Luftgradirung (air graduation house) for the preliminary concentration of weak brine. At Bad Soden, near Frankfurt a/M, graduation houses raised a weak brine of only 1½ per cent (scarcely brackish to the taste according to Dr. Gilbert Burnet who visited there in 1685) to 35 per cent before boiling. A Leckwerk was in use at Nauheim, Saxony, in 1579. Graduation houses were commonly of enormous size. That built at Rosières (Lorraine) in 1739, for instance, was over 3,000 feet long, 45 feet high and 26 feet wide.

15. The surveying and levelling of the line were carried out by Tobias Volcksmer, who presented his draft to the ducal commission in June 1616. The building of the installations in 1617-18 was the work of Hans Reiffenstuhl. The plan of the pipe line (a copy of the original made in 1755) shows numerous massive trestle structures, water towers and cuttings. The survey and plan are both preserved in the archives of the Deutsches Museum, Munich.

16. E. Neweklowsky, op. cit., pp 238-244.

17. (i) C. Caron, <u>Traité des bois servans a tous usages</u>, Paris 1676, Vol. 1, p. 107, "...on jette le bois bûche a bûche dedans (in some "ruisseau assez raisonnable") et c'est ce que l'on appelle à bois perdu, qui suit le fil de l'eau jusques a ce qu'il soit arresté au lieu destiné pour estre mis en train...". Sweeping powers were given in the articles of the <u>Ordonnance</u> of December 1672 to use any waters for this work.

(ii) J. Savary des Bruslons, Dictionnaire universel de commerce, d'histoire naturelle et des arts et metiers, Geneva 1750, Vol. 1, p.497, "L'invention de flotter de bois et d'en composer en trains n'est pas extrement ancienne (sic). Jean Rouvet, bourgeois et marchand de Paris, commença le premier...en 1549...".

18. J. Turriano, op. cit., f.249r, "...Y he pensado una cosa que me pareze que se podriá servir del tal rio (strewn with many rocks - "muchas peñas"); yr entablando un camino el quel friese tan ancho que un madero pudiese caminar libramente" : "And I have thought of a way which appears to me would be of service in such a river (strewn with many rocks); that is to construct a flume (literally: path or road) of sufficient width for a log to be able to travel freely". Turriano goes on to caution against building a flume with tight curves. I have to thank Dr. Alex Keller for the transcription of this passage. The translation is my own.

19. E. Browne, A brief account of some travels in Hungary, Austria, Servia...Carniola and Friuli, London 1673, p.137, "...I passed a neat river or notable cut called La Brentella, sixteen miles long...for the better bringing down of wood from the mountains to be used in the making of glasses at Muran; it is all paved with a good stone bottom and sides...". I have not been able to discover when this was built but I suspect that the notable increase in woollen textile manufacture in Venice after about 1550 may well be connected with improvements in fuel supply.

20. (i) C.T. Delius, op. cit., p.514, "...der Rechen zu Neusohl bey 600 Klafter in der Lange hat".

(ii) E. Browne, op. cit., p. 105, "...there is a bridge of wood to pass the river at this town, and an handsome building of piles...to stop the wood thrown into this river ten miles higher where the country is full of wood; and by this artifice without labour or charge, it is conveyed to Neusohl". Browne visited Neusohl in March 1670.

21. Principally the region extending from Aniche to Aachen but many other small fields were worked in France and Germany. By the 1740s and 1750s there was, in both countries, a growing consciousness of the need to expand the production of coal.

22. I have drawn the details for this sketch from L. Hauska, 'Joseph Rosenauer und sein Werk', Zentralblatt für das Gesamte Forstwesen, Vol. 66, 1940, pp 87-99; E. Neweklowsky, op. cit., pp 580-583; and J. Blau, 'Böhmerwälder Hausindustrie und Volkskunst', Beiträge zur deutsch-bohmischen Volkskunde, Vol. XIV, 1917-18. On p. 71 Blau has a charming photograph of a lady signaller (with pole) standing by her 'signal box'. The Bavarian government ordnance survey maps are indispensable if one wishes to trace the details of Rosenauer's survey. The dimensions of the Schwemmkanal, trapezoidal in form, were from 3.8 to 5.7 metres in width at the top, 1.9 metres at the bottom and 96 cm deep.

23. E. Neweklowsky, op. cit., pp 527-28. Saxony had a peculiar nomenclature of its own. Flösse which elsewhere signified rafting was used here for the free floating of wood and was

even extended to include wood delivered by lubricated slide ways. The word for rafting having been pre-empted in this way, it became necessary to use the awkward term Floss-Schiffahrt (raft-ship transport) in its place. See also H. Wilsdorf et al, op. cit., p.56.

24. C.T. Delius, op. cit., p. 511 and plate XXIII. His entire section on forest economy (p. 508ff) is of the highest interest. See also J.G. Krunitz, Oeconomische Encyclopädie oder Allgemeines System der Staats-Stadt-Haus-und Landwirtschaft, Berlin 1778, Vol. XIV, p.291. "Es ist in den Waldungen ein Bach so klein der nicht zur Holzflösse gebraucht werden könnte".

25. H. Wilsdorf et al, op. cit., p.57. The floating characteristics of the different species of wood had also to be considered. Beech would not swim more than twelve miles, and birch, which swam well at first, became saturated and sank after twenty-four hours. Most varieties could not be floated in their freshly cut state: hence the need to stockpile billets well before the floating season. The French term for Senkholzer was bois-canards.

26. C.T. Delius, op. cit., pp 510-11. P. Deffontaines, 'La vie forestière en Slovaquie', Travaux Publiés par l'institut d'études Slaves, Vol. XIII, 1932, records that in 1926 wood transport by water was still practised on many rivers especially on the Hron (Gran) and Vah. The storage quays at Banska Bystrica (Neusohl) were capable of stocking 40,000 cubic metres of wood.

27. J.E.O. Feigenpuz, Iter per salinas Tyrolenses, Innsbruck 1707, p.303.

28. L. Hauska, op. cit., p.98.

29. C.T. Delius, op. cit., p.509 and plate XXII, figs. 1 and 2. The upturned end was called a Sprung. A propos of billets landing well clear of the end of the 'pipe', I cannot forbear to mention the famous iron pipe at Urach in Wurtemberg noted by Johann Keysler about c.1729. It was over 900 feet long, and the billets, almost like bullets, shot out of its mouth at such speed that they flew ("in freyer Luft hinausfahrt") over two hundred paces before landing. Ordinary slides were sometimes up to a mile in length.

30. J.G. Krünitz, op. cit., p.296ff and figs. 772 (Schlitt) and 773 (Winterbahn: Schmierweg).

31. E. Neweklowsky, op. cit.,pp.531-32. "...die mineralische Kohle das Holz als Brennmittel allmahlich verdrängten, was mit der Erbauung der Bahnen hand in hand ging".

32. Ibid., p. 236, "Der Rückgang der Flösserei begann mit der Mechanisierung des Verkehrs durch die Einführung der Dampfmaschine".

33. G. Huffel, Économie forestière, Paris 1910, Vol. 1, pt. 1, p.19, establishes this equation.

34. F. Jeandel, J.B. Cantegril, L. Bellaud, Études expérimentales sur les inondations, Paris and Nancy 1862, p.139, note 1.

35. Ibid., p. 140, note 2.

36. Ibid., pp 141-43.

37. C.G. Bates, A.J. Henry, op. cit., Monthly weather review No. 30, Washington 1928, pp 1-79.

38. In 1767, for instance, the Augsburg senate records state

that the Wertach had by then become scarcely floatable. The collections of codes of forest laws such as those of N. Meurer, Jagd und Forstrecht..., Frankfurt 1576, and A. Fritsch, Corpus juris venatorio-forestalis, Romano-Germanici, tripartitum, Leipzig 1702, constitute an archive in themselves. It is clear also from A. Surell, Étude sur les torrents des Hautes Alpes, Paris 1841, that French forest laws would prove an equally valuable fund of source material.

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