DESIGN OF PLANT FOR EXTRUSION OF PIGMENT PASTES

by

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Dedication

To Mr. Stuart Pugh

To my wife, Bunmi whom I left to bear the burden of my family while I was away in the U.K.

To my children for waiting patiently while Daddy was away.

A C K N O W L E D G E M E N T S

The financial support for me to carry out the research and design project described in this thesis has been provided by Blythe Colours Limited, Kidsgrove, through Mr. Stuart Pugh, my project supervisor to whom I am deeply indebted. I also want to thank him for his expert advice that led me to the systematic approach in my design work.

I wish to express my sincere thanks to Mr. Ken Ponting of Blythe Colours for organising the finance and providing necessary instrumentations for the project.

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SUMMARY

In the light of the requirement for a controllable and reliable extrusion plant for preforming various types of inorganic pigment into spaghetti shape onto a convective band dryer to facilitate drying, a study of the preforming method currently in use by the sponsors has revealed that the screw extruder being used cannot perform this function satisfactorily. The main reason being the thixotropic nature of the pigments. They do not readily tolerate mixing or working, which is inherent in the screw extruder. This necessitated a study of other preforming methods.

The thesis reviews the available methods of preforming, existing theories on extrusion of material, and various extruder concepts generated during the initial stages of the project. The concept chosen is discussed. A mathematical model based on test results carried out on a Laboratory model of the chosen extruder concept and the complete design of the full scale extrusion machine, together with its charging units and the plants' control system is presented.

An analysis of the performance tests carried out on the new plant is discussed.

The thesis concludes with a comparison between the new plant and the screw extruder in current use regarding their performances and product qualities. Proposals for further work and test are also made.

NOTATION

A	=	Extrusion cylinder cross sectional area	mm^2
a	=	Extrudate cross sectional area	mm^2
D	=	Extrusion cylinder diameter	mm
d	=	Extrudate diameter	mm
D_1	=	Barrel diameter	mm
D_2	=	Hole diameter	mm
X	=	Length of zone 1	mm
P	=	Extrusion pressure	MPa
P_E	=	Pressure behind the piston	MPa
P_C	=	Pressure at the beginning of the dead zone	MPa
P_B	=	Pressure at the die	MPa
P_A	=	Atmospheric pressure	MPa
L_D	=	Length of die hole	mm
Y	=	Cohesive yield stress	MPa
ϕ	=	Half angle of cone (dead zone)	
μ	=	Coefficient of friction	
R	=	Extrusion ratio defined as the ratio of the extrusion cylinder cross sectional area to the total cross sectional area of the die holes	
LP	=	Low pressure pump	
HP	=	High pressure pump	

CONTENTS

INTRODUCTION

In 1977 The Engineering Design Centre of Loughborough University of Technology (L.U.T.) was asked by Blythe Colours Limited, Kidsgrove to investigate the performance and hence product quality of the process they were using for the preforming of their cadmium based pigments. The investigation and evaluation would lead to the preparation of a product specification and the design for manufacture of an equipment to supersede the existing extruder if need be.

Cadmium based pigment is normally processed in two stages. In the first stage the cadmium precipitate is pressed in a filter press where excess water is squeezed out after it has been washed. The cake formed there of is taken into a pre-former in the form of a screw extruder where it is preformed onto a continuous band dryer where it is dried (see Fig. 1.1). At this stage of production the material is called "unfired pigment". In the second stage of production the dried pigment from the dryer after the first stage is passed through a high temperature oven where it is fired. After this stage of production the pigment is known as "fired pigment". The fired pigment is sent back to the filter press for washing after which it is again preformed and dried. In general the unfired and fired pigment paste respectively contain about 45 to 50 and 25 to 35 percent water prior to extrusion or preforming. It is essential to preform the paste into spaghetti like shape to facilitate drying in a forced connected band dryer where the water content is reduced to below one percent by weight.

To this end between January and September 1978 the Engineering Design Centre of L.U.T. commissioned a team of

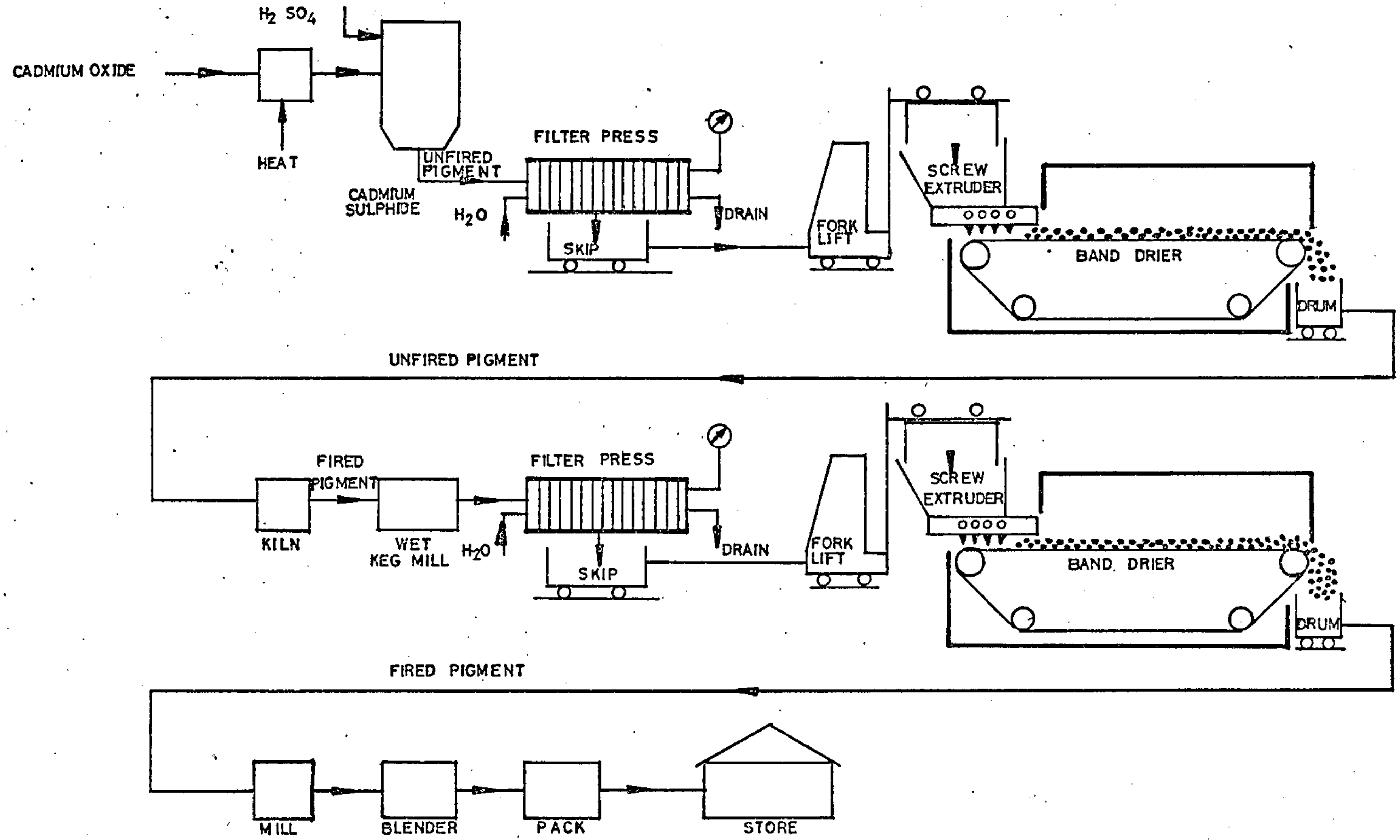


FIG 1-1

PIGMENT PRODUCTION PROCESS IN CURRENT USE postgraduate students on the Masters design course to investigate the problems involved in the pigment production and design if need be a new plant to meet the Company's requirements. The author was a member of this team. Tests were carried out on various pigments in production at the company by the team. It was observed that the main reason why the performance of the screw extruder is unsatisfactory is that extrusion pressure is applied only to that portion of the material actually in the barrel of the extruder and in consequence any local zones of inhomogeneity in respect of water content of the material affects the quality of the extrudate leading to poor drying. Zones of excessive wetness will be extruded as a flowable material or even as slurry thus blocking the air passages on the conveyor belt and in consequence not being properly dried. A zone of excessive dryness on the other hand, will tend to block the holes of the extruder. Also due to the inherent high shear, high mixing effect in the screw extruder it causes the material to coalesce because of its thixotropic nature.

After analysing the problems and studying other available extrusion equipment it was decided that the best way to overcome the above problems was to use a preformer in the form of a ram extruder. However, from the study of existing methods of preforming in those industries processing fluid materials of medium to high viscosity such as plastics, food stuffs, clays, the screw extruder is widely used.

Various concepts based on the ram extrusion principles were generated as discussed in Chapter 4. A detailed evaluation of the concepts is given in[1].

The author took over the project in January 1979 with a view to carrying out further studies of the pigment in production at the sponsors works, the designing, manufacturing and commissioning of a complete equipment with the following responsibilities:

(a) design and construction of a Laboratory test facility for the determination of the force required to extrude various pigments in production, using a ram extruder;

(b) theoretical and experimental analysis of the ram extruder;

(c) formulating a system configuration within the constraints imposed by existing ancillary equipment;

(d) the design of the complete extrusion plant, i.e. the extrusion machine, its material transfer unit and the system control unit;

(e) the provision of detailed drawings and process specification to the manufacturer of the plant, the supervision of and technical liaison with the manufacturer on behalf of the sponsoring company;

(f) supervision of the installation and commissioning of the equipment at the company's works at Kidsgrove and later at Stratford in East London;

(g) preparation of maintenance manuals;

(h) testing and evaluation of the complete installation.

CHAPTER 2

PROJECT OVERVIEW

In this chapter the initial work carried out by the project team (the author et al) is presented, the full detail of their report is given in [1] .

2.1 INFORMATION SEARCH

Early in the project, following a careful study of the existing preformers used by the sponsoring company the team decided that there are two areas needed to be studied.

(1) a general investigation of equipment available for preforming of viscous fluids and wet particulate material;

(2) a detailed investigation into the behaviour of viscous fluids and wet particulate material during the preforming process.

In carrying out the first investigation, the search area was divided into sections, viz:

(i) Type of extruder in use.

(ii) Industries using extruders.

(iii) Materials normally extruded.

(iv) Effect of the extrusion process on the properties of the material being extruded.

The outcome of the investigation showed that the equipment used for producing preformed viscous fluid and wet particulate materials may be divided into three basic types:

(i) Direct preformers.

(ii) Positive displacement pumps.

(iii) Extruders and other devices where pressure is built up through shear flow, intermittent suction, and centrifugal action.

FIG. 2-	TYPE	MECHANICAL WORKING OF MATERIAL	PREFORM X-SECTION	PREFORM LENGTH	FEED SYSTEM	MANUFACTURING PRECISION
1	Granulator	Considerable	Must be solid	Short	Continuous	Low
2	Extruder	Considerable	Must be solid	Short	Continuous	Low
3	Gear Pump	Considerable	Any shape	Any length	Continuous	High
4	Twin screw Extruder	Considerable	Any shape	Any length	Continuous	High
5	Ram extruder	Low	Any shape	Any length	Batch	Medium
6	Ram pump	Low	Any shape	Any length	Continuous	High
7	Peristaltic Pump	Moderate	Any shape	Any length	Continuous	Medium
8	Single Screw Extruder	Considerable	Any shape	Any length	Continuous	Medium

TABLE 2.1

Comparison chart for preformers (1)

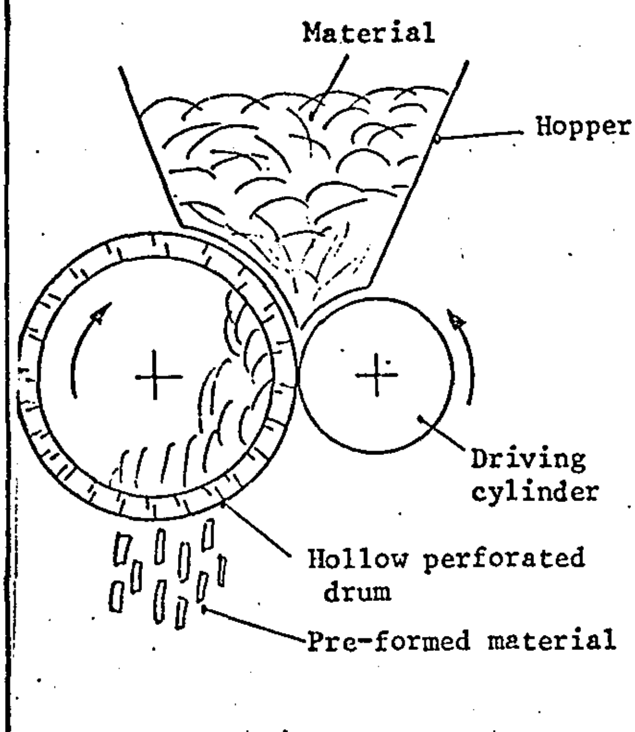


Fig.2-1 Granulator

Applications: Foodstuffs
Pharmaceuticals
Paint Pigments

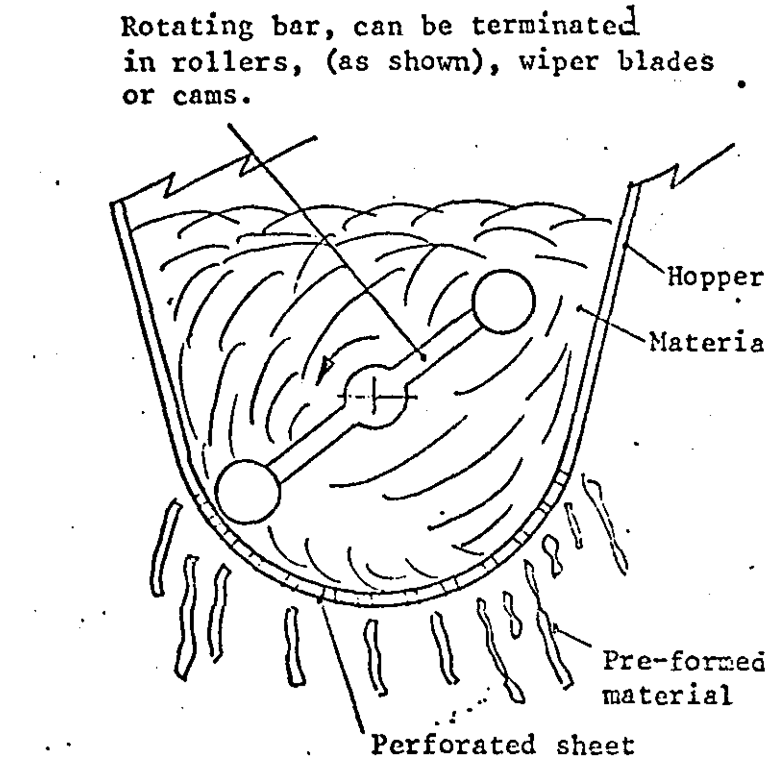


Fig.2-2 Extruder (Roller type)

Applications: Foodstuffs
Pharmaceuticals
Paint Pigments

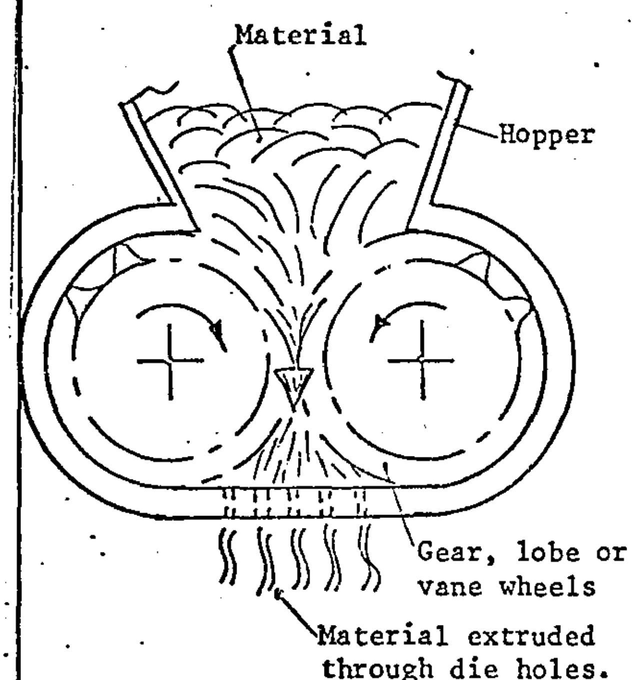


Fig.2-3 Gear pump

Applications: Foodstuffs
Chemicals
Pharmaceuticals

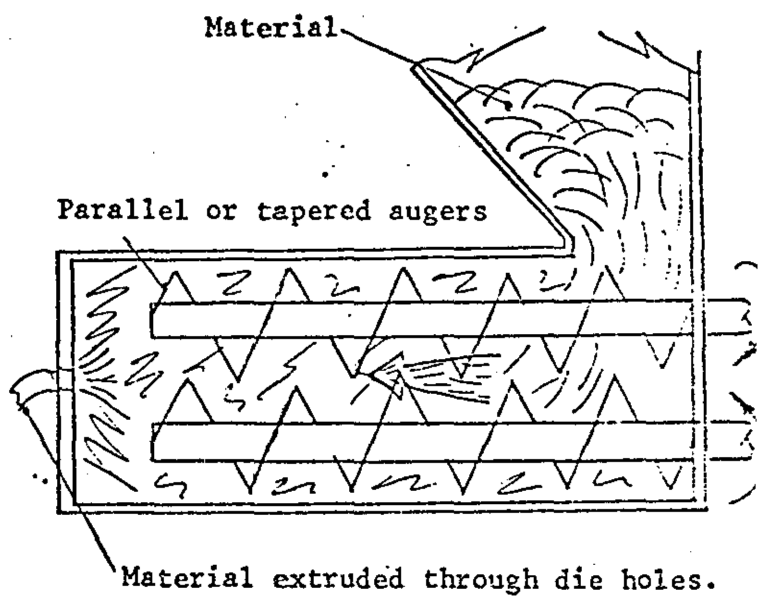


Fig.2-4 Twin-screw extruder

Application: Plastics

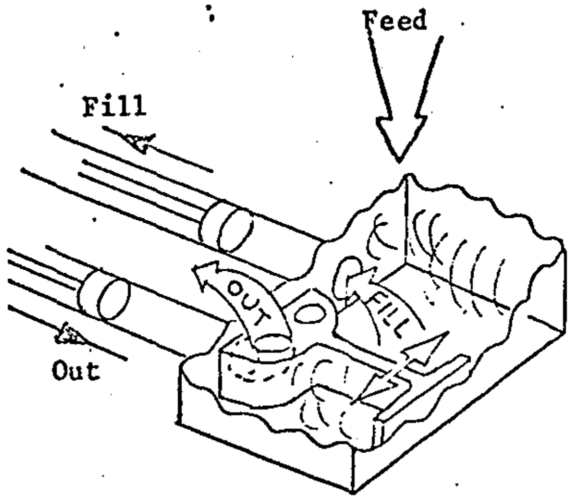


Fig.2-5 Ram pump

Application: Concrete pumping

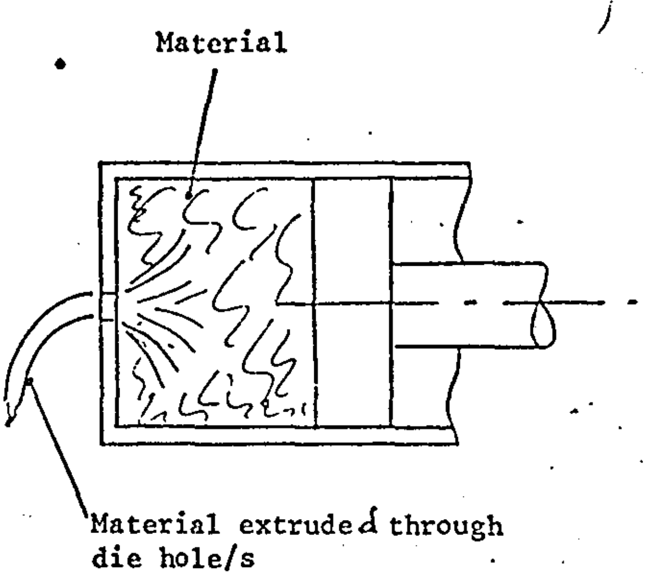


Fig.2-6 Simple ram

Applications: Metal extrusion
Plastic extrusion

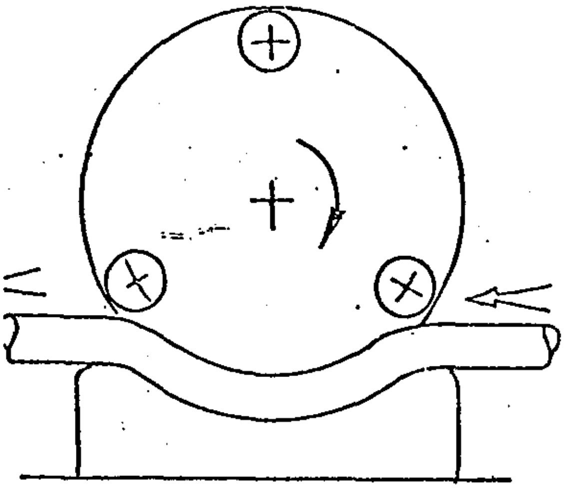


Fig.2-7 Peristaltic pump

Applications: Slurry
Cream
Many other fluids

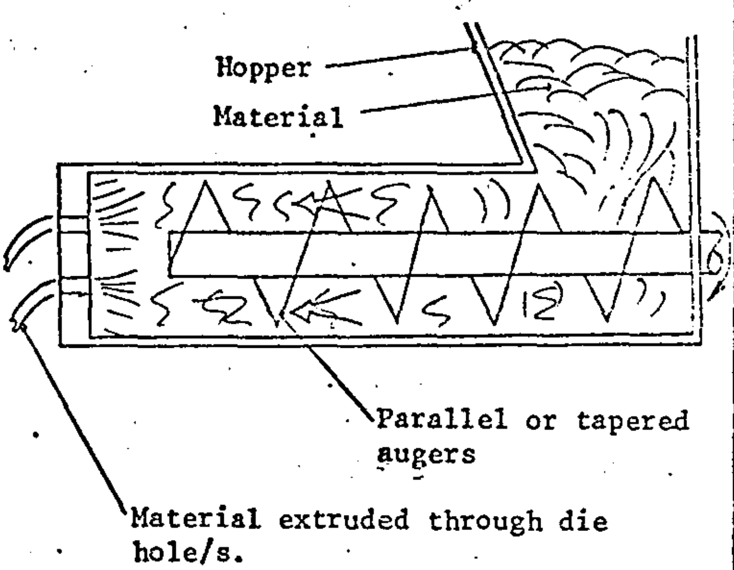


Fig.2-8 Single screw extruder

Applications: many applications
including:
Foodstuffs
Clays and ceramics
Plastics

FILTER CAKES OF UNFIRED PIGMENTS

SHADE	CODE	COMP^N	SPECIFIC GRAVITY g/cc	MOISTURE CONTENT
Pure Yellow	Y37 Y01	cds	1.65 1.78	47.9% 48.6%
Pure Primrose	P06 P91	cds.Zns	1.72 1.66	49.8% 53.2%
Lithopones	L00 L02	} Cds.Zns.$BaSO_4$	1.92	45.9%
	L57	cds.$NaSO_4$	1.66	48.1%
Orange	R01 R02	Increase in cds	1.78 1.65	50.0% 49.7%
Light Red	R03	↑	1.90	44.7%
Medium Red	R04	Cds.Cdse	1.80	46.1%
Deep Red	R06 R07	↓	2.0 1.88	42.5% 46.5%
Maroon	M96 M59	Increase in Cdse	1.28 1.72	46.5% 51.7%

TABLE 2.2

Material properties, unfired pigments

FILTER CAKES OF FIRED PIGMENTS

SHADE	CODE	COMP^{N}	SPECIFIC GRAVITY g/cc	MOISTURE CONTENT
Pure Yellow	Y77 Y01	) cds)	2.36 2.50	25.4% 28.9%
Pure Primrose	P06 P91	) cds.Zns)	2.54 2.38	24.(½ 26.1%
Lithopones	L00 L02	) $cds.Zns.BaSO_4$)	2.50 2.32	23.8% 24.9%
	L57	$cds.BaSO_4$	2.38	26.2%
Orange	R01	Increase in cds	1.92	36.3%
Orange	R02		2.04	33.1%
Light Red	R03	↑	2.05	33.1%
Med. Red	R04 R05	cds.Cdse	2.17 2.38	30.7% 27.2%
Deep Red	R06 R07	↓	2.27	28.9%
Maroon	M96 M59	Increase in cds	2.50 2.50	26.8% 26.9%

TABLE 2.3

Material properties fired pigments

Sketches and brief descriptions of typical devices belonging to the above categories are shown in Figs. 2.1 to 2.8. The granulator and the Roller type extruder, Figs. 2.1 and 2.2 respectively are direct preformers. The Gear pump, Twin screw, Ram pump, Simple ram, and the Peristaltic, Figs. 2.3, 2.4, 2.5, 2.6, 2.7 respectively are positive displacement. The screw extruder, Fig. 2.8 belongs to the third group where pressure is built up by shear flow.

From Table 2.1 it is seen that most of the currently used methods of preforming tend to mix the materials, often excessively.

Since the material is inhomogenous, thixotropic, i.e would not tolerate excessive mixing, Investigation of other methods in which mixing is at a minimum was found necessary.

A form of ram extruder was chosen as the basis for a new design.

An information search of the physical and flow characteristics of cadmium pigments revealed disappointingly that such information was not available. It was decided therefore that a test programme be carried out to resolve areas of uncertainty.

2.2 MATERIAL PROPERTIES

Information relating to the material chemical composition, density, specific gravity and moisture content, as supplied by the sponsors is shown in Table 2.2 and 2.3.

Information relating to the rheological properties of clay - water materials and the behaviour when subjected to an extrusion process were found in [2].

A small scale ram extruder was built to enable the team to determine the bulk flow properties of pigments. Tests were also carried out to determine the shear stress and angle of friction of the material in the line set out in[3] and[4].

Test results for the small scale ram extruder are discussed in Chapter 3.

The observed shear stress are tabulated in Table 2.4 together with their test methods.

It was observed that the shear stress (or cohesion value) of the pigment increases with compaction pressure.

2.2.1 Conclusion

A series of tests were carried out on the ram extruder model by the project team. From the test results obtained the following conclusions were drawn:

(1) That the extrusion force required to extrude various pigments at the same extrusion rate and extrusion ratio depends on their yield stress i.e. an increase in the latter is accompanied by an increase in the former, (see Table 2.5).

(2) That some pigment particles absorb and retain water which is gradually squeezed out during extrusion process. Thus there is a controlled flow of die lubrication, (see Fig. 2.9a). This type of pigment (e.g. unfired yellow) requires lower extrusion force.

(3) Other pigment particles are non-absorbent and all the water is contained between particles. Thus during extrusion the water drains away readily and only part of it is available for die lubrication, (Fig. 2.9b) an example

MATERIAL	PIGMENT PRESSURE p OR CONDITION OF PIGMENT	AVERAGE VALUE FOR COHESION		TEST METHOD
		KN/m^2	lbf/in^2	
U/F Yellow	Uncompacted	17.5	2.54	Weissenberg Rheo'meter
	$p = 14\ kN/m^2$	22.7	3.3	Shear Box
	$p = 43\ kN/m^2$	34.8	5.0	Shear Box
	$p = 56\ kN/m^2$	40.9	5.9	Shear Box
	$p = 67\ kN/m^2$	>40.9	5.9	Shear Box
	Slightly compacted	43	6.2	Lab. Vane
U/F Red	Uncompacted	27.6	4.0	Weissenberg Rheo'meter
U/F Lithopone	Uncompacted	97	14.0	Lab. Vane
Fired Lithopone	Slightly compacted	11.5	1.2	Lab. Vane

TABLE 2.4

Experimental Shear Stress values for Pigments (1)

MATERIAL	Shear Stress from Tests		Extrusion Rate and Die Aperture (50 mm Dia.Ram)	Extrusion Force	
	kN/m^2	lbf/in^2		kgf.	lbf
Fired Lithopone	11.5	1.2	120 mm/s; 5.5 mm	95	209
U/F Red	27.6	4.0	120 mm/s; 5.5 mm	120	264
U/F Yellow	43	6.2	120 mm/s; 5.5 mm	160	352
U/F Lithopone	97	14.0	120 mm/s; 5.5 mm	300	660

TABLE 2.5

Shear Stress/Extrusion Force Relationships (1) of this type of pigment is the fired red pigment. Electromicrographs of sample pigment are shown in Fig. 2.10.

(4) That a better quality of extrudate, i.e. better texture, homogeneity; extrudate continuity and beam strength, is obtained at higher extrusion rate. An extrudate velocity of around 120mm/sec. from a 5.5 mm diameter hole suits all the pigments tested.

(5) That the extrudate produced at around an extrusion rate of 120 mm/sec. has a better surface finish than at lower or higher rate. Good surface finish of the extrudate results in less dust formation during drying.

2.2.2 Hypothesis

The following hypotheses were developed by the author during the test period:

(a) That, when extruding wet pigment through a die, at some extrudate velocity, liquid will start to migrate through the material to lubricate the interface between it and the die, see Fig. 2.11a. This is by virtue of "capillary pumping action", see Fig. 2.11b.

(b) That there exists a range of extrudate velocity for which the force required to maintain extrusion is minimum. That is, as the extrudate velocity increases from zero, the extrusion force drops until the minimum force zone is reached. After this range, the extrusion force starts increasing.

The minimum extrusion force depends upon:

(i) The actual pigment being extruded.

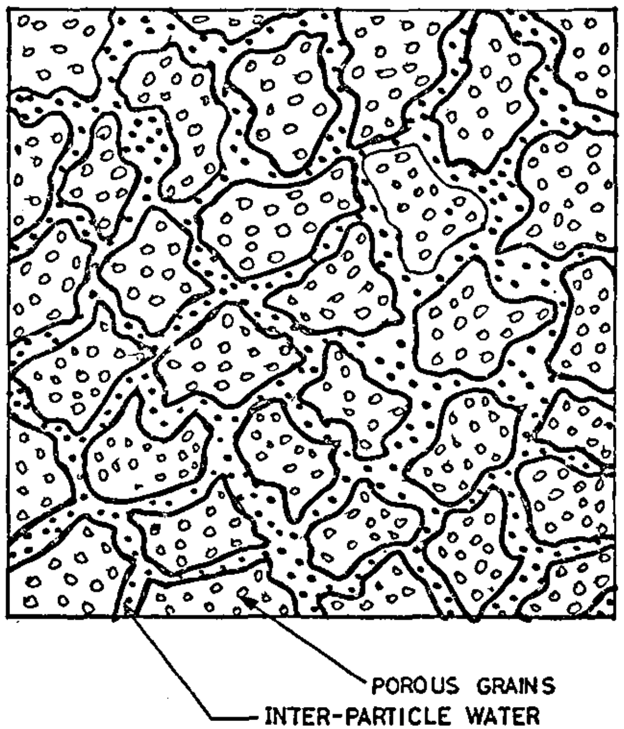


FIG 2-9a

ABSORBENT MODEL

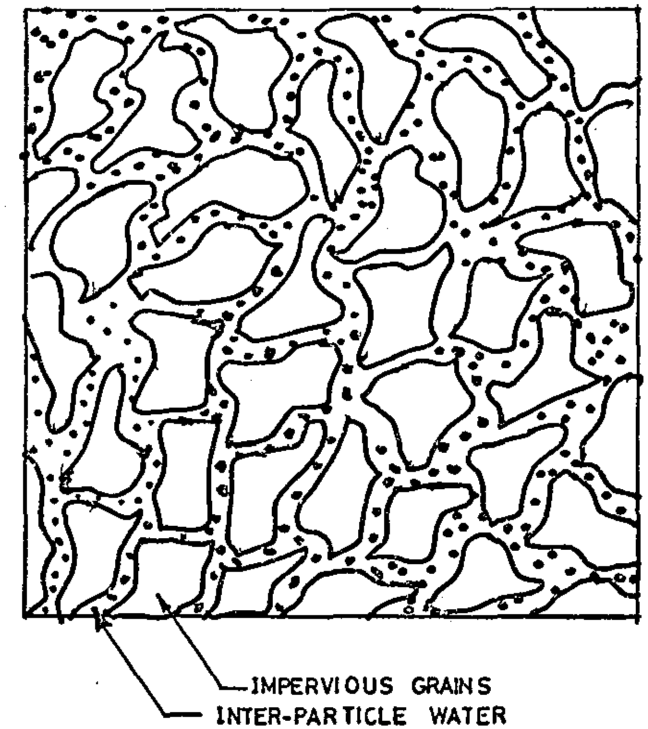
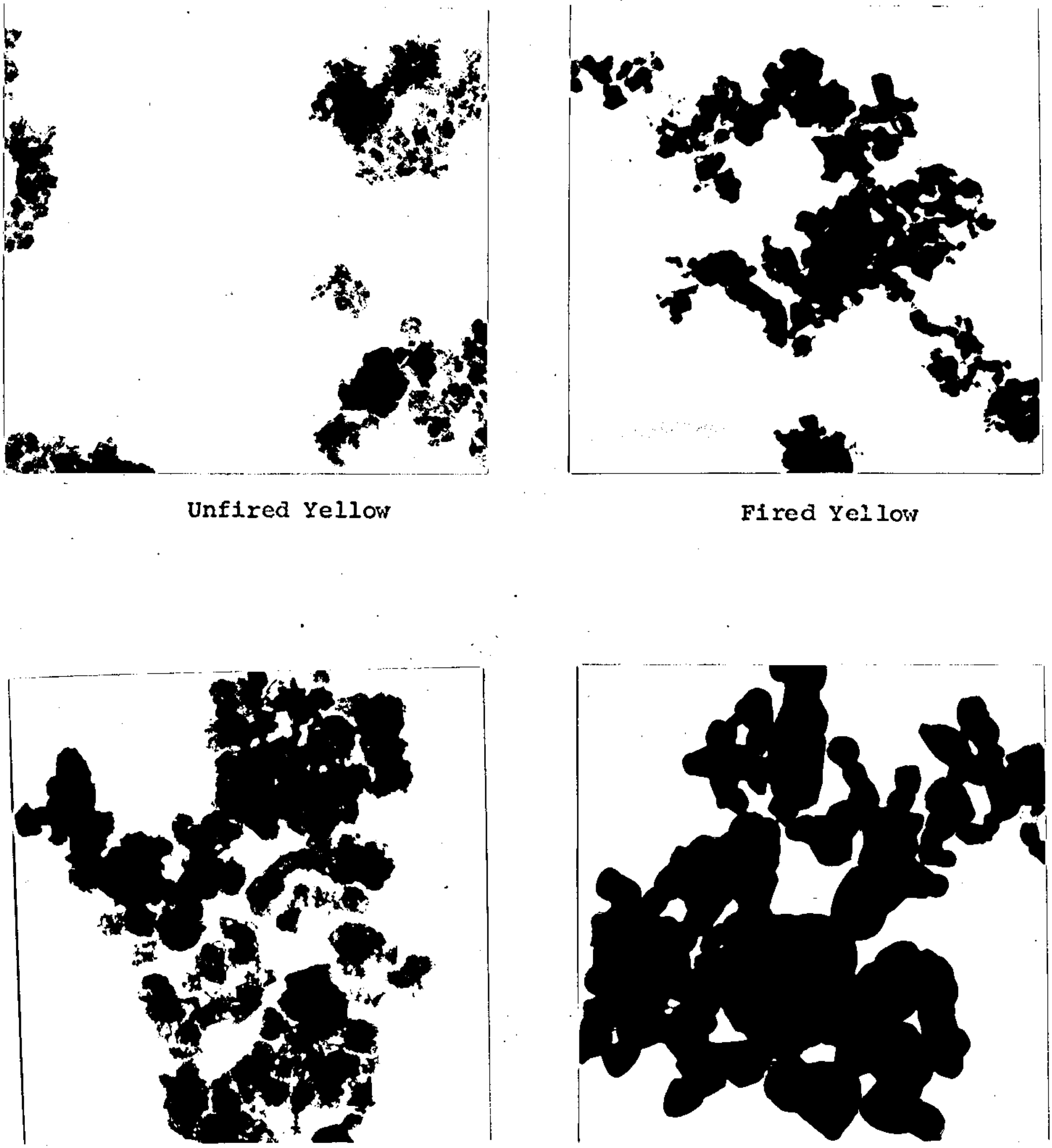


FIG 2-9b

NON-ABSORBENT MODEL



Unfired Yellow   Fired Yellow

Unfired Red   Fired Red

FIG. 2.10

Electronmicrographs of Pigment Samples
(x 20)[1]

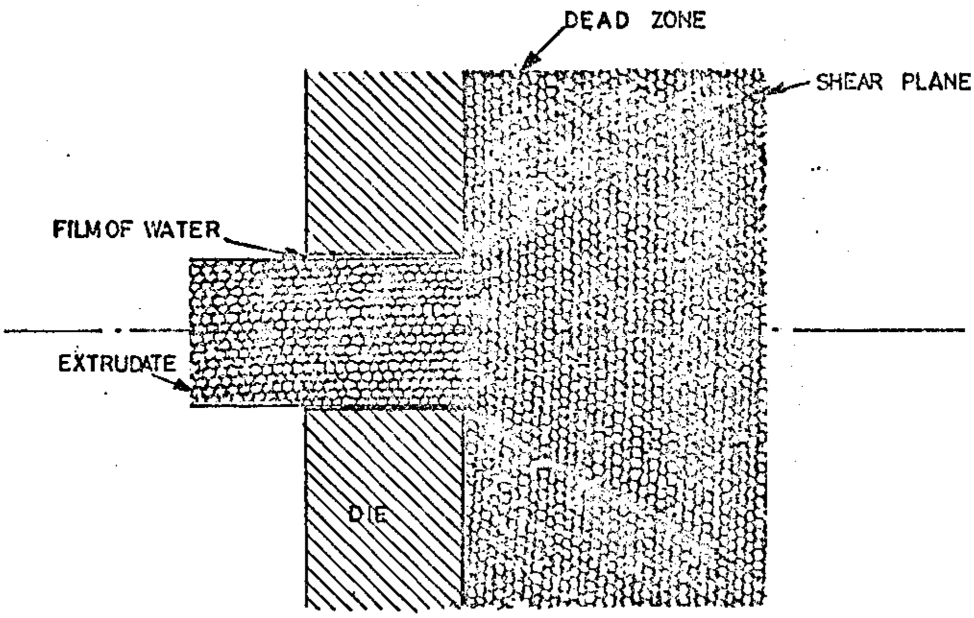


FIG 2-11a

DIE LUBRICATION MODEL

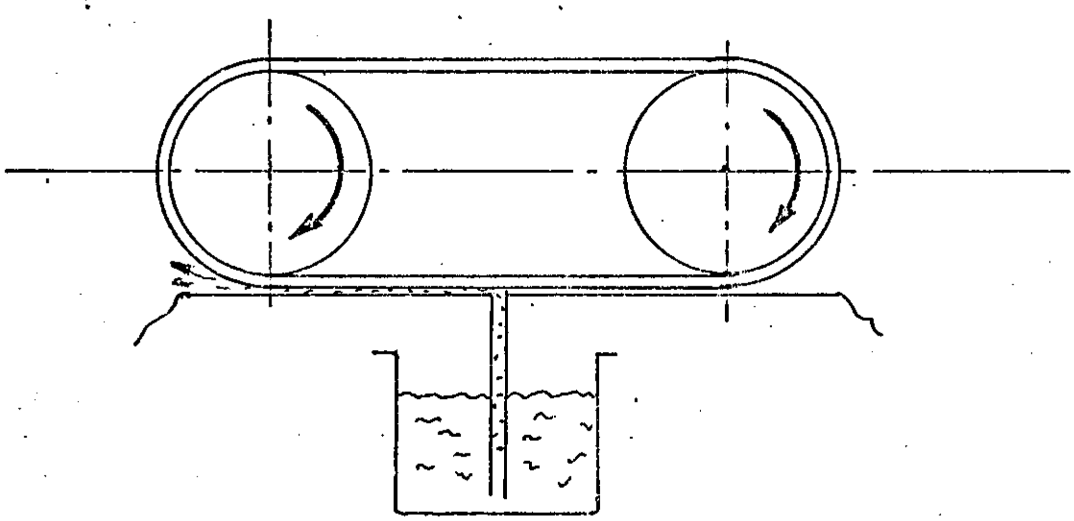


FIG 2-11b

CAPILLARY PUMPING ACTION (ANALOGY)

(ii) Its moisture content.

(iii) The extrusion ratio.

(iv) Extrudate velocity.

The second hypothesis was verified by the author and is discussed in Chapter 3. The first hypothesis could not be verified due to the time constraints and instrumentation involved.

2.3 DRYER TEST

The dryers used by the sponsors are supposedly a through circulation dryer. The essential features of a through circulation dryer is the passage of hot air through a permeable bed of wet material which passes continuously through the dryer. A description of the dryer is given in Chapter 4.

Although the project did not include the design of a dryer, it was felt that since the new preformer to be designed will have its products dried in this manner, it was necessary to become familiar with:

(i) the drying mechanism involved in reducing the moisture content of particulate material;

(ii) the performance of the existing dryer.

A model of the dryer constructed was based on the work of Nonhebel and Moss [5]. Tests were also carried out to evaluate the performance of the dryers.

Various observations made during the tests are given in[1] and the conclusion drawn is as follows:

(i) That the dryer is not operating as a through circulation dryer but as a continuous tray dryer.

(ii) That the fan capacity is too low to generate enough pressure head to force air through the band.

(iii) The perforated plate through which air is discharged onto the band is, if anything, acting as a diffuser and does not create the mass velocity effect required.

(iv) The temperature above the band is too high and can be harmful to the pigment. A maximum temperature of 80°C is preferred.

(v) The high humidity of the almost stagnant air above the band has an adverse effect on the dryer efficiency.

2.4 MATHEMATICAL MODEL OF THE RAM EXTRUDER

A mathematical model to describe the behaviour of pigment during extrusion was developed by the team and is discussed in Chapter 4.

2.5 EQUIPMENT SPECIFICATION

The team prepared an initial product specification which was presented to the sponsors for their approval. This specification was later revised and modified by the author. The final specification is given in Appendix 'A'.

2.6 CONCEPTUAL DESIGN

Following agreement of the product specification with the sponsors, various concepts of preformers (twenty-one in all) were generated. These concepts were then evaluated using matrix techniques . The ram extruder concept was chosen and the work done by the team in its development is discussed in Chapter 4.

The team work concluded with the consideration of various approaches based upon the ram extruder concept. This work, being minimal and inconclusive due to the course timescale.

CHAPTER 3

PROCESS ANALYSIS

In carrying out detail design, safety factors used in design calculation are often recognized as being too large and probably add unnecessarily to the product cost. Very often, safety factor codes dictate the practice. However, even when no code applies as in this case the designer loathes to reduce his section dimension arbitrarily. This is particularly true if his design is based on principal forces and safety factor has been covering the influence of unknown or unstudied secondary forces.

From the literature survey carried out it was disappointing to note that there were no published matter dealing with the extrusion of pigments or like materials. This being the case it was considered not only worthwhile but essential to carry out both a theoretical analysis of the ram extrusion process and an experimental analysis on a prototype ram extruder. This would enable the deduction of logical rules for proportioning the important parts that make up the extruder. These rules can then be applied in selecting a judicious safety factor thus minimizing weight, cost, complexity of form and improved reliability.

There are in reality two important parameters to be ascertained:

(i) the forces required to extrude various grades and colour of pigments; and

(ii) the pressure distribution within the chamber from where it is being extruded.

3.1 THEORETICAL ANALYSIS

Analytical work in the field of ram extrusion of pigment or like material could not be found. This might be attributed to the fact that these materials are almost exclusively processed using the screw extruders.

Experimental study encounters inherent limitations in the absence of adequate theoretical support. Such support is provided in this section of analytical approach to the study of the ram extrusion process of pigment particulate.

In all extrusion processes the pressure required to extrude is usually the sum of three terms:

$$P = f(Y) + f(\mu) + f(C)$$

In the case of pigment Y can be termed the cohesive stress of the particulate mass, μ the coefficient of friction between particles and the walls of the extrusion chamber and C is the geometrical factor that is essentially defined in terms of the piston and die configuration.

The structure of the pigment influences its cohesive stress. The coefficient of friction depends on the water content of the pigment, its chemical and physical characteristics. The geometry of the extrusion chamber and the die will largely determine the constraints that are imposed upon the material in altering its shape and therefore determines the manner in which it flows.

3.1.1 Work and Pressure for Homogeneous Deformation

By considering the elemental work done in deforming a precompacted slug of pigment from its original form and then integrating this over the whole deformation region, the force required to carry out the deformation assuming a uniform deformation in the absence of friction and die constraint would be obtained.

If the compacted pigment has an instantaneous yield stress Y at the strain ε corresponding to an appropriate cross-section area a and length ℓ, the increment of work done in increasing the length of the specimen by δℓ beyond this strain is given by the product of force and displacement

$$\delta W = (Ya)\,\delta \ell$$

The increment of work done, per unit volume V is:

$$\frac{\delta W}{V} = \frac{\delta W}{a\ell} = Y\frac{\delta \ell}{\ell}$$

Assuming that the volume remains constant we may integrate this expression between the original length ℓ_0 and final length ℓ_1

$$\frac{W}{V} = \int_{\ell_0}^{\ell_1} Y\,\frac{d\ell}{\ell}$$

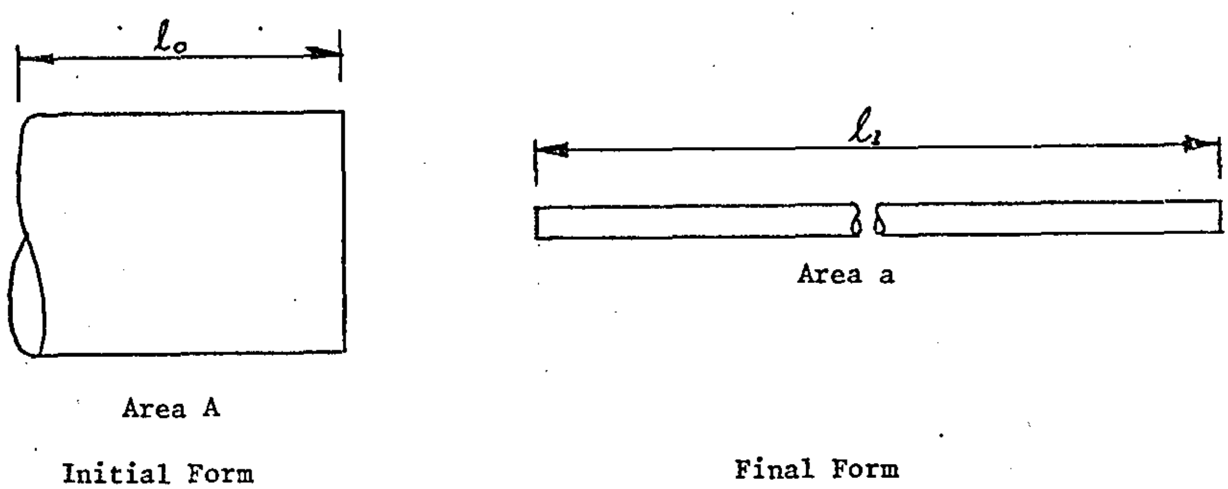


FIG. 3.1

This gives the result that the work done per unit volume in homogeneous deformation is equal to the area of the stress - strain curve, between the appropriate strain values. This result was also obtained by Siebel and Fangmeier[16] and G.Sachs and W. Eisbein[17] for metals.

The integral may be evaluated directly from the dimension change, assuming an average yield stress $\bar{Y}$.

$$\frac{W}{V} = \bar{Y}\int_{\ell_o}^{\ell_1} \frac{d\ell}{\ell} = \bar{Y}\ \ell n\ \frac{\ell_1}{\ell_o}$$

If A was the original area of the slug and a_1 the final area after deformation:

then $$V = A\ell_o = a_1\ell_1$$

$$\therefore \frac{\ell_1}{\ell_o} = \frac{A}{a_1}$$

Substituting in the equation for W/V we have:

$$\frac{W}{V} = \bar{Y}\ell n\ \frac{A}{a_1}$$

In the extrusion process this work is done by a force or pressure pushing the material through the die, if this force is PA where P is the force per unit area causing extrusion to take place, then

$$W = P\ A\ell_o = PV$$

$$\therefore P = \frac{W}{V}$$

$$= \bar{Y}\ell n\ \frac{A}{a_1} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Although the coefficient of friction between material particles and extrusion chamber wall may be reduced to a low value due to the presence of water in the material, it is clear that the extrusion process will always operate with some constraints imposed upon the flow of material by the die and thus cannot be homogeneous.

The result of the shear box test carried out by the author et al[1] on unfired yellow pigment, Table 3.1 indicated that the yield stress of the pigment increases with increase in compaction pressure. The rheological test result, Table 3.2

P (N)	F (N)	Normal stress f_c = P/A		Shear stress = F/A	
		(kN/m^2)	(lbf/in^2)	(kN/m^2)	(lbf/in^2)
9.5	15	14.4	2.1	22.7	3.3
28.5	23	43.2	6.3	34.8	5.0
37.5	27	56.8	8.2	40.9	5.9

TABLE 3.1

Results from Shear Box Tests, (for Unfired Yellow Samples) (1)

Strain Rate $\dot{\gamma}$ (S^{-1})	Test Duration (S)	Material Tested			
		Unfired Yellow		Unfired Red	
		Shear Stress		Shear Stress	
		(kN/m^2)	(lbf/in^2)	(kN/m^2)	(lbf/in^2)
0.017	60	18.7	2.71	37.3	5.41
0.167	60	18.8	2.73	26.0	3.75
1.670	60	17.0	2.47	19.5	2.82
16.670	60	15.4	2.23	-	-

TABLE 3.2

Results from Weissenberg Rheogoniometer Tests (1) shows that the yield stress is also strain rate dependent. Thus the ideal equation (1) above cannot be applied, since the functional relationship between the pressure, strain rate and yield stress is not exactly known.

To involve the effect of friction and inhomogeneous deformation in the ideal pressure equation it can be assumed that during an extrusion process, the drop in power required during the extrusion of long billets is ascribable entirely to reduced friction between the compacted pigment and the wall of the extrusion chamber, (see Fig. 3.2); the additional force that

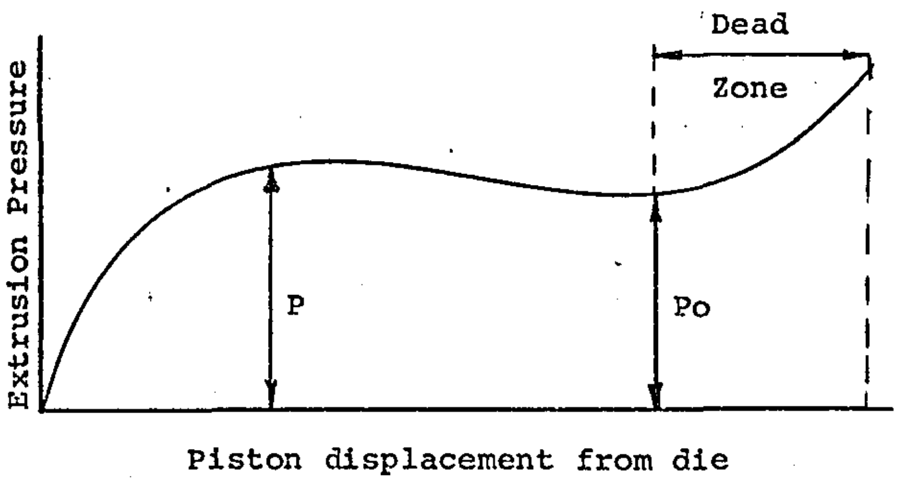


FIG. 3.2

(Typical pressure curves for extrusion of pigment)

this entails can be evaluated as shown below.

If a thin slice of the compacted pigment, of area A and thickness dx (see Fig. 3.3), is in equilibrium, then the force on the face nearest to the ram equals the frictional force acting at the cylindrical surface plus the force on the opposite face i.e. $Adp = \pi Ddx.\ \mu P$

where P is the pressure, D the diameter of the compacted pigment and μ the coefficient of friction between the pigment concerned.

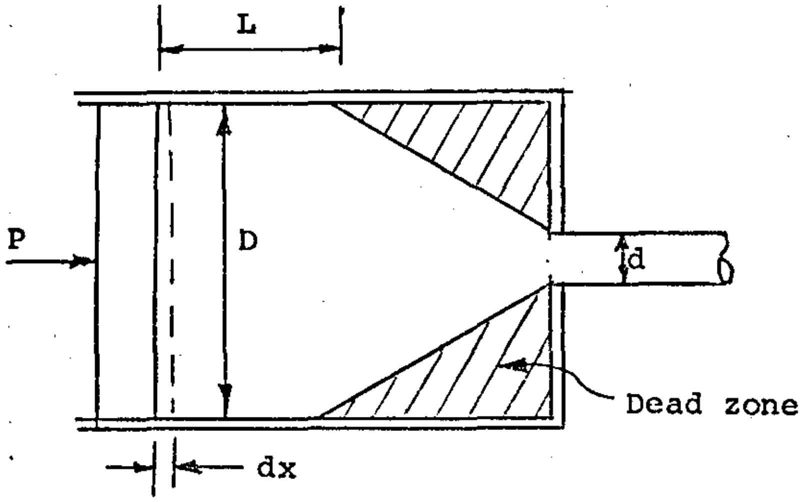


FIG. 3.3

Single die direct extrusion

Hence $\frac{dP}{P} = \frac{\pi D}{A} \mu dx$

$= \frac{4\mu dx}{D}$

On integration over the length L of the pigment excluding the dead zone, this gives:

$$P = Po \exp(4\mu L/D) \quad \ldots\ldots. \quad (2)$$

where P is the maximum pressure, at the beginning of extrusion, and Po the minimum pressure, given by the ideal equation 1 above, (see Fig. 3.1). From the experimental pressure/piston displacement curves obtained (see Figs. 3.10 to 3.17) the curvature of the line joining P and Po (Fig. 3.2) is small, and can be approximated to a straight line of slope represented by the tangent to the exponential curve at the maximum piston travel excluding the dead zone, then equation 2 becomes:

$$P = Po\ (1 + \frac{4\mu L}{D}) \quad \ldots\ldots. \quad (3)$$

In arriving at equation 3 it was assumed that the pressure acting on the extrusion chamber wall Pt is equal to the mean axial pressure P inside the undeformed compacted pigment, however, experiment by the author et al shows that it is less than the latter, but that the pressure acting on the chamber wall P_t is related to the axial pressure by:

$$P_t = KP$$

where K is the ratio of the transverse to axial solid pressure.

Equation 3 is then modified to:

$$P = Po\left(1 + \frac{4\mu K \ell}{D}\right) \quad \ldots\ldots\ldots \quad (4)$$

Again tests have shown that the coefficient of friction μ for each pigment varies with extrusion pressure (see Table 3.3) for some pigments.

The fact that the yield stress and the coefficient of friction are both dependent on the extrusion pressure and the material being extruded prompted the author et al to formulate other mathematical models based upon a power equation. The material within the extrusion chamber was divided into three zones, (see Fig. 3.4). The area in which the material is moving parallel to the extrusion chamber wall is labelled zone 1; and the area where the material deforms to pass through the die hole is labelled zone 2. In zone 2 deformation or reduction of the cross sectional area takes place and a part of the material becomes stationary behind the die (dead zone). Finally the material flows into zone 3 to emerge as extrudate.

The equations for pressure in each zone as derived in[1] for materials with coefficient of friction $\mu = Kp^n$ are

$$PB = PA\left(1 - 4Kn\,\frac{L_D P_A{}^n}{D_1}\right)^{-1/n} \quad \ldots\ldots\ldots \quad (a)$$

$$P_C = PB\left(1 - \frac{2Kn}{\tan \emptyset}\, f\,\left(Ln\,\frac{D1}{D_2}\right) P_B\right)^{-1/n} \quad \ldots\ldots \quad (b)$$

$$PE = \left(P_A{}^{-n} - 4Kn\,\frac{L_D}{D2} - 4Kn\,\frac{X}{D1} - \frac{4Knf(L-X)}{D_1-D_2}\,Ln\frac{D1}{D2}\right)^{-1/n} \quad \ldots \quad (c)$$

Material	Friction/ pressure relationship	Approximate pressure at which μ became constant		Approximate value of constant μ
		bar	lbf/in^2	
Unfired Red	$\mu=0.32p^{-0.119}$	3	45	0.16
Fired Orange	$\mu=0.43p^{-0.228}$	4	60	0.1
Fired Yellow	$\mu=1.68p^{-0.74}$	5	75	0.09
Fired Red	$\mu=1.75p^{-0.9}$	5	75	0.04
Unfired Yellow	$\mu=2.316p^{-0.84}$	7	105	0.05
Unfired Lithopone	$\mu=\quad 6p^{-1.06}$	8	120	0.04

TABLE 3.3

Friction/Pressure relationship[1]

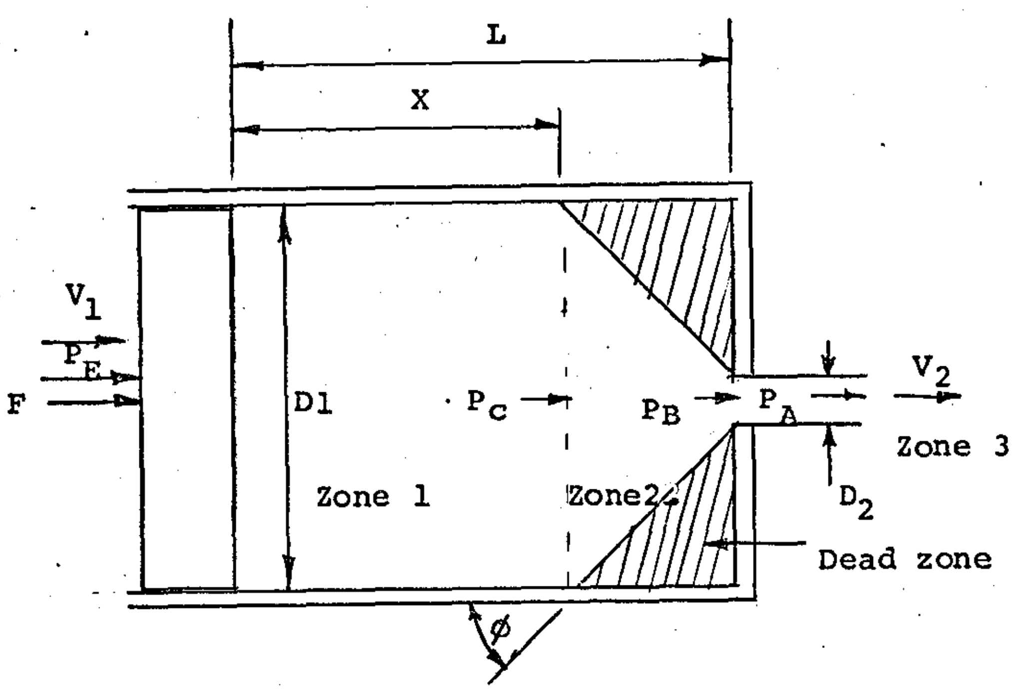


FIG. 3.4

Mathematical Model for Ram Extrusion[1]

for materials with μ = constant, C (e.g. fired Orange and unfired Red pigment) the pressure equation were also derived as:

$$\ell nPB = \ell nP_A + \frac{4C}{D_2} L_D \quad \ldots\ldots\ldots \quad (d)$$

$$\ell nP_C = \ell nP_B + \frac{2Cf}{\tan \emptyset} \; n \frac{D_1}{D_2} \quad \ldots\ldots \quad (e)$$

$$\ell nP_E = \ell nP_A + \frac{4CX}{D1} + \frac{4CLD}{D2} + \frac{4Cf}{(D1-D2)} (L-X) \; Ln\frac{D1}{D2} \ldots \quad (f)$$

The variable 'f' in equations (b), (c), (e) and (f) were found empirically for the pigments as shown in Table 3.4.

The complexity of these equations is obvious. Five constants C, f, K, n and μ have to be determined for each pigment, this will obviously decrease the accuracy of the results obtained when it is applied in practice. Extrusion pressures obtained using the above equation varies from between 45% for single hole die to 300 per cent for multiple hole die ram extrusion process.

Since the proposed ram extruder has to have multiple hole dies it was considered essential to determine a more acceptable model.

Work by Johnson and Kudo[7] and Shappard and Greasley[8] shows that direct extrusion process can be represented by the equation:

$$P = a + b \; \ell n \; R \quad \ldots\ldots\ldots \quad (5)$$

where P is the maximum extrusion pressure R the extrusion ratio, a and b are constants that reflect upon the extrusion speed, die contour, lubrication and other properties particular to the material being extruded.

Johnson and Kudo[7] derived the equation using slip-line field theory while Shappard and Greasley[8] derived it empirically.

Purchase and Tupper[9] obtained a curve (see Fig. 3.5) which can be represented by equation (5).

Although equation (5) is strictly empirical it has its origins in slip-line field theory and has the advantage that it is relatively simple to manipulate and the constants can be derived easily. It is interesting to note the resemblance of equation (1) to equation (5).

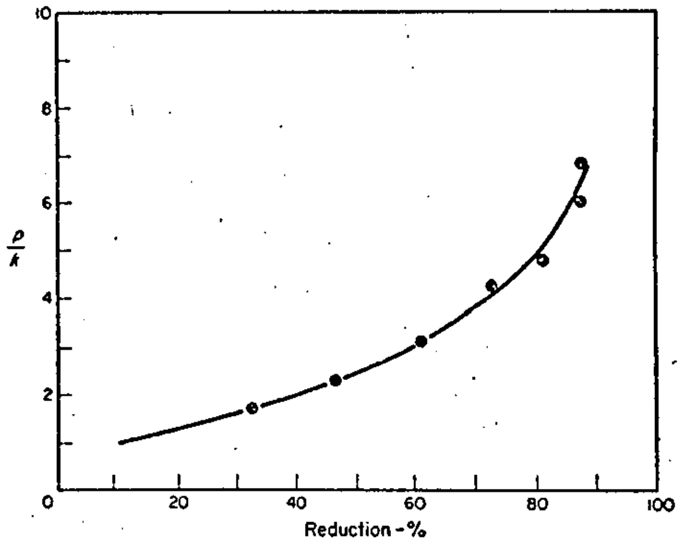
The results obtained from equation (5) are claimed to have an accuracy of about 10 per cent except for extrusion ratios below about 4 (ℓn R ≈ 0.4) where pressure is proportional to R and not ℓn R.

The applicability of equation (5) was verified and the values of the constants a and b were derived for various pigments as discussed in the next section.

$\mu = C$		$\mu = kp^n$	
MATERIAL	f	MATERIAL	f
Fired Orange	6	Fired Red	14
Unfired Red	0.35	Fired Yellow	13
		Fired Lithopone	4.2
		Unfired Lithopone	7
		Unfired Yellow	2.8

TABLE 3.4

'f' Factor for various materials



K = shear yield stress

FIG. 3.5

Comparison of theory and experiment in plane strain extrusion of lead with various reductions (Purchase and Tupper J.Mech Phys. Solids)

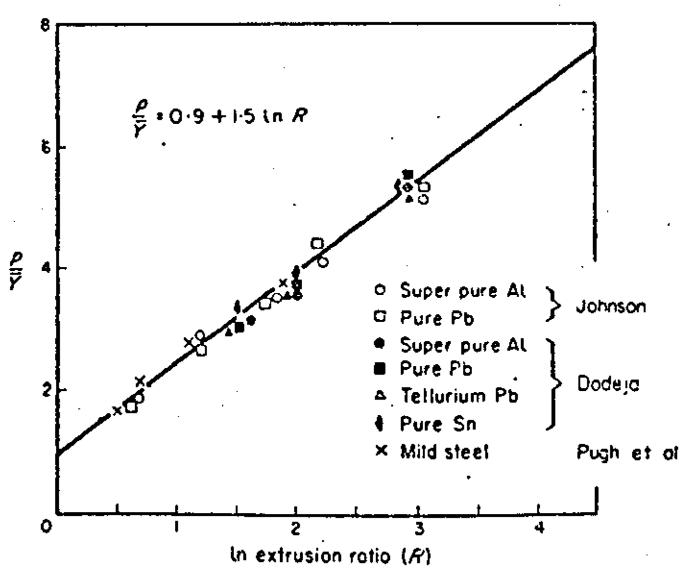


FIG. 3.6

Effect of extrusion ratio upon pressure required for extruding various materials through a 90^{o} die (Wilcox and Whitton, J.Inst Metals Results for steel from Pugh et al Sheet Metal Ind.)

3.2 EXPERIMENTAL ANALYSIS

3.2.1 Extrusion

Extrusion tests were performed on 0.5 MN Avery compression testing machine in the Department of Civil Engineering at the Loughborough University of Technology.

Fig. 3.7 shows the test rig. The extrusion cylinder has a boxed rectangular top which supports it on four I beams as shown. On the closed end of the cylinder 17 holes are drilled and tapped such that suitable die sleeves can be screwed into them when needed, otherwise the holes are plugged off using suitable plug screws. This arrangement enables the extrusion ratio R to be varied without having to change the die plate. Tests were carried out for extrusion ratios of between 51 and 414.

The compression tester is equipped with a Sangamo load cell which was connected to the Y input of a PHILLIPS X-Y recorder type No. PM8141. The piston displacement was monitored by displacement transducer (Fig. 3.8) which was built by the author using a resistance wire. The wiper of the transducer was connected to the X input of the recorder.

The extrusion speed, which governs the prevailing strain rate, was controlled by setting the pacer velocity on the compression tester.

3.2.2 Pressure/extrusion rate diagram

The second hypothesis stated in section 2.2.2(b) was verified using unfired yellow pigment at various piston speeds (extrusion rate) between 17 mm/min and 140 mm/min. with an extrusion ratio of 103.

The plot of the extrusion load versus extrusion speed is

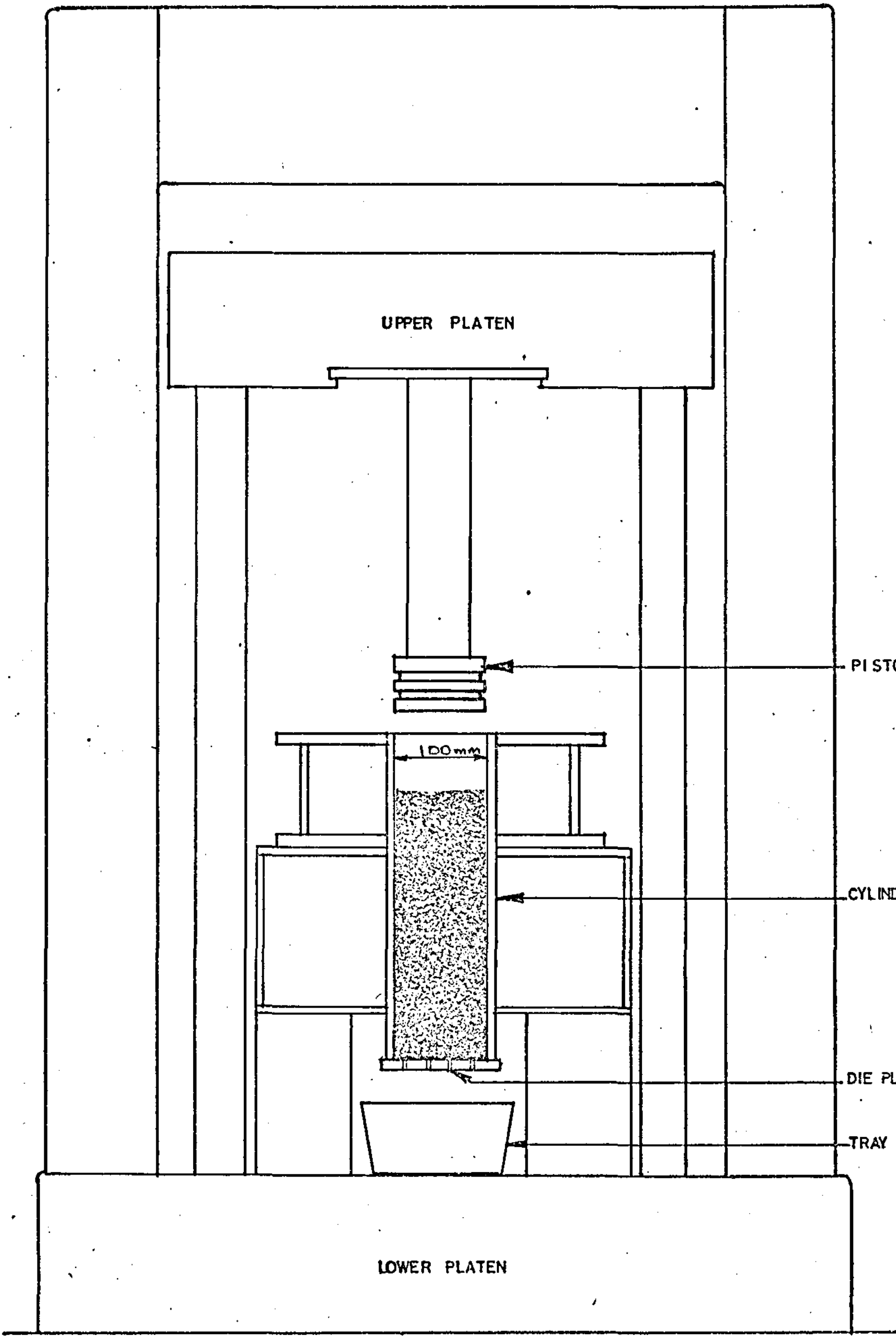


FIG 3-7A
THE LABORATORY TEST RIG AS MOUNTED ON THE COMPRESSION TESTER

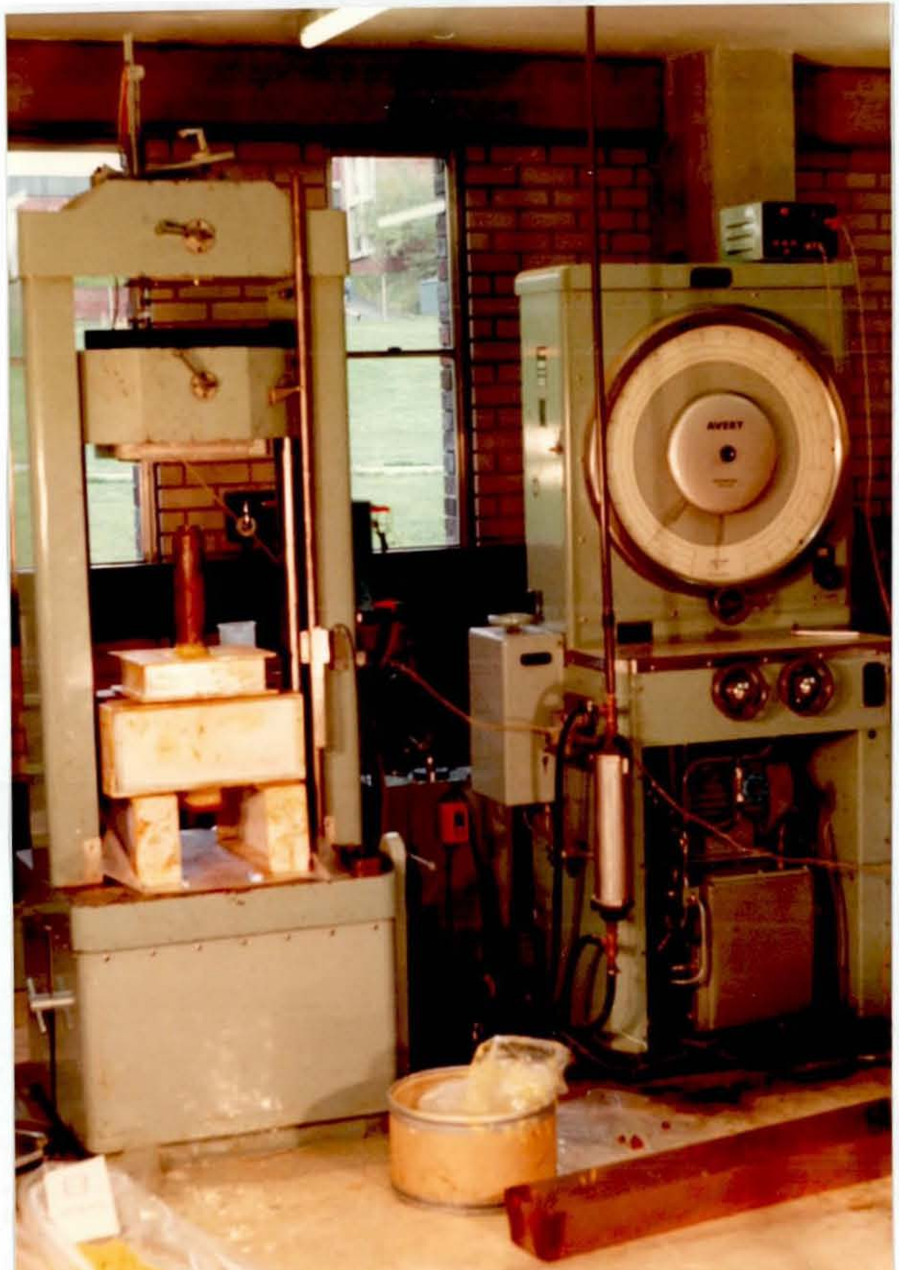


FIG 3-7B

THE LABORATORY TEST RIG AS MOUNTED ON THE COMPRESSION TESTER

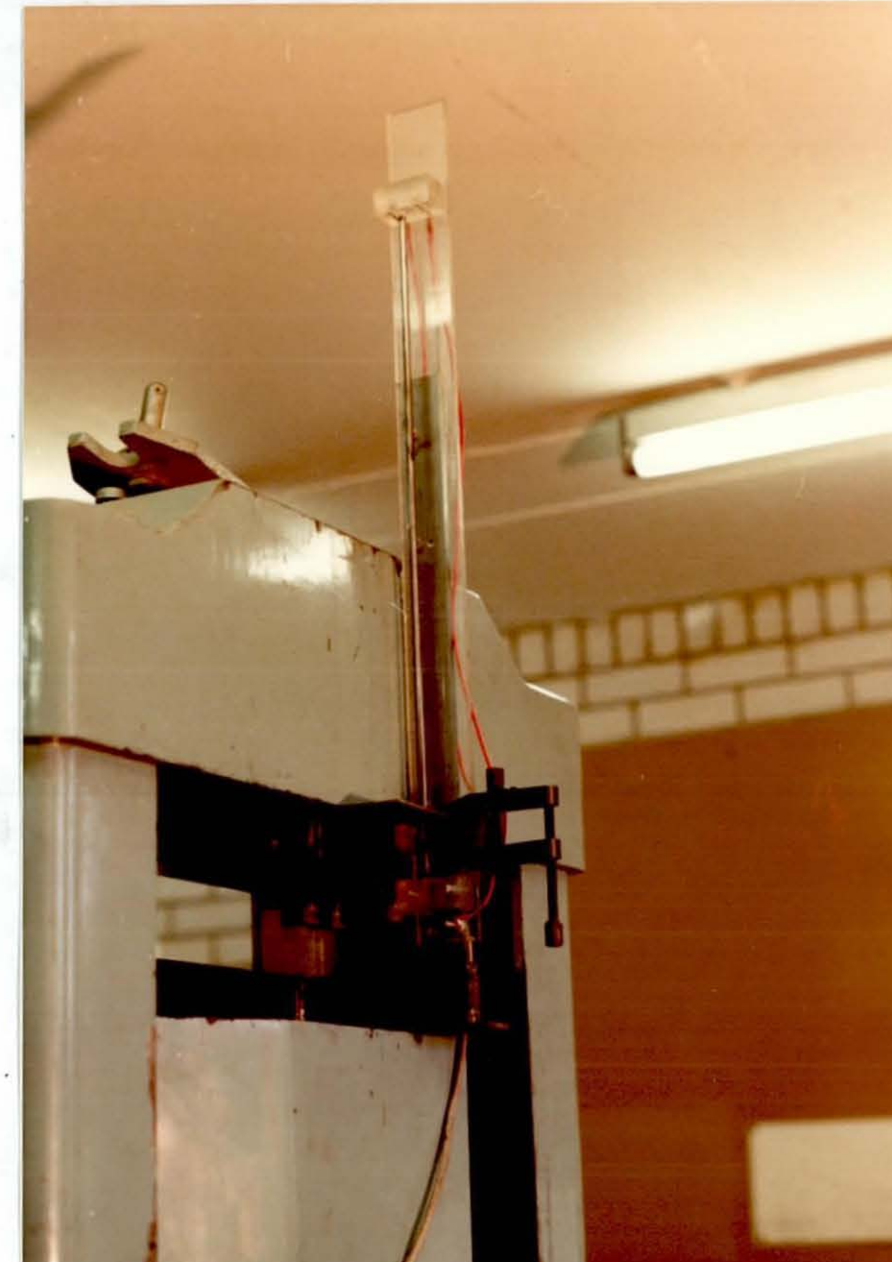


FIG 3-8

DISPLACEMENT TRANSDUCER MOUNTING DETAIL

shown in Fig. 3.9. It was found that there was a range of speeds in which the extrusion load is minimum as was originally believed. At very high extrusion speeds the extrudate exhibits poor surface quality characterised by the fir-tree surface defect. Extrudate of this type are not very suitable for drying as they crumble inside the dryer and turn into dust.

3.2.3 Extrusion pressure requirements

The results of previous workers as stated in section 3.1 shows that the extrusion process can best be described by the logarithmic law relating pressure and extrusion ratio. They used the pressure at the end of the extrusion stroke as the pressure parameter since this eliminates the contribution due to friction. This law was verified for various pigments. A minimum of four tests were carried out at extrusion ratios of 414, 207, 103 and 51 respectively with the piston speed set to give an extrusion rate of 120mm/sec, in each case using a square edge die.

The load displacement output traces obtained from the recorder are shown in Figs. 3.10 to 3.17.

Each trace can be divided into two regions, the compaction region and the extrusion region. In the compaction region there is a linear increase in load until the stock in cylinder attains its extrusion density, after which the load drops or remains constant depending on the pigment being extruded.

The extrusion region can be sub-divided into two zones; zones 1 and 2 (Fig. 3.4). Zone 1 is the normal extrusion zone in which the material movement is parallel to the container walls. Zone 2, the dead zone is close to the die in which area reduction takes place. When the piston enters zone 2, the extrusion load starts increasing as the piston continues to destroy the conical dead zone formed by the material.

As it is essential on the full scale machine to extrude virtually all the material in the cylinder, the pressure at the end of the stroke   mm from the die face was selected as the maximum extrusion load that will be required.

The logarithmic law curves for the various pigments investigated are shown in Fig. 3.18 and the equations of linear fit obtained are given in Table 3.6.

Pigment	Type	Relationship $P = a+b \ \ell n \ R$
R05	Fired	$P = -2030 + 107 \ \ell n \ R$
M59	Fired	$P = -2632 + 1141 \ \ell n \ R$
R01	Fired	$P = -2457 + 1000 \ \ell n \ R$
Y77	Fired	$P = -1092 + 518 \ \ell n \ R$
P06	Unfired	$P = 0 + 259 \ \ell n \ R$
R01	Unfired	$P = 784 + 98 \ \ell n \ R$
Y77	Unfired	$P = 210 + 93.1 \ \ell n \ R$
R04	Unfired	$P = 686 + 322 \ \ell n \ R$

TABLE 3.6

These equations are applicable to extrusion ratio above 12.

3.3 CONCLUSION

Figure 3.18 shows that the extrusion pressure is in fact a function of $\ell n \ R$ as in conventional extrusion process. Figure 3.9 shows that the extrusion pressure varies with the speed of the piston. It is accepted that during conventional mechanical working there exist a relationship which shows that the yield stress of the material (and hence the extrusion pressure) increases as the strain rate increases.

Figure 3.18 shows that there is less increase in pressure with increase in extrusion ratio for the unfired pigments as compared with the fired ones. This is in agreement with the original work carried out by the author et al[1] suggesting that more redundant work is required for the non-absorbent fired pigment particles. The non-absorbability of this grade of pigment results inevitably in the water originally contained in the pigment draining away during extrusion, not being retained in the body of the pigment, contributing little to the slip plane lubrication.


EXTRUSION FORCE - PISTON SPEED CURVE
FOR UNFIRED YELLOW PIGMENT
Y06
(EXTRUSION RATIO OF 103)
EXTRUSION FORCE (10^3 kg)
1·4
1·2
1·0
0·8
0·6
0·4
0·0
0
10
20
40
60
80
100
120
140
160
180
PISTON SPEED (mm/min)

FIG 3 - 9

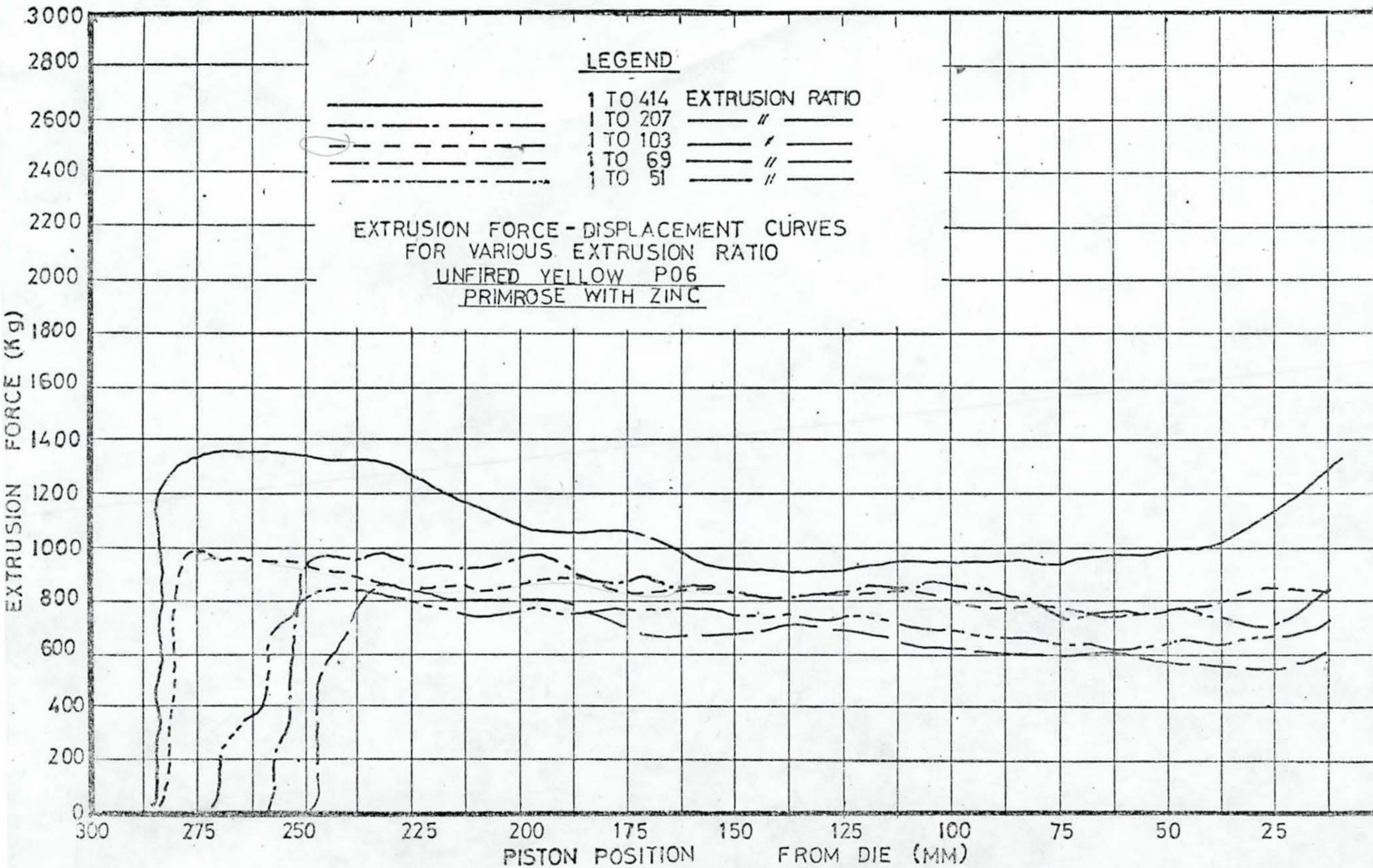

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 ″
1 TO 103 ″
1 TO 69 ″
1 TO 51 ″
EXTRUSION FORCE-DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
UNFIRED YELLOW P06
PRIMROSE WITH ZINC
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-10

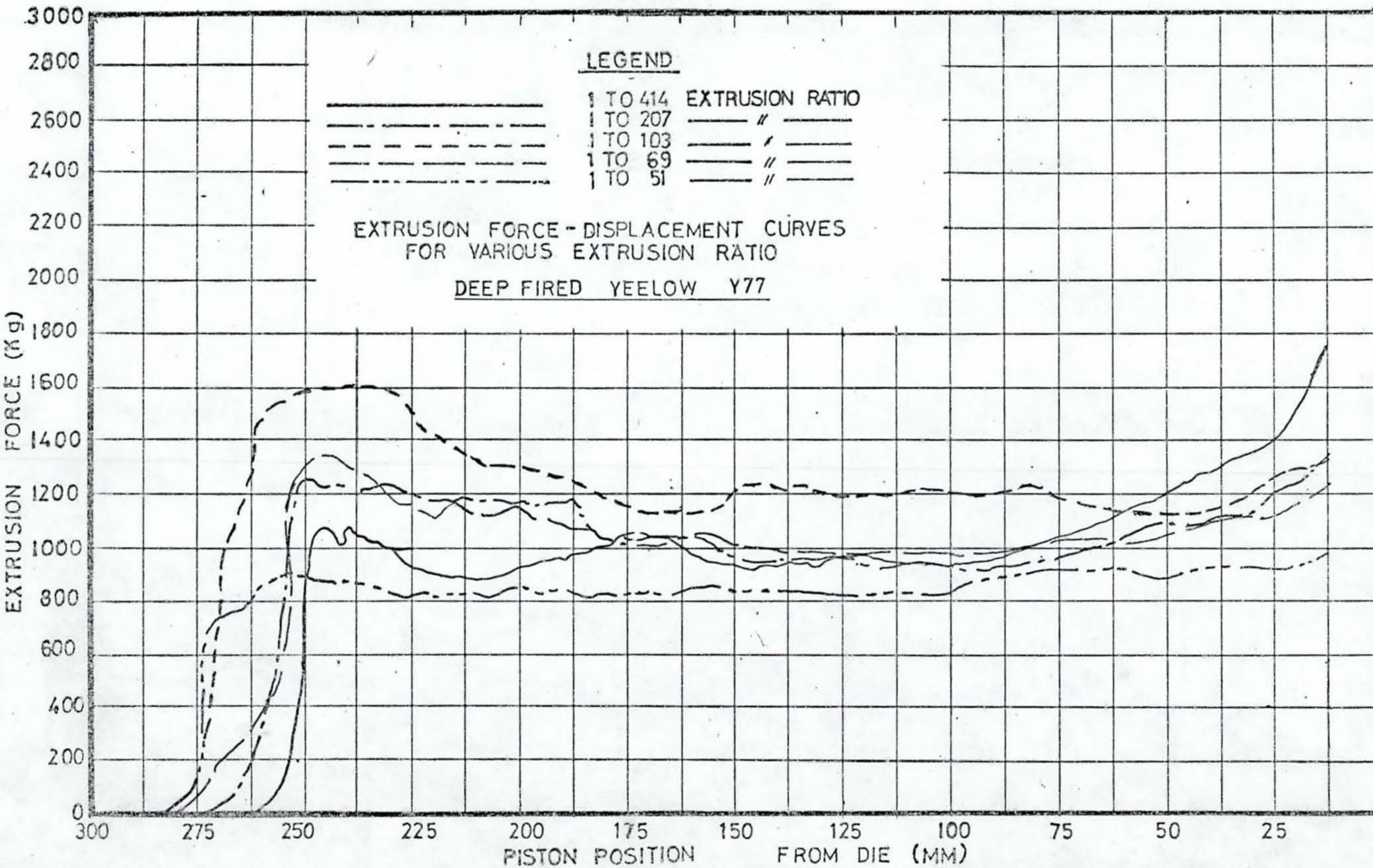

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — // —
1 TO 103 — / —
1 TO 69 — // —
1 TO 51 — // —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
DEEP FIRED YEELOW Y77
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-11

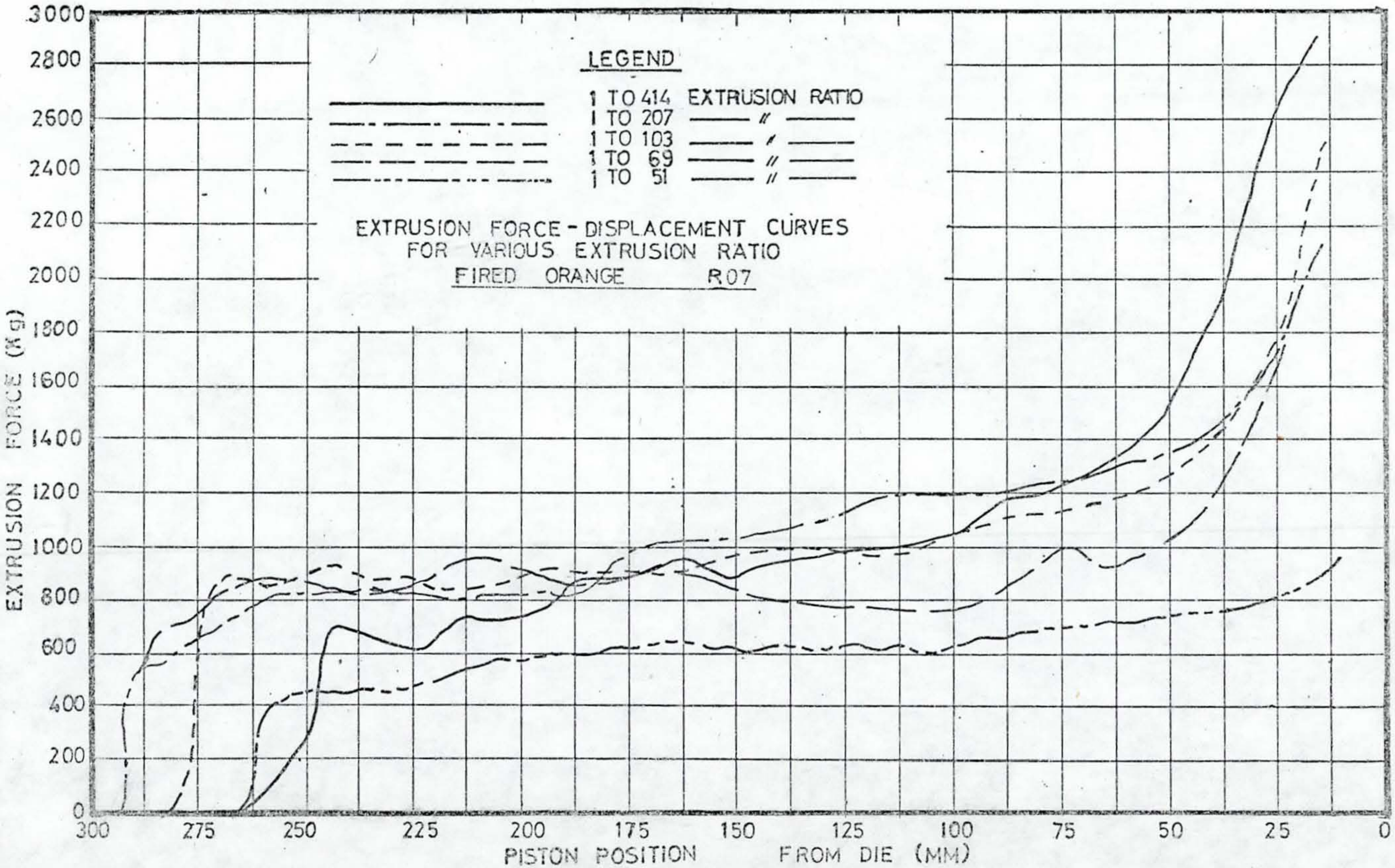

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — // —
1 TO 103 — / —
1 TO 69 — // —
1 TO 51 — // —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
FIRED ORANGE R07
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-12

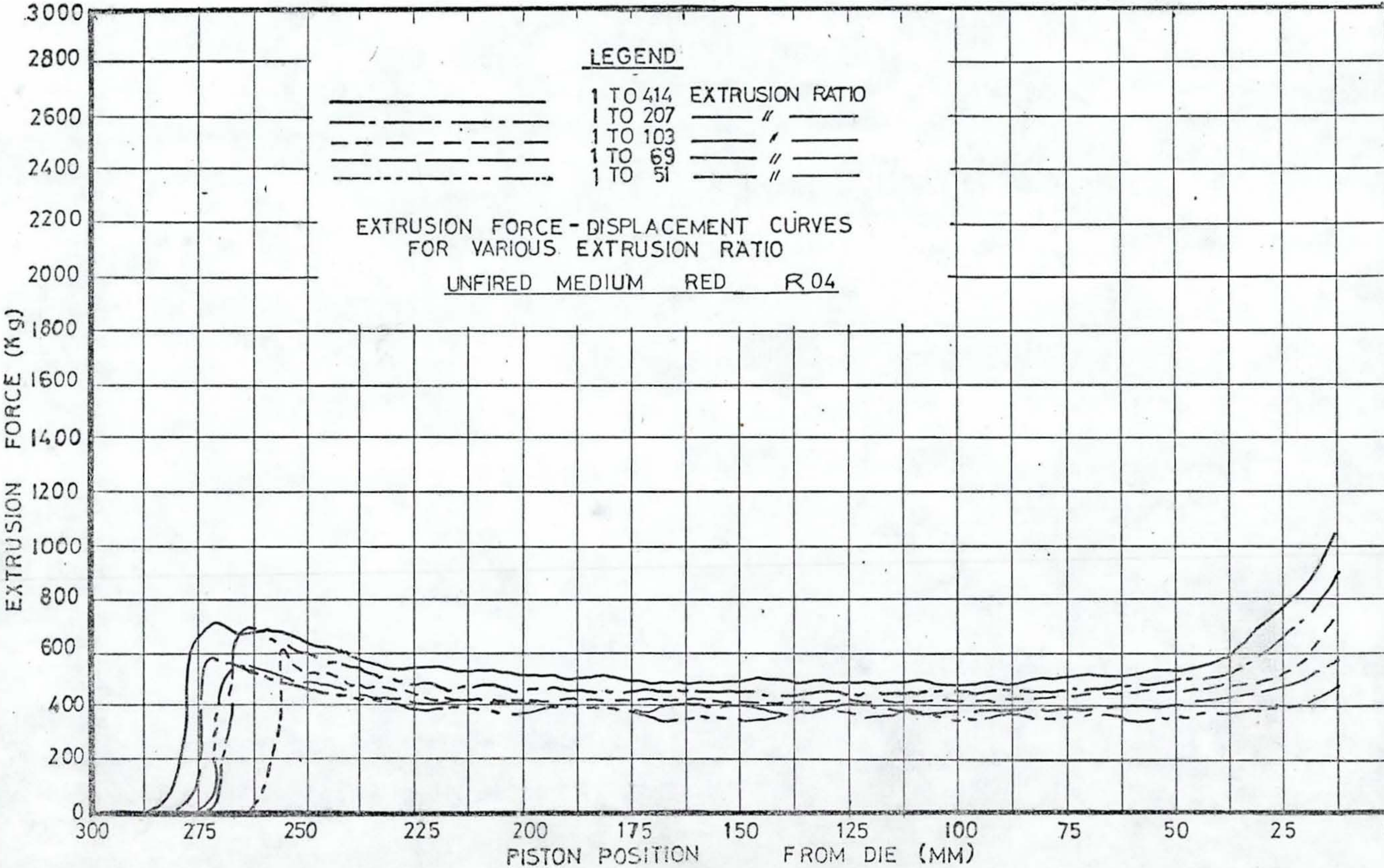

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — // —
1 TO 103 — / —
1 TO 69 — // —
1 TO 51 — // —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
UNFIRED MEDIUM RED R 04
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-13

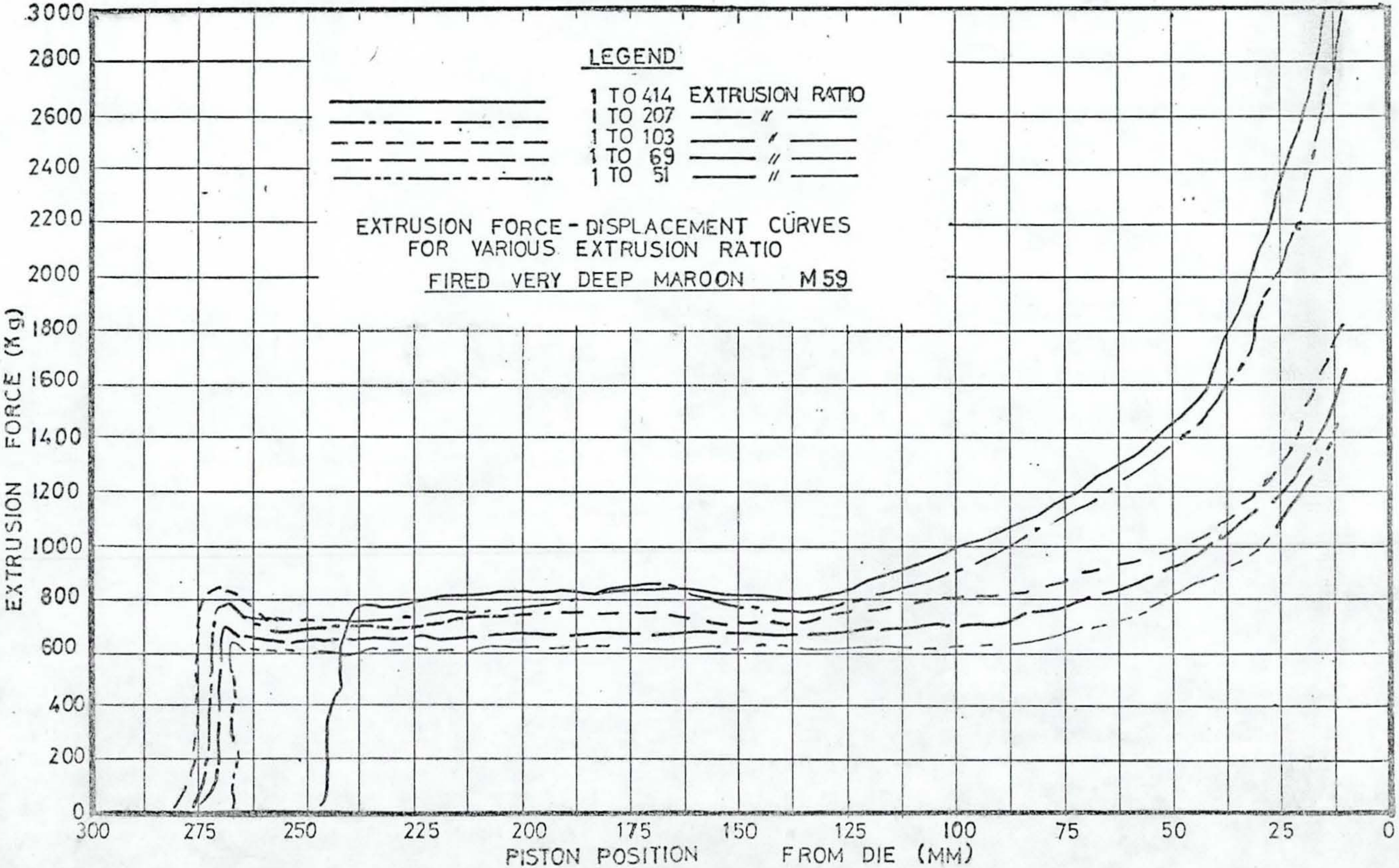

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — " —
1 TO 103 — " —
1 TO 69 — " —
1 TO 51 — " —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
FIRED VERY DEEP MAROON M 59
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-14

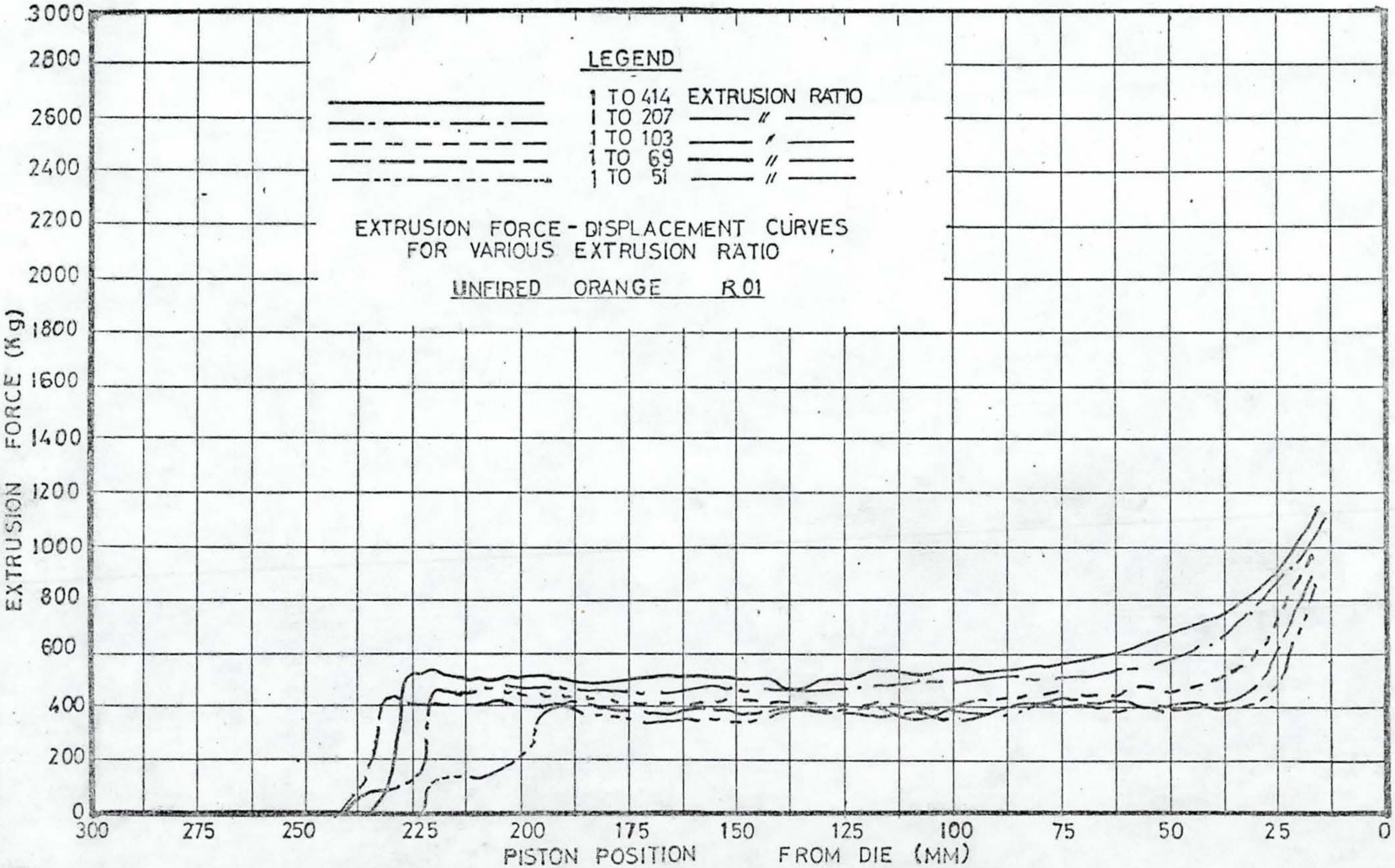

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — // —
1 TO 103 — // —
1 TO 69 — // —
1 TO 51 — // —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
UNFIRED ORANGE R 01
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-15

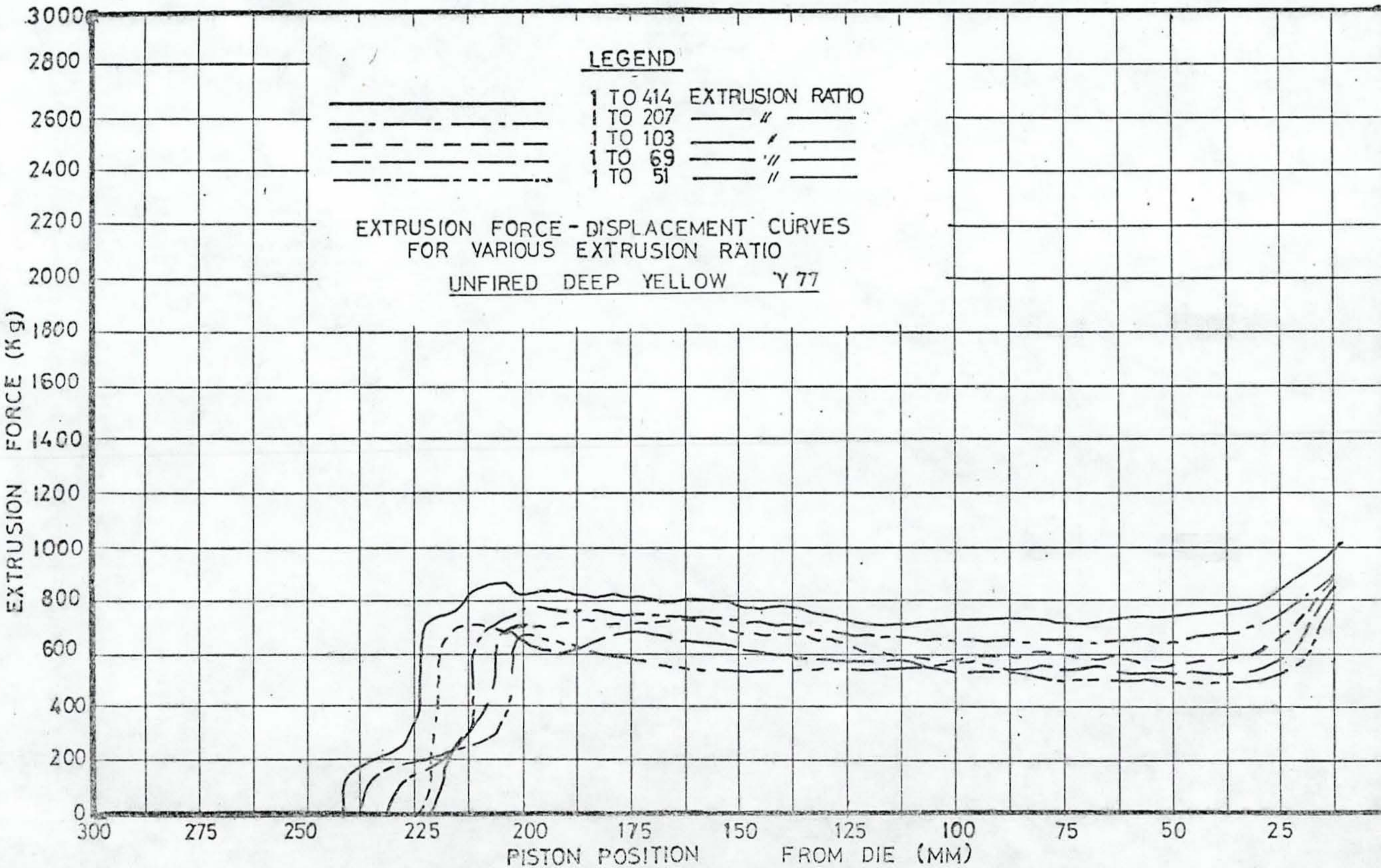

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 — " —
1 TO 103 — " —
1 TO 69 — " —
1 TO 51 — " —
EXTRUSION FORCE - DISPLACEMENT CURVES
FOR VARIOUS EXTRUSION RATIO
UNFIRED DEEP YELLOW Y 77
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-16

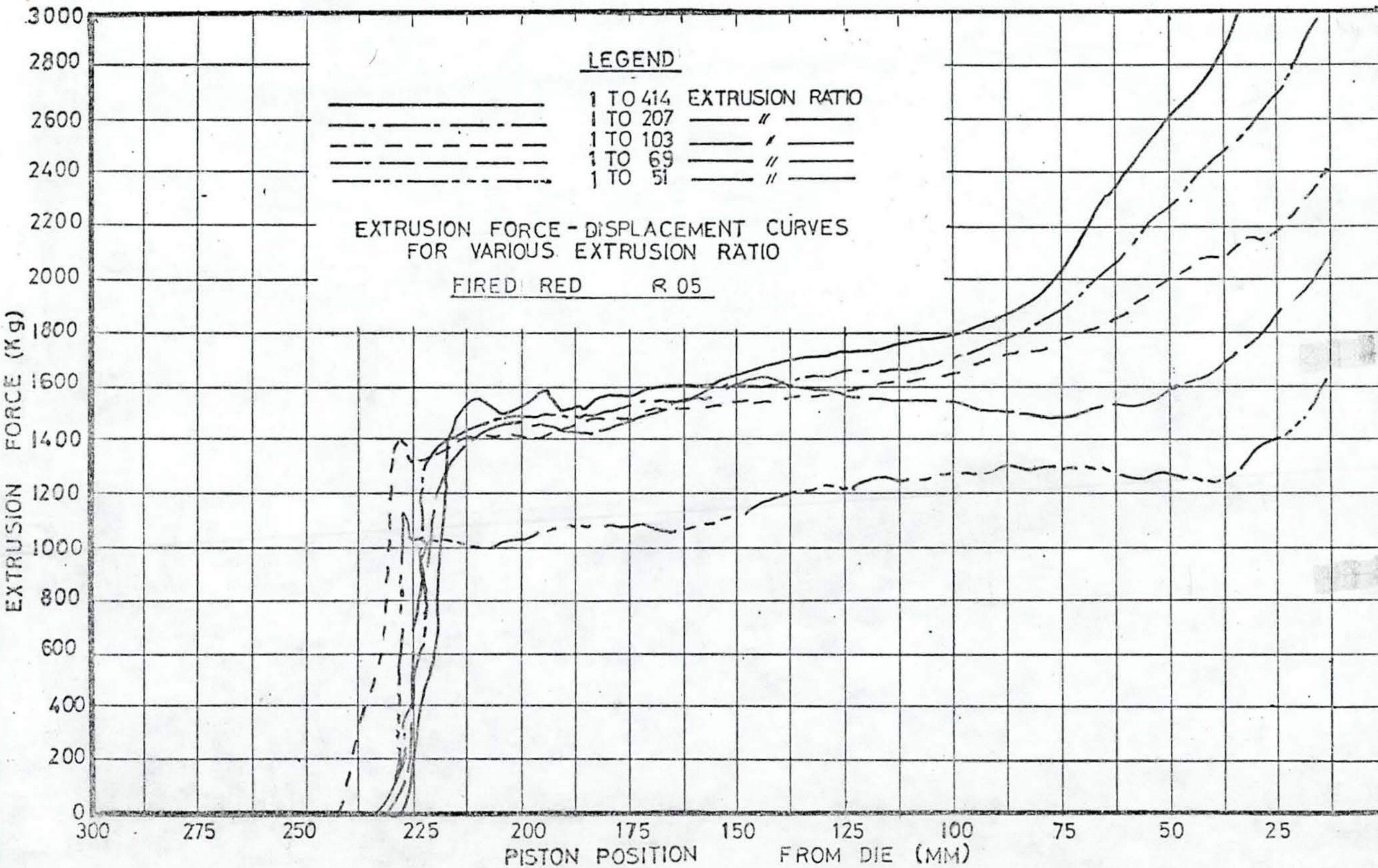
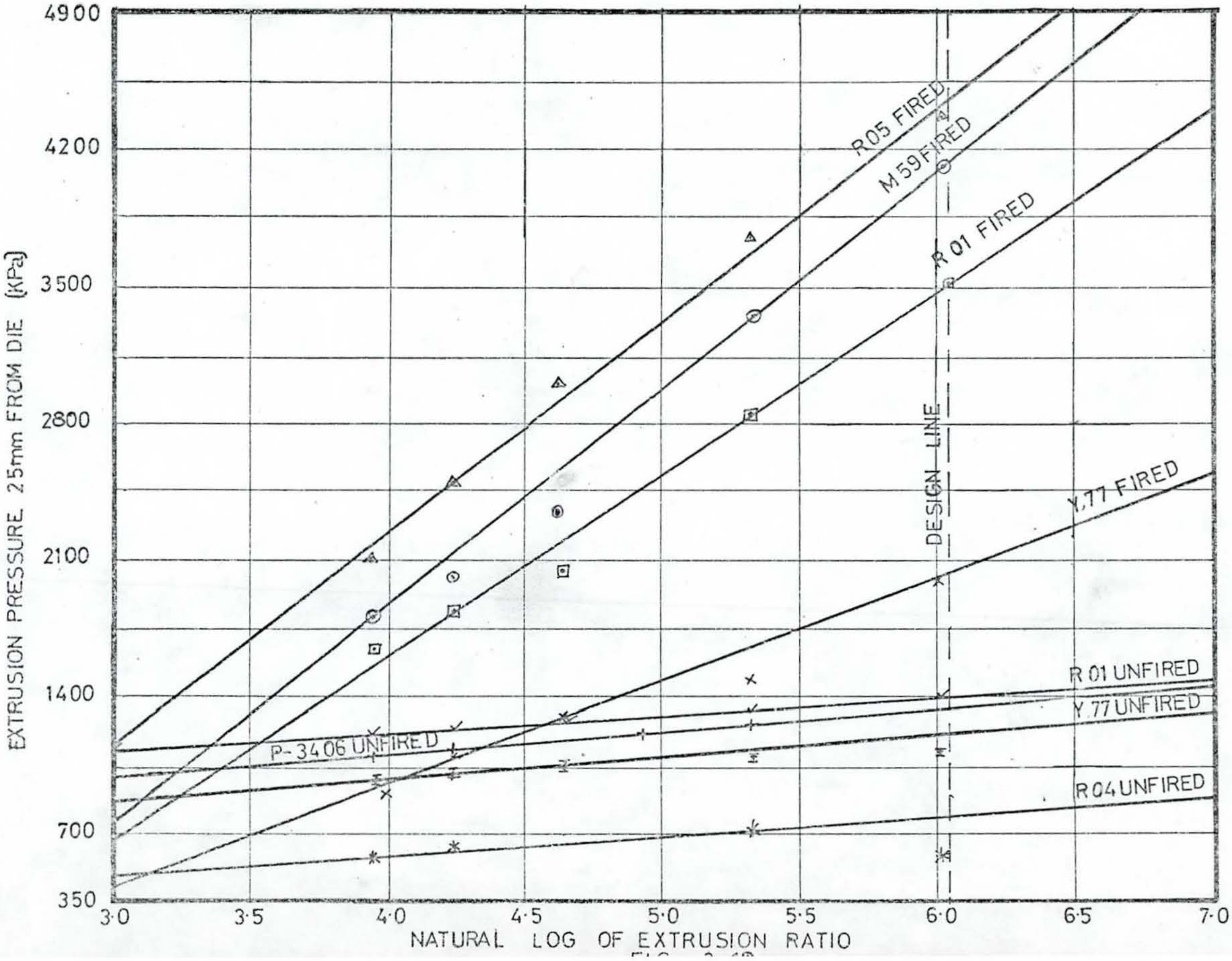

LEGEND
1 TO 414 EXTRUSION RATIO
1 TO 207 "
1 TO 103 "
1 TO 69 "
1 TO 51 "
EXTRUSION FORCE-DISPLACEMENT CURVES FOR VARIOUS EXTRUSION RATIO
FIRED RED R 05
EXTRUSION FORCE (Kg)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
300
275
250
225
200
175
150
125
100
75
50
25
0
PISTON POSITION FROM DIE (MM)

FIGURE 3-17


EXTRUSION PRESSURE 25mm FROM DIE (KPa)
NATURAL LOG OF EXTRUSION RATIO
4900
4200
3500
2800
2100
1400
700
350
3·0
3·5
4·0
4·5
5·0
5·5
6·0
6·5
7·0
R05 FIRED
M 59 FIRED
R 01 FIRED
Y 77 FIRED
R 01 UNFIRED
Y 77 UNFIRED
P-34 06 UNFIRED
R 04 UNFIRED
DESIGN LINE

CHAPTER 4

THE DESIGN OF THE EXTRUDER

The fundamental requirements for a plant which extrude pigment as requested by the sponsoring firm are as follows:

(i) That the degree of handling of the pigment be minimum.

(ii) The emerging extrudate from the extrusion plant should be of good quality.

A good quality extrudate being one that has the following attributes.

(a) Good beam strength, thus making possible the formation of uniform bed depth and good air passage on the band dryer.

(b) Homogeneous, compact internal structure that allows for rapid migration of water during drying.

(c) Good surface finish that minimises dust formation on the finally dried material.

(d) Good "colour strength". "Colour strength" is a measure of the amount of pigment required in the base material (paint or plastics), to satisfy the precise colour requirements of the customer. "Colour strength" can be adversely affected by excessive mechanical working and excessive drying time and temperature all of which tend to alter the pigment structure.

4.1 ANCILLARY EQUIPMENT

In this chapter the approach has been to examine all ancillary equipments currently being used in the pigment production process and to outline the constraint they impose on the new design, and from this to determine a suitable overall system configuration.

4.1.1 The filter press

The filter press is used to wash and filter pigment slurry. The press is as shown in Fig. 4.1. The basic structure of the filter press comprises a fixed end, crossnut unit, deep section side bars, a moving end casting which closes the the press pack tight and runs on the side bars.

The press pack which can consist of either plates and frames or recessed plates is carried on the side bars and supports the filter media.

The press is filled by opening a set of valves which allow pigment slurry into the filtering chambers. After the chambers have been filled, filtration commences and the cake builds up in the chamber. All valves are then closed and a wash liquor is allowed in through the appropriate valve. At the end of the wash cycle the wash liquor is allowed to drain away.

The washed filter cakes are knocked off the plate pack into skips, Fig. 4.1, placed under the pack and then transported to the extruder/dryer.

The daylight between the frame and ground varies from 0.8 m for Johnson filters to about 1.1m for the Fletcher filters.

4.1.2 The drier

The dryers in use at the sponsor's plant are through circulation dryers purchased from A.P.V. Mitchell of Carlisle. This type of dryer is popular in situations where the material to be dried has a constant output from a preforming device.

The dryer is built in modules. Each module consists of a high capacity centrifugal fan, steam heating coil and air inlet grill. A number of modules are joined together to make up a dryer in which a conveyor band is driven.

FIG 4-1
FILTER PRESS WITH A SKIP UNDER THE PACK

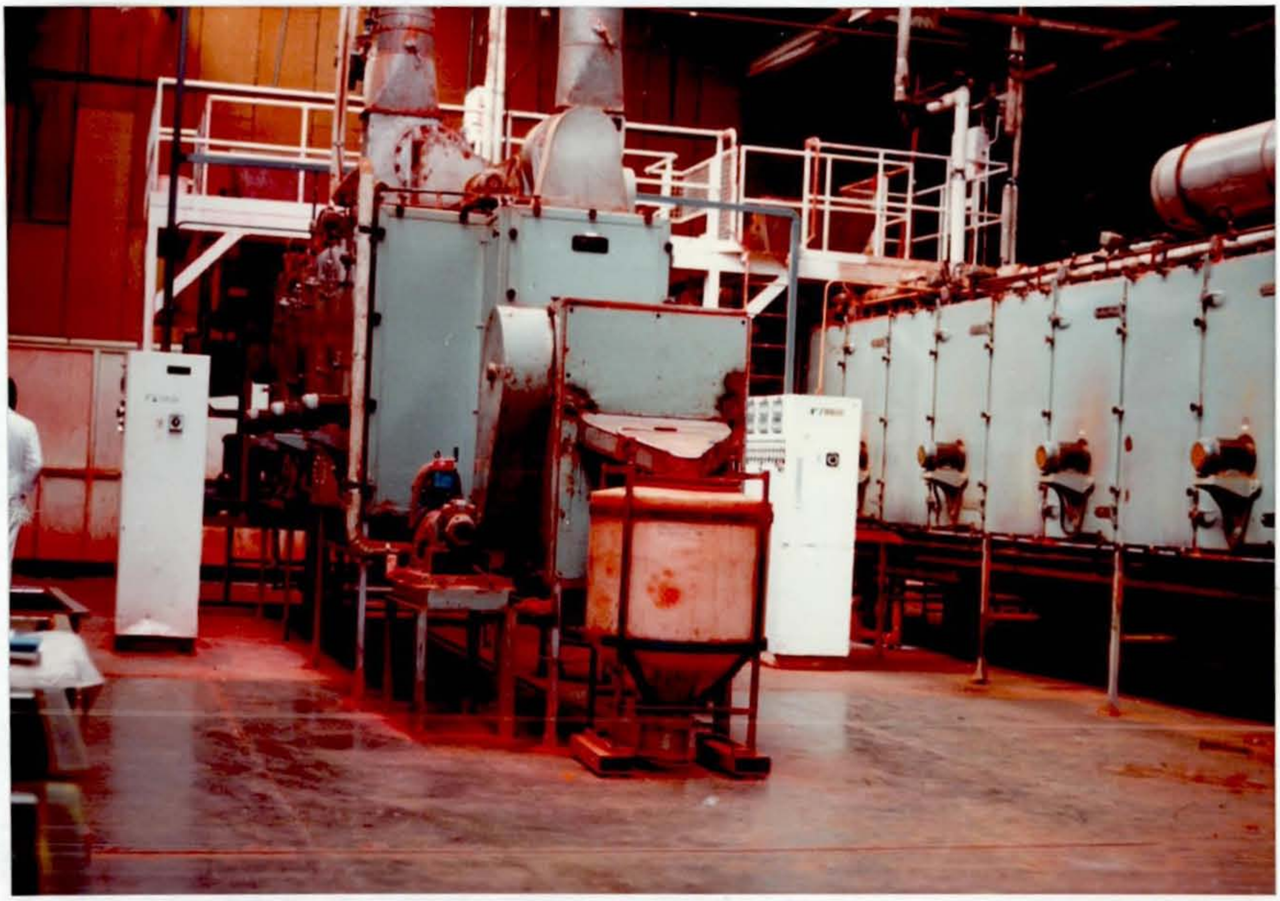
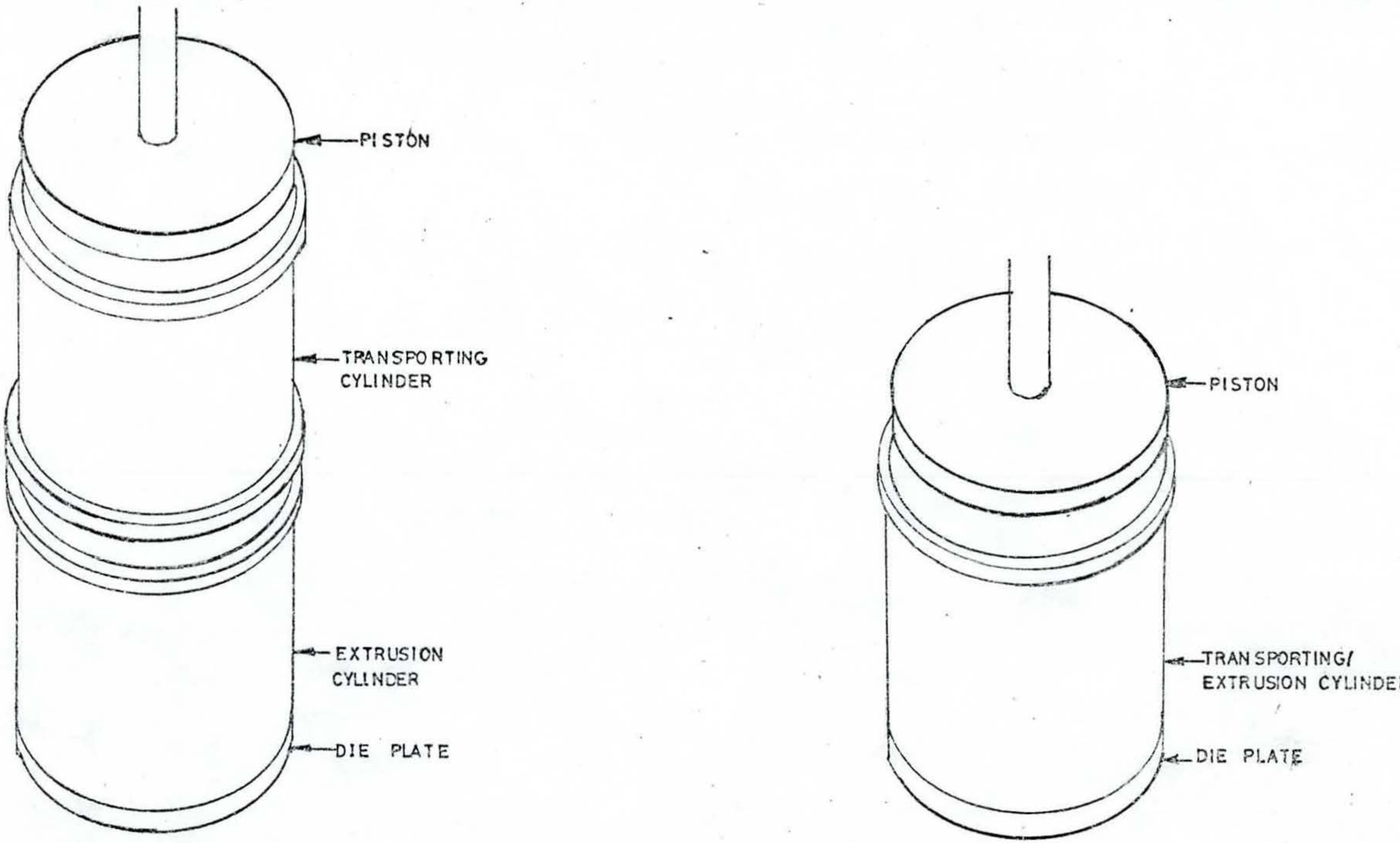


FIG 4-2
BAND DRYER



CONCEPT (1)

CONCEPT (2)

FIG 4-3

SELECTED CONCEPTS[1]

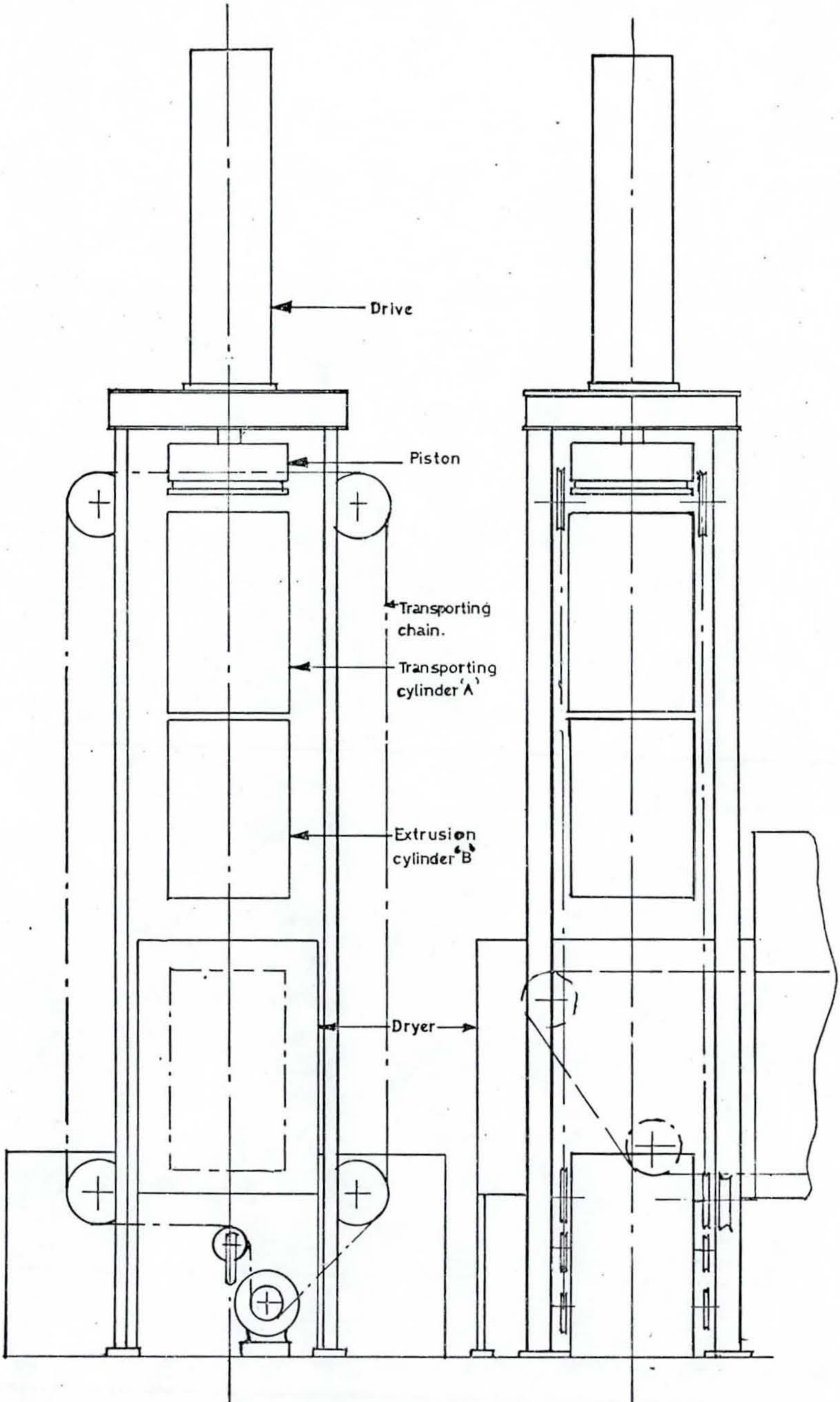


FIG 4-4

BLOCK SCHEMATIC DIAGRAM THE EXTRUSION PLANT AS PROPOSED BY THE TEAM (1)

Fresh air is drawn into the drying chamber through inlet ports disposed along the dryer as shown in Fig. 4.2. At the entry end of the dryer is positioned one exhaust fan for exhausting the humid air to atmosphere.

Between the drying chamber and the delivery end is located a dead zone where an extract fan is positioned to extract dust from dry pigment before they are delivered.

The height of the conveyor band at the inlet port varies between 2.0 metre and 2.1 metre for the four dryers in use at the sponsors' work.

4.1.3 The screw extruder

This is an indirect or viscous-drag type of extruder. It develops extrusion pressure by viscous drag and therefore modifies the characteristics of the extruded product.

The pigment is fed from a hopper through the feed throat into the channel of the extruder. The screw rotates in a barrel. Four extruder barrels are arranged in such a way as to give an acceptable spread of extrudate onto the band dryer. They are all driven from a single motor through a speed reduction gear. The backward thrusts of the screws are absorbed by a thrust bearing.

As pigment is conveyed along the screw channel, it is simultaneously subjected to mixing and shearing. When close to the discharge end i.e. near the die, it is at a high pressure and finally it is discharged out of the die onto the conveyor belt.

4.2 DESIGN CONSTRAINTS

Ancillary equipments such as the dryer and the filter press impose certain constraints on the system configuration and equipment design. These constraints are:

1. The dryer:

(a) The height of the conveyor belt onto which pigment is extruded at the inlet port is on the average (for the four dryers in use) about 2.0 metres. This means that pigment has to be raised to this level before or after it is extruded. It is desirable to reduce the height of the dryer but since other ancillary equipments used in the process have been manufactured to fit this height, this objective cannot be achieved due to the huge cost and lóng shut down time that would be involved.

Thus the new system must include a means of lifting the pigment to this height.

(b) The maximum available area at the inlet port onto which material can be extruded is 0.60 x 0.60 metre. This imposes a constraint on the cross-section of the extrusion container to be used in the new machine.

2. The filter press:

Skips are used in transporting the filter cake from the frames of the press to the extruder. They also serve as holding containers leaving the press free for another pressing/filtration operation to commence.

It would be desirable to knock down the cake directly into the extrusion containers if a discontinuous process is designed in place of the present system in order to keep the discontinuity to a minimum. To achieve this the containers should have the maximum possible volume. As stated above the dryer has imposed a constraint on the containers' cross-section. Thus only the containers' height can be maximized.

The optimum height of a container requires that the daylight between the filter frame and ground be increased. This cannot be done without high loss in production time. A detailed analysis of this constraint is given in section 4.5.

4.3 CONCEPTUAL DESIGN

In order to satisfy the product specification, the group originally working on this project generated many concepts, details of the concepts are given in[1]. The decision matrix used in evaluating the concepts indicated that those concepts which are simple in appearance and in operation work the paste less than those concepts that have complex features. This is why concepts 1 and 2 (see Fig. 4.3) were selected. They are basic. The pigment paste is pressurized and squeezed through die holes by the linear movement of the ram. Their main components are in line, thus the applied extrusion forces are also in line. Hence, it is envisaged that these concepts will require minimum development time and will stand a good chance of successful operation against the performance requirements.

A 600 mm diameter ram extruder based on concepts 1 and 2 were presented to the sponsors in July 1978 as a result of the constraints imposed by the band dryer width.

The sponsors agreed that the simplicity of the arrangement was an obvious and commendable feature. They raised three main points of concern:

(i) The feed system to the ram is discontinuous and a material handling system has to be considered. The group explained that the system proposed will operate one hour non stop.

(ii) That the design introduces a large pressure vessel into the production process whose size would involve special testing and insurance procedures. This was shown not to be the case since high pressure is only experienced towards the end of the extrusion stroke and the maximum extrusion pressure will not exceed 4.8 MPa (see load/displacement curves in Chapter 3).

(iii) That the pigment transporting containers were likely to be subjected to damage, not only from normal movement procedures but also from occasional vigorous handling by machine operators.

After the initial concept selection and presentation, the group went into the detailed consideration of various means of driving the ram. As stated above, a 600 mm diameter extrusion cylinder was used with an average ram speed of 15 mm/min during extrusion.

The machine then being developed was based on concept 1 (see Fig. 4.4) in which two cylinders were used. The top cylinder A is the transporting cylinder, and the fixed cylinder B, is the extrusion cylinder. Cylinder A has a sliding base which is opened when it is being located onto the extrusion cylinder B.

The group went into the detail design of the extruder by considering mechanical drives (lead screw), hydraulic and Pneumatic drives. At that time a mechanical drive was favoured.

The whole project was reviewed by the author when he took over the project and the work done is detailed in the next section.

4.4 EXTRUDER DETAILED DESIGN

When the author took over the project it was necessary to review the chosen concept by the previous group working on the project. As was mentioned in the last section (4.3) the group favoured a mechanical (lead screw) for driving the ram and also the use of the two container systems.

When all the control and allied equipment required for the implementation of the chosen concept were considered, it was found that the cost of components involved was at variance with the target cost. The author then decided to consider other alternatives.

The requirements of the drive mechanism then were:

(i) It should be able to deliver an extrusion pressure of 21 kPa.

(ii) It should have a working stroke of 2 metre.

(iii) It should be capable of being driven fast forward and fast return as the system demanded and should operate at a ram speed of about 15 mm/min during extrusion.

Before commencing the detailed design of the new plant it was considered necessary to answer the following questions:

(i) Was the selected concept economically sound?

(ii) Would it be easy to manufacture and assemble?

(iii) How reliable would the plant be?

(iv) How easy would it be to maintain?

(v) Had the specification as agreed changed in anyway?

To answer these questions, alternative schemes that fulfil the basic chosen concept within the framework of the specification have to be considered and developed.

4.4.1 Main drive

Before describing the alternatives drives considered the mechanical drive favoured by the group is described.

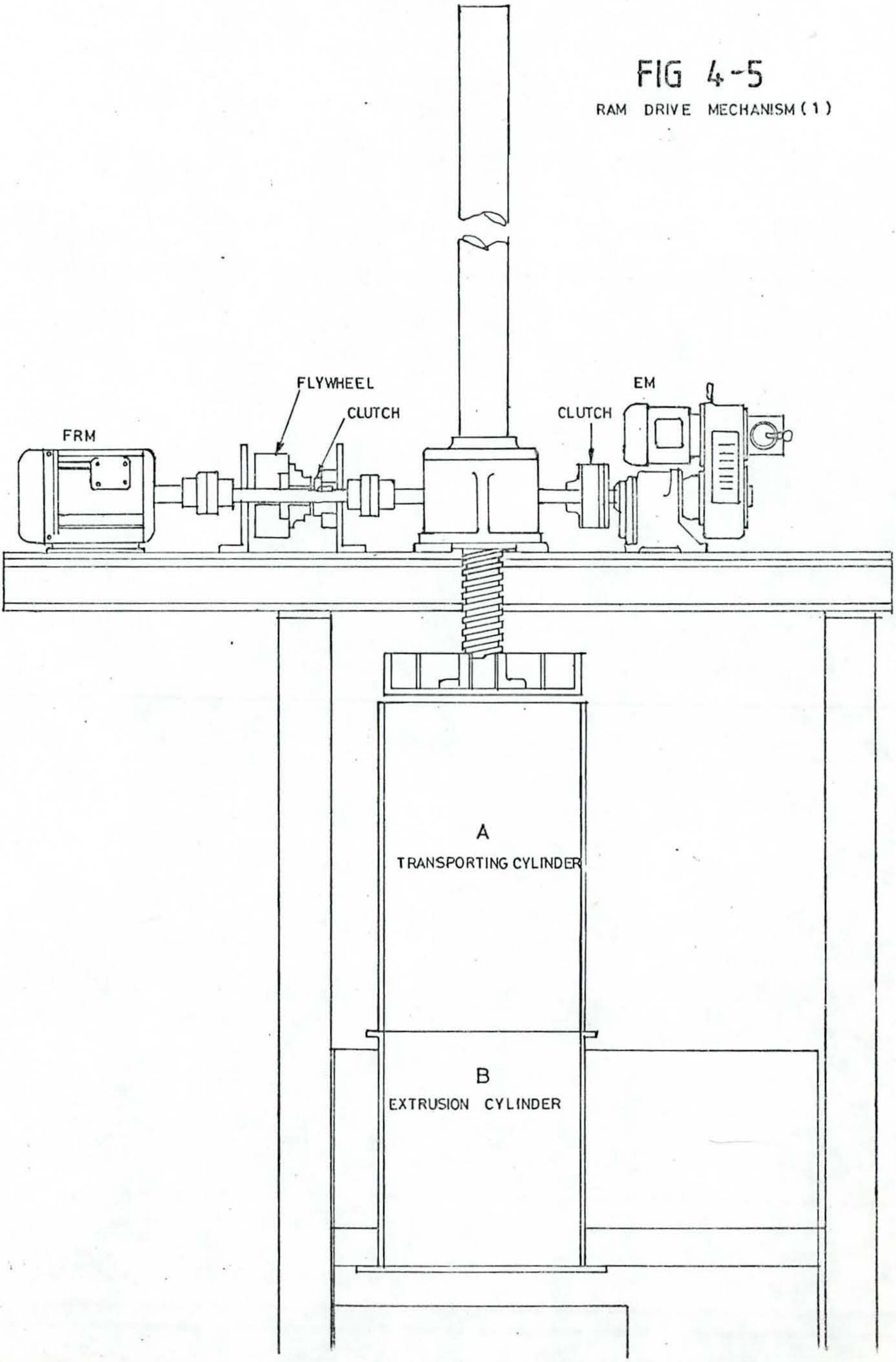
The scheme was as shown in Fig. 4.5, and has seven main operations.

(i) Lifting the transporting cylinder A to position.

(ii) Aligning cylinder A with the extrusion cylinder B.

FIG 4-5

RAM DRIVE MECHANISM (1)



(iii) Transferring pigment from cylinder A into cylinder B and compacting the pigment.

(iv) Extruding the pigment.

(v) Withdrawal of the piston after extrusion.

(vi) Removing cylinder A.

(vii) Lowering cylinder A to ground level from where it is taken for refilling.

The transportation, lifting, aligning and lowering operations are described in [1]. To aid in the understanding of the scheme a brief description of the transporting cylinder will be given. This cylinder has the same diameter as the extrusion cylinder B. It has a sliding base which is removed when it is being aligned with cylinder B ready for material transfer.

When the cylinder A and its contents have been properly aligned with cylinder B the fast forward/return motor (FRM) is energised to drive the piston fast forward. This action transfers the material from cylinder A to cylinder B.

This motor runs at 1440 rpm and drives the piston at a speed of 2300 mm/min. It is coupled to the screw driving the piston through a flywheel and a pneumatically actuated clutch. This clutch is used to disengage the flywheel from the FRM motor shaft during the piston withdrawal operation. When the piston has moved 1000mm and the content of cylinder A has been transferred to cylinder B the motor is de-energised and the energy stored in the flywheel is used in compacting the pigment.

When the material has been compacted the extrusion motor (EM), which is coupled to the piston driving screw through a triple reduction gear box, and another pneumatically actuated clutch is energised to commence extrusion. The EM motor has an output speed of between 5 and 20 rpm. After the completion of the extrusion operation the FRM motor is energised, but it runs in the opposite direction, with the flywheel disengaged, in order to return the piston to the cycle starting position.

The two motors FRM and EM are energised through the same single pole double throw (SPDT) switching relay to ensure that the operation of the two motors are mutually exclusive.

The clutches are pressure actuated fail safe.

On the analysis of the above scheme, it was found that many components were involved. As Pugh stated in his paper[10] 'Simplicity of design is the key to both quality and cost'.

Carroll and Bellinger[11] remarked that 'Perhaps the major single contributor to operating reliability is simplicity' and 'That superior design is one which encompasses the necessary operating and protective functions with absolute minimum number of components and connections!'.

Bearing this simplicity approach in mind the author set out to find simpler drive alternatives.

The first alternative that came to mind was a hydraulic drive with suitable flow control to achieve system specification. The sponsors raised objection to the use of a hydraulic drive as they feared that leakage of hydraulic fluid into the pigment cannot be tolerated since this will destroy the colour strength and other consumer required characteristics.

It was considered that a fluid drive would potentially be simpler and more reliable than the mechanical drive. Consideration was given to the pneumatic and water drive which will have no destructive effects on the pigment. Using a standard pneumatic working pressure of 10.5 MPa, a 400 mm bore cylinder will be required to deliver the 1.4 MN design thrust required. This cylinder is obviously too large, none standard and will be expensive.

The use of water as hydraulic fluid would have been feasible except for the high equipment cost that will be involved since special components will be required.

A study of the use of hydraulic powered system in general revealed that with proper preventive maintenance scheme and by design, a hydraulic oil powered system could be used without the fear of oil leakage. This re-evaluation was put to the sponsors, and they then agreed to the use of oil hydraulics.

A detail description of the hydraulic drive is given in Chapter 6 on controls.

The advantage of the hydraulic powered drive over the mechanical is that apart from the fewer numbers of parts required to achieve the objective, the same power pack could be used to drive other ancillary equipment, that make up the plant.

4.4.2 Extrusion cylinder selection

By reconsidering the pros and cons of the dual cylinder system proposed by the author et al in their original work and comparing the cost and shutdown time that would be involved as discussed in section 4.3, the concept of using a single cylinder for both transportation and as the extrusion cylinder was favoured.

The use of a single cylinder reduces the stroke requirement of the drive by half. That means a smaller diameter piston rod could be used in the drive as the slenderness ratio is reduced.

The detail design of the extrusion cylinder is given in section 4.4.5.

4.4.3 System configuration

After an agreement was reached on the main drive unit, and the extrusion cylinder selected, it was then necessary to consider unit combinations that would yield an acceptable working system. The configuration to be discussed here was selected to satisfy the following objectives.

(i) To have minimum unit/component count.

(ii) To allow for minimum handling of material between the press and the extruder.

(iii) To allow a degree of automation to be built into the system.

(iv) To yield a system with high reliability.

(v) To yield a system that will require minimum maintenance.

The system as a whole consists of two main sections; the extrusion unit, and the filter cake handling unit (FCHU) with a common power pack and control unit.

The extrusion unit incorporates the extrusion frame, lifting mechanism, panning (movement in the horizontal plane), extrusion ram, and two extrusion cylinders.

One extrusion cylinder charged with pigment by the handling unit is loaded into the extrusion frame at ground level. The lifting mechanism lifts the extrusion frame to a height 10 cm over the inlet port of the band dryer and the panning mechanism pans the extrusion frame to a suitable position over the dryer ready for extrusion to commence.

4.4.4 System layout

In this project, floor area is a constraint. Essentially what is needed is that the elements of the plant should be assembled together in such a way as to maximize the distance between them so as to reduce unwanted couplings and to ease the problem of maintenance, at the same time the overall volume is minimized and the connections between elements kept as short as possible. Obviously these requirements are mutually incompatible, and the problem of layout design is to reconcile the requirements. A Series of assembly drawings of the system elements were prepared. Different layouts made from the drawings were tried until a suitable arrangement was found. The layout obtained is such that the whole assembly could fit into the available volume while the required spacing around the elements is maintained.

Figure 4.6 shows the final general layout of the plant. A factor that was much in mind during the layout design is repair and maintenance. It was ensured that ample room is available for elements removal and replacement with minimum of disturbance of other elements.

4.4.5 Extruder component selection and design

Concurrently with the latter stages of the system layout process, thought was turned to the components of the complete extrusion plant.

As ennumerated in sub-section 4.5.3 the extrusion machine consists of a number of sub-systems. The sub-system numbers refer to part numbers shown in Fig. 4.6.

1. Main Power Source.
2. Extrusion Frame
3. Main Structure
4. Lifting Mechanism
5. Panning Mechanism

6. Extrusion Ram A/Piston B

7. Extrusion Cylinder

8. Control System

9. Filter Cake Handling Unit.

The choice between alternative sub-systems depends on a number of considerations. The decision tree Fig. 4.7 provides a good method of control and records all arguments for future reference. The decision tree design approach was postulated by Marples[12] as a generalised model of the design process in which each solution will give rise to a series of subsidiary problems, each of which has, usually more than one solution. The starting point of the table corresponds to the initial formulation, followed by the proposed solutions to the resulting second rank of problems and so on. A complete design results from paths through the tree subject to the following rules:

(a) When a number of alternative solutions are presented, any one may be accepted and the rest rejected.

(b) All of the problems dependent on the choice of a particular alternative solution must be solved.

(c) A particular branch of the tree must be followed until a solution is reached which does not have a dependent problem. Provided that this solution is the preferred one at this point, then the branch terminates.

The sub-systems that make up the plant were investigated using block schematic diagrams. It will be appreciated that none of these sub-systems is completely independent.

Each of these sub-systems will be described, and the distinction made between alternative sub-systems outlined, for example, alternative extrusion frame.

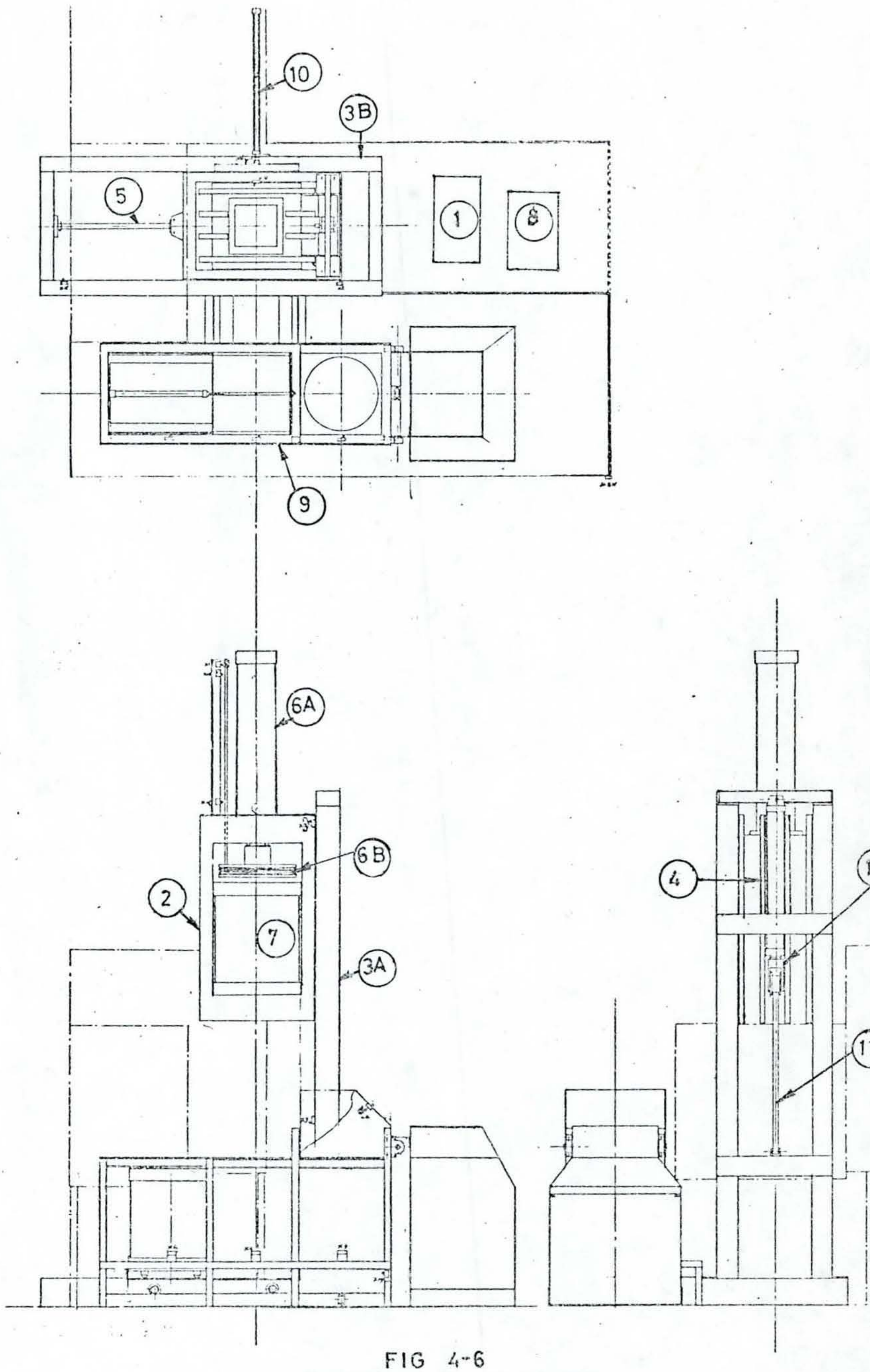


FIG 4-6
EXTRUSION PLANT LAYOUT

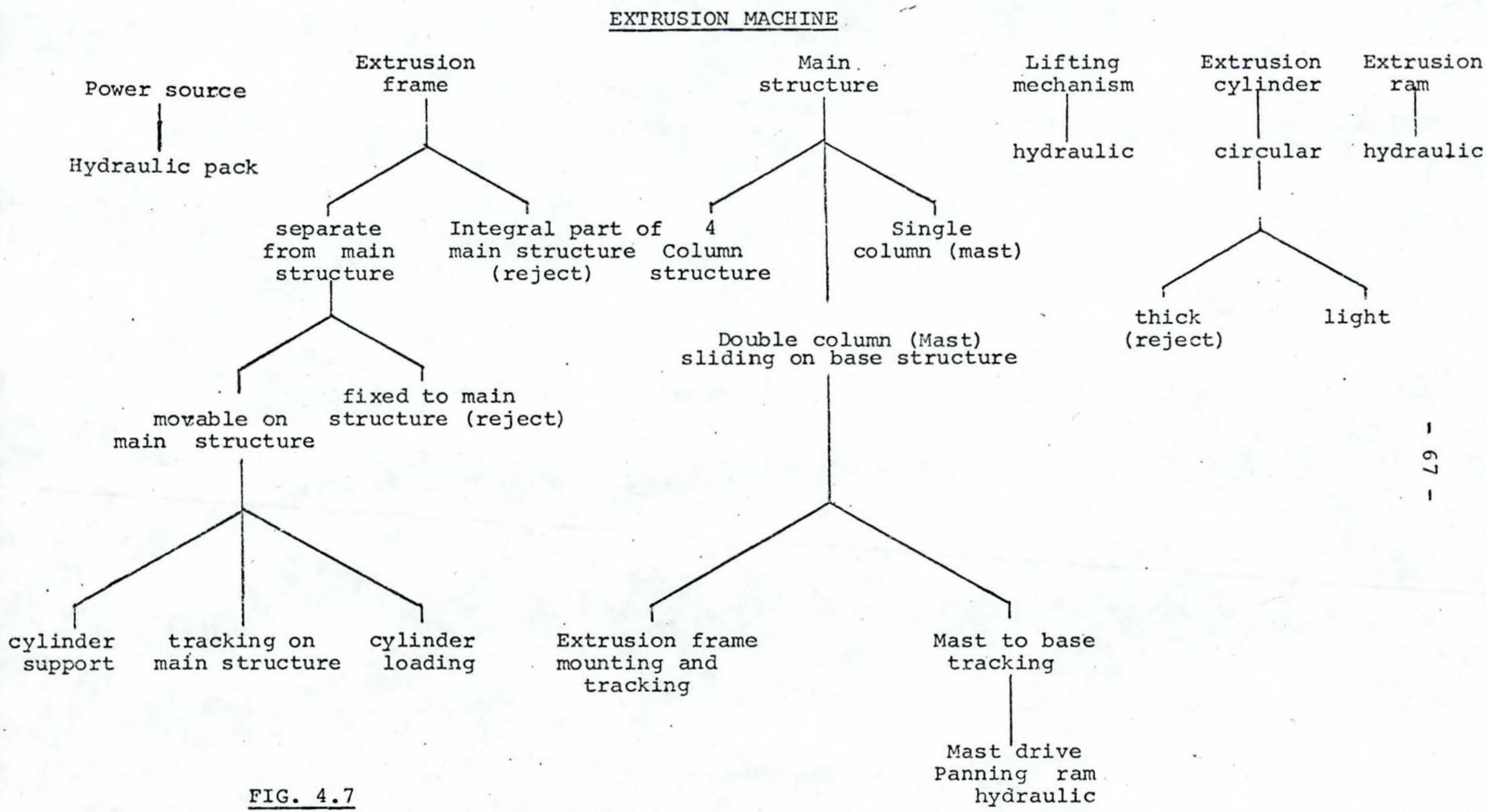


FIG. 4.7

Decision tree for Extrusion Machine Design

The main power source and the control system are described in Chapter 6. The reasons behind the selection of the main power source has already been given in section 4.5.1.

Pugh[13] advocated the use of the "load lines" approach to detail design of mechanical components. This approach, when applied, not only yields simple and cost effective components which forms a complete system but also makes the choice between block schematic diagram of alternative systems easier and their load analysis simpler.

The extrusion frame is a component of the plant into which an extrusion cylinder is loaded and it is in this frame that extrusion takes place. The extrusion frame can either be an integral part of the main structure as proposed in[1] or separate from it. An extrusion frame separate from the main structure was chosen. This will allow some flexibility in its design. It will also keep the extrusion forces away from the structure. This gives rise to the question of whether to have it fixed to the main structure or movable. A movable extrusion frame has been chosen. This enables loading of the extrusion cylinder to be done at ground level where the operator can easily correct any misalignment of the extrusion cylinder and the piston when being loaded. The frame can then be lifted to the height where it will extrude onto the band of the dryer.

It was also decided that the extrusion ram (6A) which drives the piston(6B) will have to be mounted directly on the extrusion frame. This arrangement will allow the piston to be permanently aligned with the extrusion frame during manufacture/assembly.

Having selected the type of extrusion frame it was now left to decide on its structure. Four possible structures were considered (see Fig. 4.8).

Structure (1) is a T-slot frame into which a square top flanged cylinder will be loaded. This arrangement has a simple and light structure for the extrusion frame but has the disadvantage that the whole extrusion force will have to be borne by the cylinder flange. Thus each extrusion cylinder will have to be designed to withstand the extrusion load. The alignment of the cylinder will depend on the flange.

Structure (2) is also a T-slot frame but it supports the cylinder at its bottom. This has the disadvantage that each cylinder bottom has to be structured to be able to withstand the extrusion force and its bending effect.

Structure (3) is a boxed frame opened on two opposite ends through which the extrusion cylinder is loaded. It has the advantage that the extrusion load is distributed within the frame. The cylinder bears only the circumferential stress that might arise due to extrusion pressure within it. The bottom of the cylinder can thus be light. Alignment of the cylinder in the frame is easier since it is guided on two sides. The alignment can be built in during the fabrication of the frame.

This structure has the disadvantage that clearance holes have to be provided on the bottom part of the frame through which extrudate from the die holes on the cylinder can pass without interference. This will increase the depth of the structure at this part of the frame.

Structure (4) consists of two plates, top and bottom plates connected together by four tie rods.

This structure is light and easier to manufacture. It has

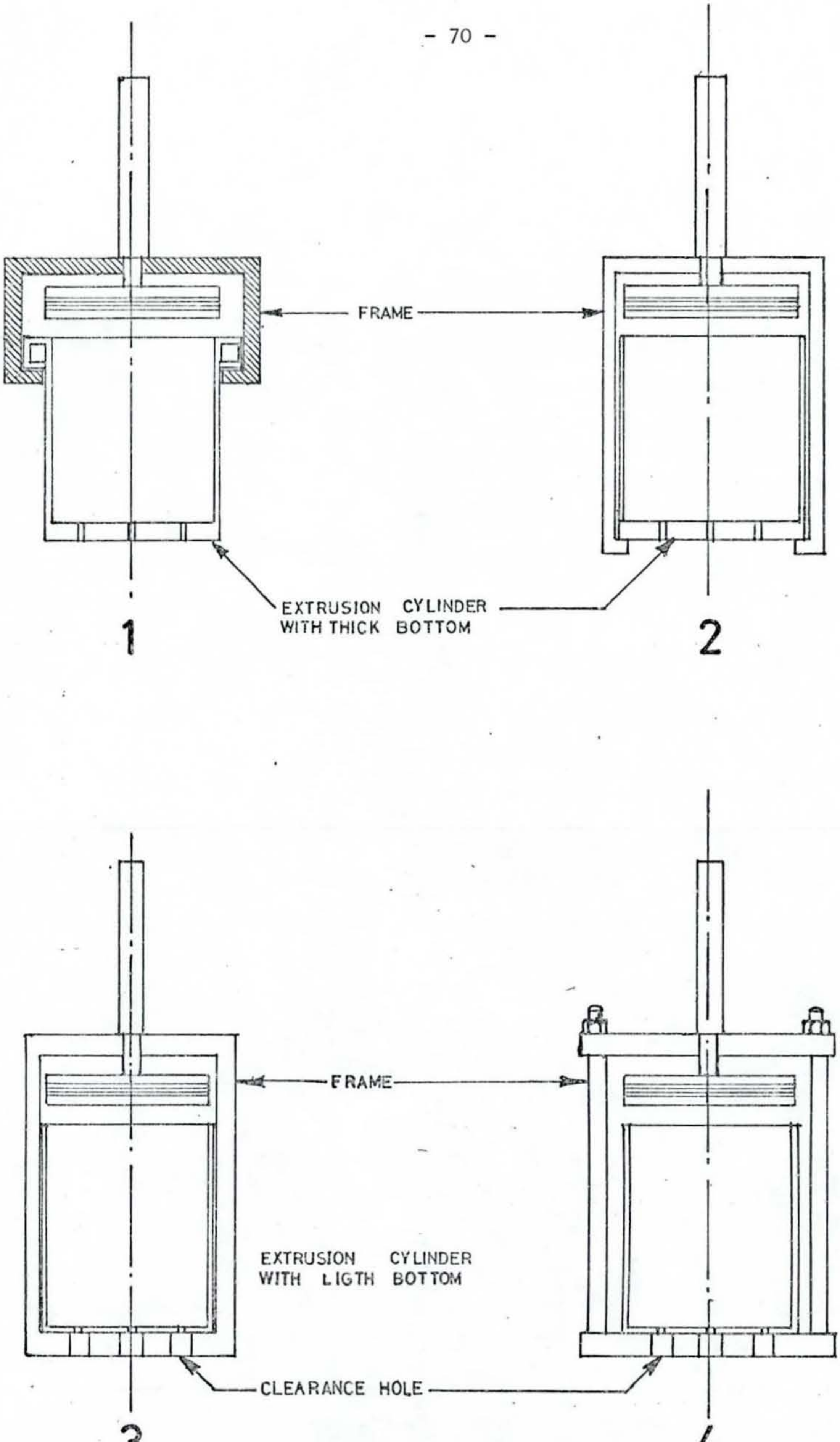


FIG 4-8

EXTRUSION FRAME CONCEPTS

the disadvantage of structure 3 but it is not as rugged. Alignment of cylinder with the piston will be more difficult.

Structure 3 was selected for the frame due to the advantages mentioned above and from aesthetic point of view.

The choice of the type of main structure to use is based on the constraints imposed by the dryer layout, its height and space availability. A two column L shape mast sliding on a rectangular horizontal base Fig. 4.9, was chosen. This arrangement yielded a more space saving scheme and is more aesthetically pleasing. The extrusion frame runs on the up-right part of the L shape mast while the lower part of the mast runs on the base, thus enabling the extrusion frame to move both in the vertical and horizontal planes. The single column L shape mast with a suitable base could be used but this will have less stability compared with the two column mast. Also, lifting arrangement for the extrusion frame will be more complex.

The choice of other sub-systems, the lifting mechanism, panning mechanism, extrusion ram were based on the main power source which is hydraulic. They all have an hydraulic ram as actuator .

The lifting mechanism consists of a lifting ram(4), lifting chain(11) and lifting shackle(12). The ram has a clevis mounting head attached to cross beam (see Fig. 4.6). The chain is fixed at one end to a lower cross brace on the mast. It is passed over the lifting shackle carried on the end of the lifting ram. The other end of the chain is fixed to a lifting tab(Fig. 4.11) on the extrusion frame. This arrangement has the advantage of putting the lifting ram rod in tension only, and gives a lift twice the stroke of the ram.

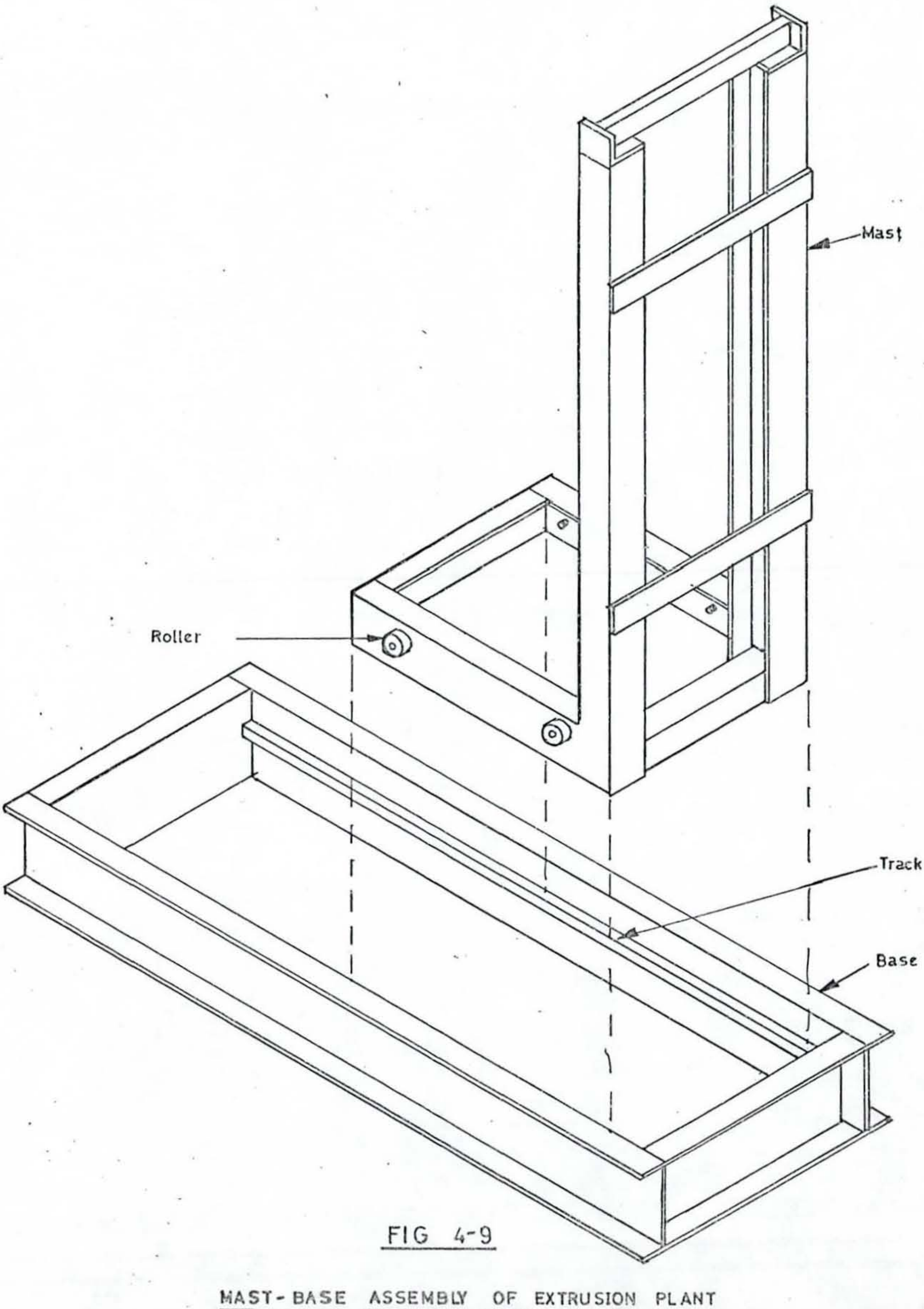


FIG 4-9

MAST-BASE ASSEMBLY OF EXTRUSION PLANT

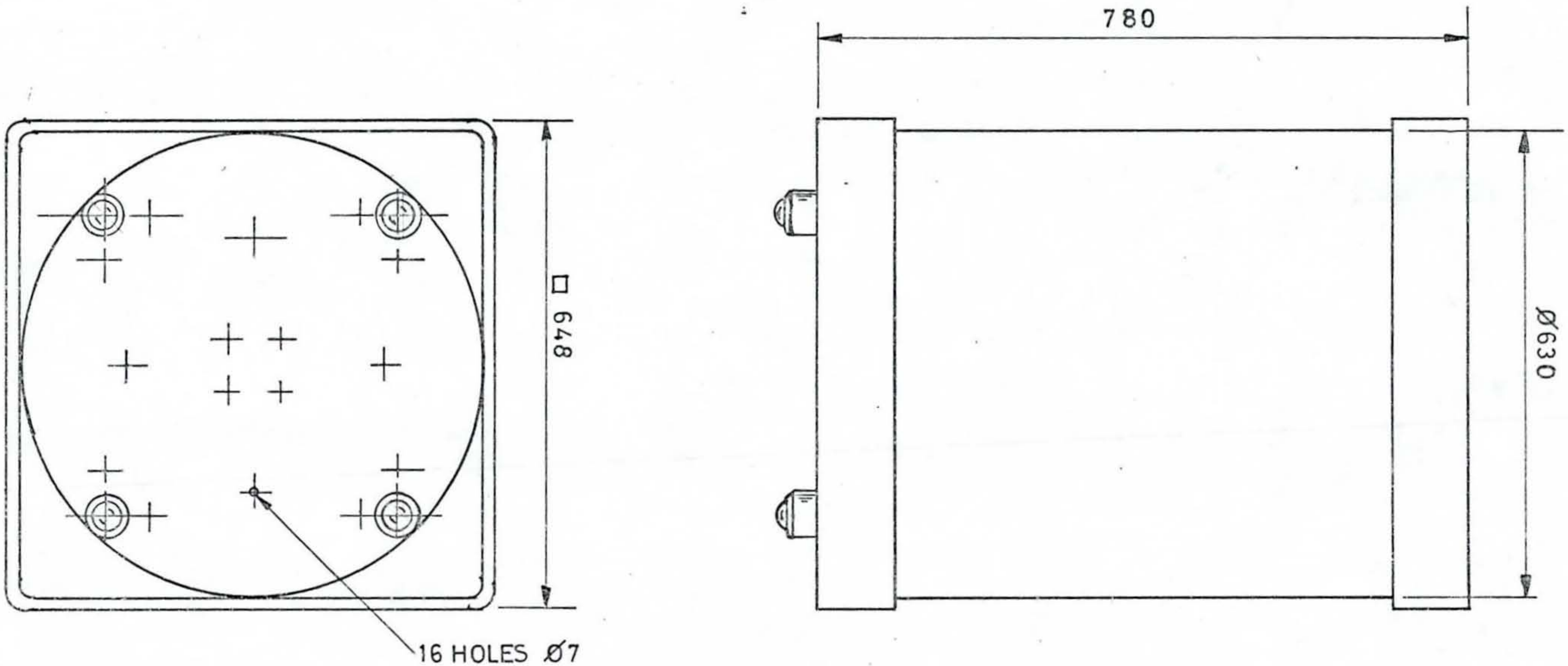


FIG 4-10

EXTRUSION CYLINDER

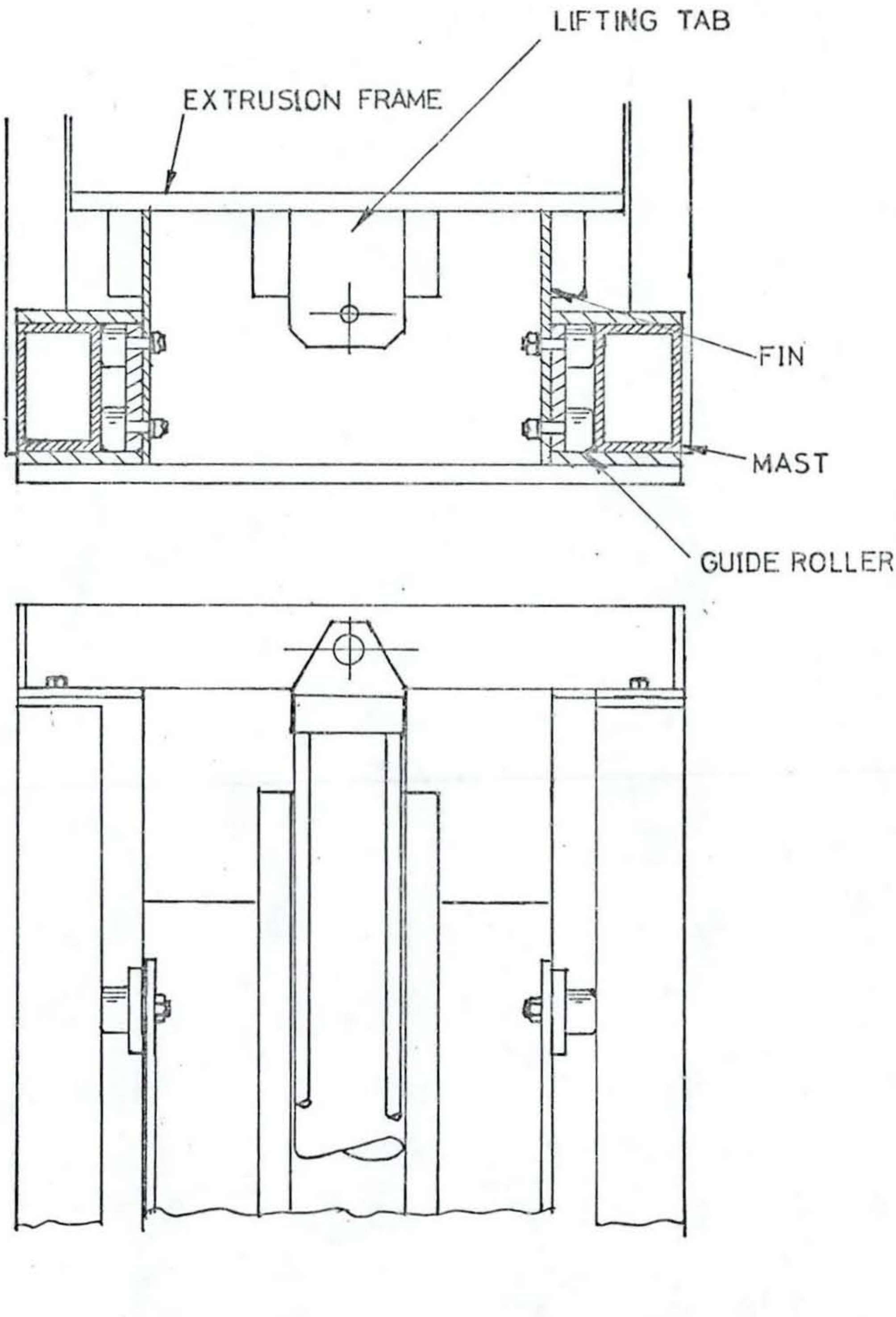


FIG 4-11

EXTRUSION FRAME LIFTING AND TRACK ARRANGEMENT

The panning ram provides movement of the mast (thus the extrusion frame it carries) in the horizontal plain. The panning ram head is bolted to the mast bottom beam and the rod end bolted to the base frame.

The extrusion cylinder(7) (see also Fig. 4.10) is open at one end and closed at the other. Extrusion holes are provided on the closed end. Four ball transfer units are also provided on the closed end to enable the transportation of the cylinder between the extrusion frame and the filter cake handling unit (see section 4.6) where it is filled with pigment. The boss of these ball transfer units also acts as dowel in holes provided on the bottom plate of the extrusion frame. This helps in aligning the cylinder with the piston when the frame is lifted. A fuller explanation is given in Chapter 5.

The extrusion frame is provided with eight guide rollers, four on each fin (see Fig. 4.11). These rollers guide the frame along tracks on the upright column of the mast.

The lower part of the mast is a framework of angle iron facing inwards on which four roller bearings two on each side, are mounted. The base frame is provided with a track on which the roller bearings run. (See Fig. 4.9).

When the extrusion frame is lowered to ground level where cylinder loading and off loading takes place, the ball transfer units are ejected out of their boss by ejector pegs as illustrated in Fig. 4.12.

4.5 FILTER CAKE HANDLING UNIT (FCHU) DESIGN

The extrusion plant incorporates a filter cake handling unit (FCHU) which enables pigment to be transferred between the filter press and the extrusion/drying station.

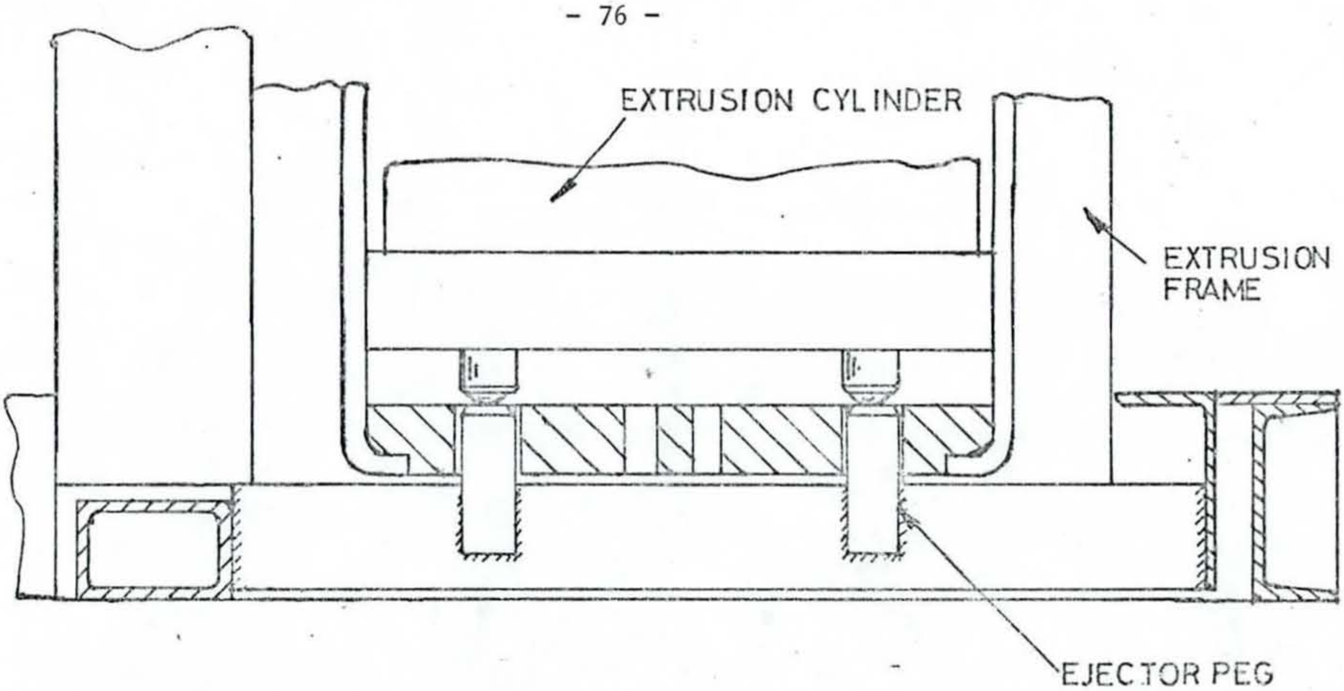


FIG 4-12

EXTRUSION CYLINDER EJECTION

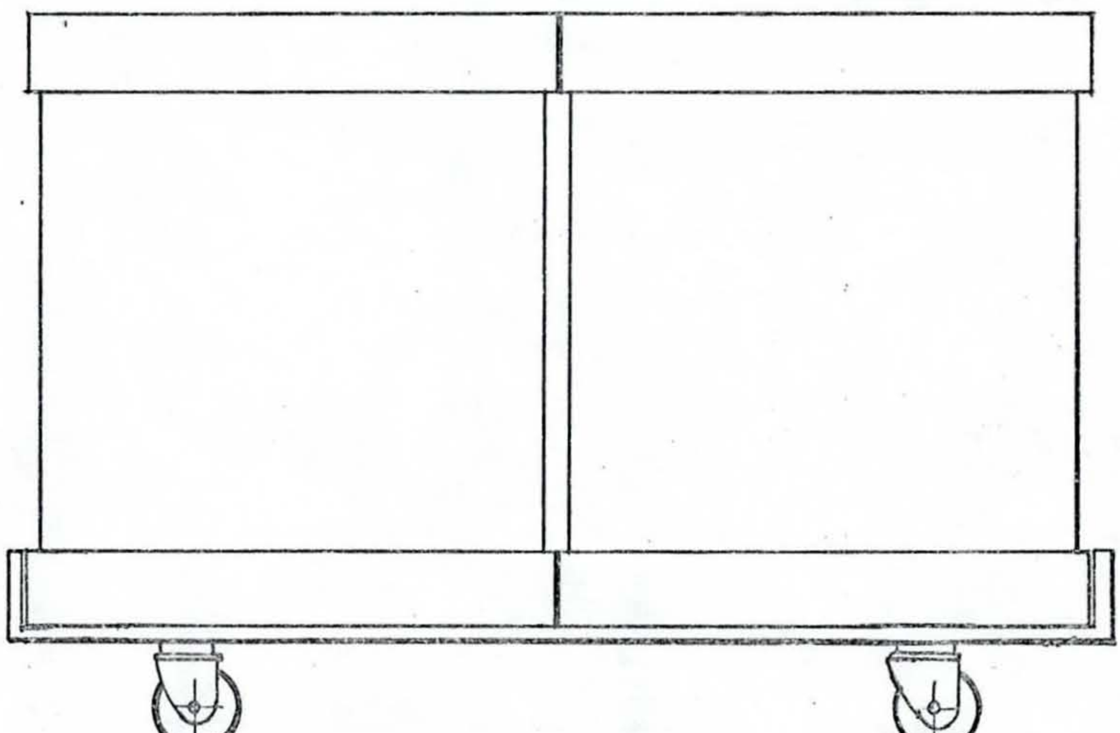


FIG 4-13

CYLINDER TRANSPORTATION

CONCEPT

With the screw extruder in use, filter cake is normally transferred in skips which are 910 mm long x 660 mm wide x 580 mm deep. The skips are made from stainless steel sheets framed with angle iron at corners. They are supported on four swivel castors which allow easy manipulation of the skips.

To fill the skips at the filter press a funnel with a receptor area of 1.27 sq. metre is fitted on the skip opening. The skip is then placed under the filter press plate pack where filter cakes are knocked into them.

The major colours which are graded as "fired" or "unfired" are each allocated six skips. These skips also serve as holding bins for the pigment such that the operation of the filter press is independent of the extrusion or drying rate. The skips are transferred from the press to the extrusion/drying station with the aid of fork lifts.

During the design of the new extrusion plant various schemes of handling the pigment were considered and are discussed below.

SCHEME 'A'

In this scheme the extrusion cylinder serves as the transporting container. A pair of cylinders are clamped together onto a transporting bogie (Fig. 4.13). Once the cylinders have been filled with pigment they will be transported to the extrusion/drying station with the aid of pallet trucks. A cylinder can then be loaded by sliding it into the extrusion frame.

During filling at the filter press, a suitably designed funnel is fitted over the opening of the clamped cylinders. They are then placed under the press where pigment is dropped into them. The funnel would have the same receptor area as the one currently used but has an area utilization of approximately

(100 x $\pi/4$) percent, using the current funnel as a datum.

The reduction in area utilization will not affect the reception of the pigment dropping into the cylinders since the pigment falls to a great extent in large lumps.

By using a pair of cylinders 600 mm diameter and 1000 mm deep, a total volume of 465 litres will be accommodated as compared to 348 litres with the present skips.

This scheme will require that the filter presses be raised to achieve a daylight of about 1300 mm between the bottom of the plate pack and the ground, in order that the cylinders could go under the press. This is a disadvantage as the whole process plant would have to be shut down to carry out this alteration. Also a total of eight cylinders and four bogies would be required per extrusion plant.

SCHEME 'B'

To avoid the necessity of raising the filter press as required by Scheme 'A', shorter cylinders of about 550 mm in depth could be used.

This alternative scheme will require 13 cylinders to hold a complete press load of pigment. Thus there are 13 cylinders per colour group. This will obviously increase the cost of each plant.

The cylinders are subjected to wear and tear during use and will require occasional replacement.

The number of machine operations required to process a batch of pigment would be increased from 8 to 13 which is 62.5% increase in the wear and tear of the extrusion machine.

The scheme has the advantage that a shorter extrusion frame can be used, thus a cheaper frame.

SCHEME 'C'

With this scheme only two 780 mm deep stainless steel cylinders are used. Pigment will still be loaded into the present skips at the press and will later be transferred into the extrusion cylinder at the extrusion/drying station.

This scheme reduces the number of cylinders required to two, and does not require any modification to the filter press.

The disadvantage of this scheme is that it requires a special handling unit which will handle the transfer of pigment from the skips into the extrusion cylinder.

On evaluation of the above schemes, Scheme C was chosen and a filter cake handling unit was designed as a corporate part of the extrusion plant. The handling unit is described in section 4.5.1.

4.5.1 Basic functional description of the filter cake handling unit (FCHU)

The filter cake handling unit Fig. 4.14 consists of the cradle(1), hopper(2), sliding table(3), tipping ram(4) and supporting structure(5). The part numbers refer to parts shown in Fig. 4.14.

Cradle: The cradle(1) is pivoted to the supporting structure using two pillow blocks(6). A skip filled with pigment at the filter press is loaded into the cradle and the cradle is then tipped by the tipping ram(4) so that the pigment contained in the skip drops into an extrusion cylinder placed under the hopper(2).

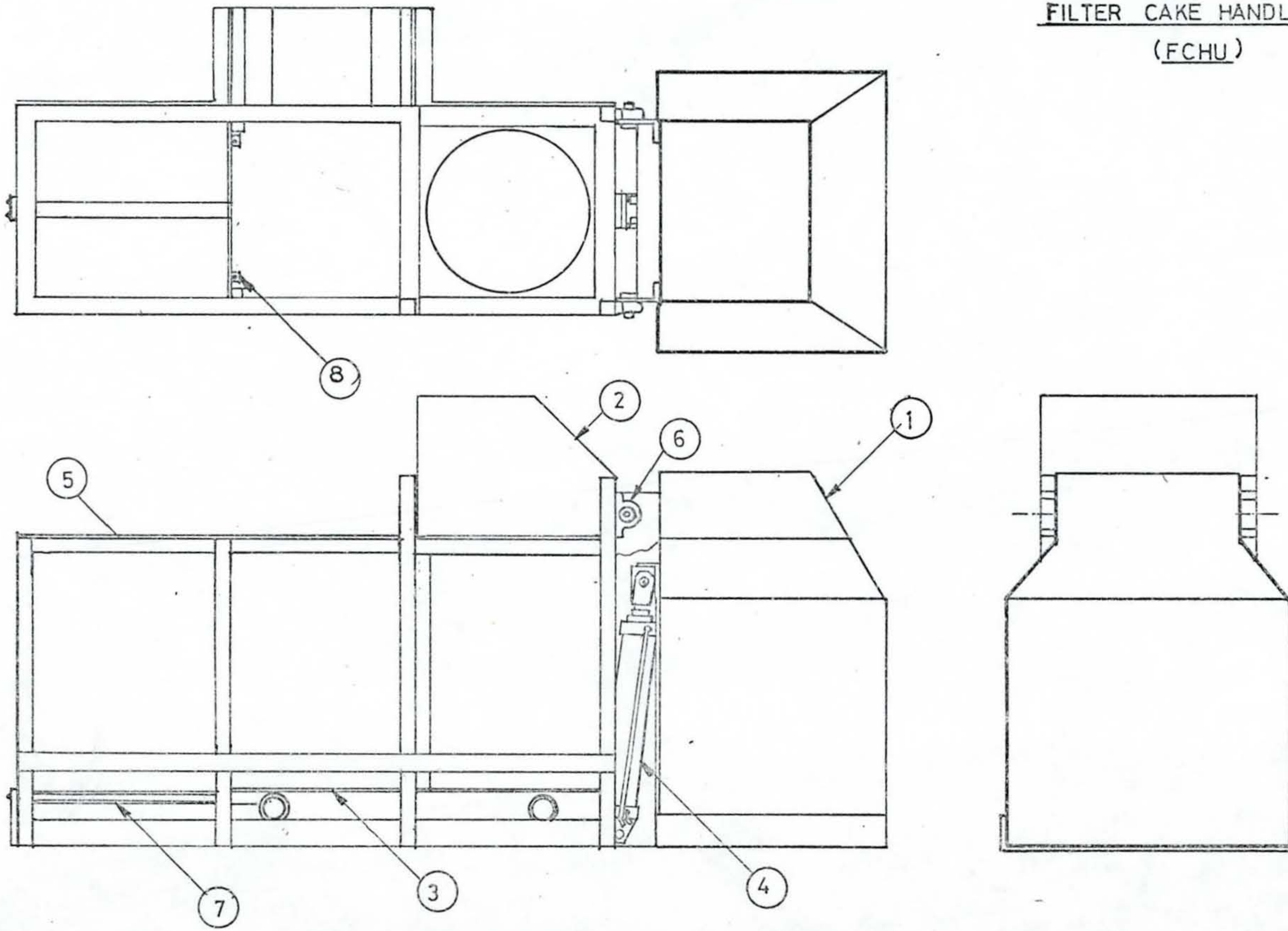
The cradle is designed in such a manner as to retain the skip during tipping operation.

Hopper: The hopper(2)is simply used to direct the material from the cradle into the cylinder placed under it.

FIG 4-14

FILTER CAKE HANDLING UNIT

(FCHU)



Sliding table(3) Is used in manipulating the extrusion cylinders into position. It has four single flanged rail wheels that run on the lip of the angle iron which forms the base of the supporting structure. It moves back and forth along the longitudinal axis of the handling unit. The movement of the table is achieved with the aid of the longitudinal positioning Ram(7). The table has two catches(8) mounted on one of its turned-up lips. The catches are used to hold a cylinder in place during one of the cylinder manipulation sequences.

Tipping Ram: The tipping ram(4) is mounted on the supporting structure. The top of the piston carries a female eye which is pivoted onto clevis bracket on the back of the cradle. The tipping ram provides the means for tipping the cradle. The ram is powered hydraulically through a directional control valve. Also a flow control valve is included in the feed line to control the tipping rate.

Longitudinal loading ram: The longitudinal loading ram(7) is used to impart movement onto the sliding table along the longitudinal axis of the FCHU. The ram has a rectangular flanged cap which is fixed to the support(5) and the piston pivot mounted onto sliding table. It has directional control valve and a flow control valve in its feed line.

Transverse loading ram: The transverse loading ram(10) Fig.4.6 is used in pushing the empty cylinder out of and pulling the charged cylinder into the extrusion frame. It has a rectangular flanged head. It is mounted to a bracket attached to the extrusion frame. A rectangular plate"push plate" (see Fig. 5.5b) is mounted on the end of the ram rod. Two solenoid actuated plungers (Pull solenoids) used in pulling cylinder into the frame are mounted on the push plate (Fig. 5.5b).

CHAPTER 5

PLANT OPERATION

5.1 EXTRUDER

The operation of the extruder is controlled by a programmable sequence controller as described in Chapter 6.

During operation, the machine is always in one of the following states.

(1) Idle.

(2) Performing piston withdrawal after extrusion.

(3) Panning the extrusion frame out of the dryer.

(4) Lowering the frame to ground level.

(5) Waiting for empty cylinder to be off-loaded and full cylinder loaded in by the handling unit.

(6) Inserting the extrusion piston into the newly loaded extrusion cylinder.

(7) Lift the extrusion frame and the new cylinder up to the drying port.

(8) Pan the frame over the dryer.

(9) Compact the pigment in the cylinder.

(10) Extrude the pigment onto the dryer conveyor belt.

Idle

During the idle state the controller checks whether the system is ready, if not, it issues an alarm call. At the same time it indicates on the indication panel that the operator should load a new skip into the cradle. Once the system is ready, the handling system tips the pigment from the skip into the extrusion cylinder placed under the hopper. The handling unit under the control of the system sequence controller manipulates the charged cylinder to the waiting bay. See detailed description of handling unit operation in next section.

Piston withdrawal

If a charged cylinder is ready in the waiting bay, the extrusion piston is withdrawn from the cylinder currently in the extrusion frame. Alternatively the controller issues an alarm call and indicates the system status on the control panel.

Panning out

The extrusion frame is panned out of the dryer ready to be lowered.

Lowering the frame

The frame is lowered to ground level and the piston is completely withdrawn from the cylinder.

Wait

During this state the transverse loading ram of the handling unit pushes the empty cylinder out of the frame onto the loading table of the handling unit. The handling unit then moves this cylinder under the hopper and at the same time aligns the charged cylinder in the waiting bay (see Fig. 5.6 a and b) with the extrusion frame. The transverse loading ram then pulls the charged cylinder into extrusion frame.

Piston insertion

When a charged cylinder is properly located in the extrusion frame the extrusion piston descends into the cylinder under the control of the sequence controller. Once a successful entry is achieved the transverse loading ram is fully retracted.

Lifting of extrusion frame

The extrusion frame is lifted upto to the dryer inlet port (see Fig. 5.2).

Panning in

The frame is panned in such that it is over the dryer. See Fig. 5.1.

Compacting

When the frame is properly positioned over the dryer, compaction of the pigment is done as the piston descends into the cylinder until the pigment extrusion density is reached. At this point the controller issues an alarm call and at the same time indicates on the indicator panel that a new skip is required.

Extrusion

Extrusion commences as soon as the material is fully compacted. The rate of extrusion is set such that a uniform band depth can be maintained.

Extrudate from the cylinder comes out of the 16 die holes on the bottom of the cylinder onto the band dryer through the clearance holes made on the bottom plate of the extrusion frame.

5.2 FILTER CAKE HANDLING UNIT (FCHU) OPERATION

The operation of this unit is also controlled by the system controller.

During operation the unit is always in one of the following states:

(1) Preforming a cylinder charging cycle.

FIG 5-1
Extrusion frame positioned over the dryer during extrusion.

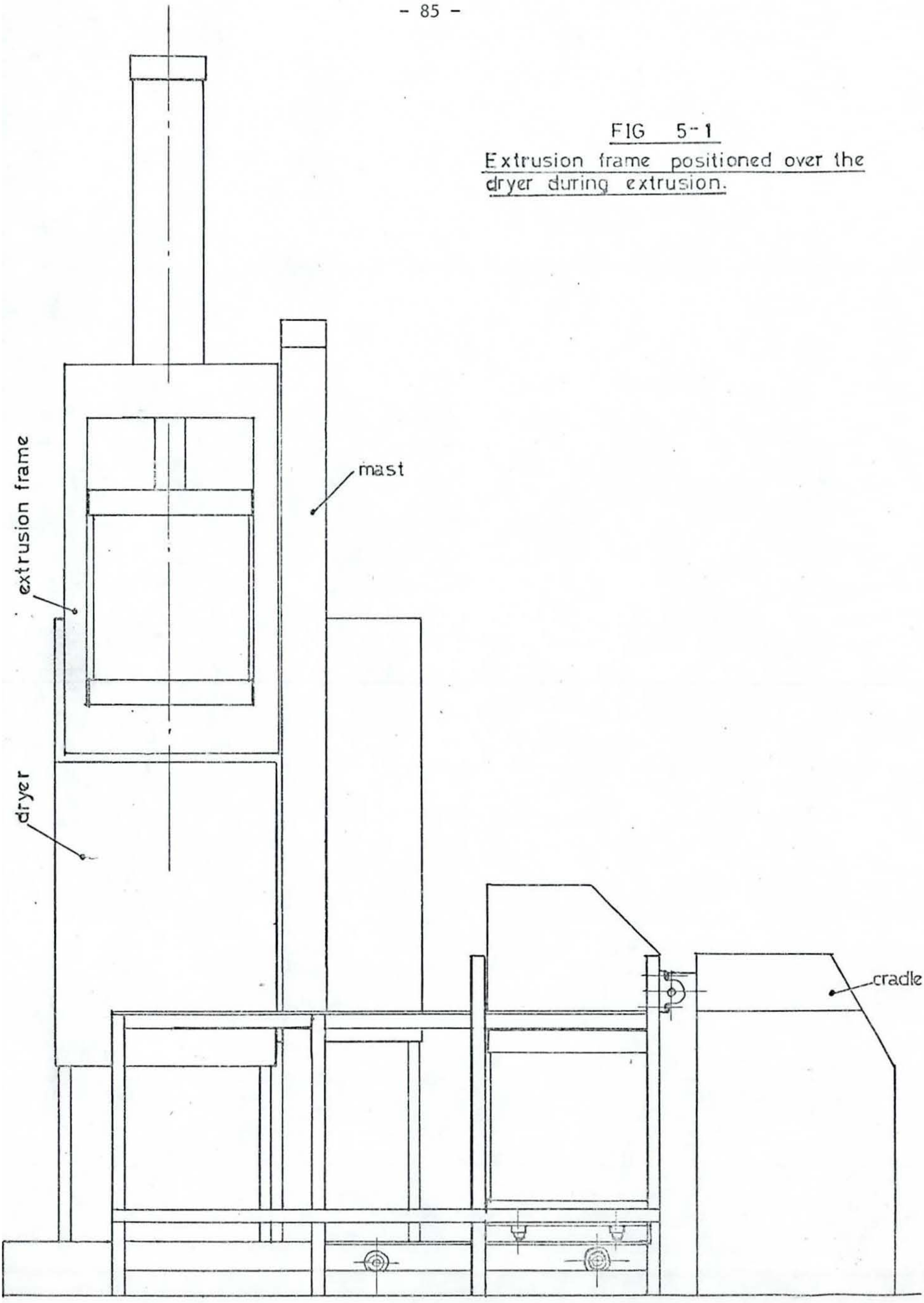
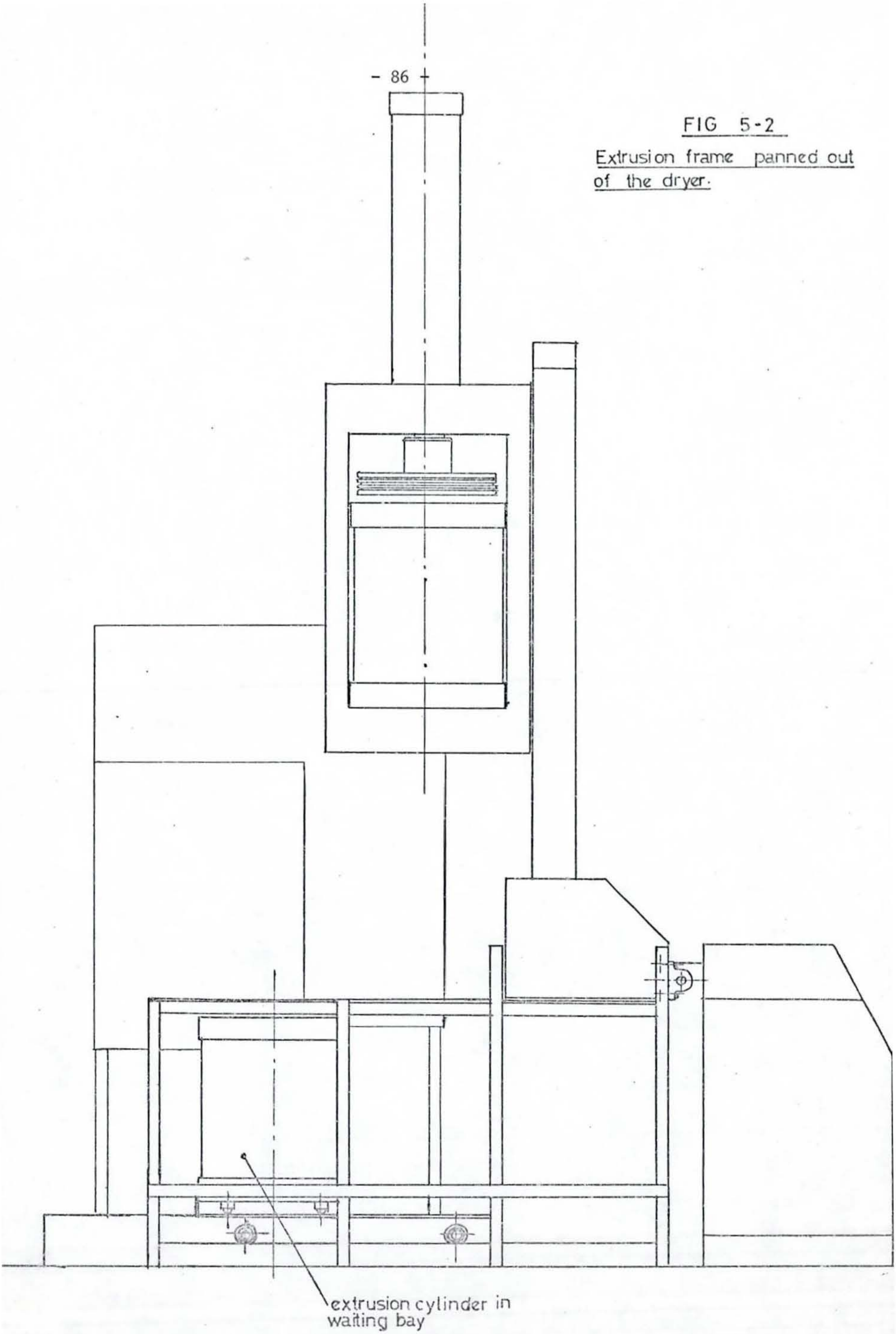


FIG 5-2

Extrusion frame panned out of the dryer.



(2) Performing a cylinder manipulation cycle.

(3) Wait.

(4) Performing a cylinder ejection cycle.

(5) Performing a cylinder alignment cycle.

(6) Performing a cylinder loading cycle.

(7) Idle.

1. Cylinder Charging

During this cycle the pigment in the skip loaded into the cradle is tipped into a cylinder which is positioned under the hopper, Fig. 5.3. A Skip filled with pigment is normally loaded into the cradle when the controller requests for it. This is just before the FCHU enters the idle state. After the set pigment dropping time on the controller, the cradle is lowered.

2. Cylinder manipulation

When a cylinder has been charged as described above, it is moved to the waiting bay. This is done in three steps.

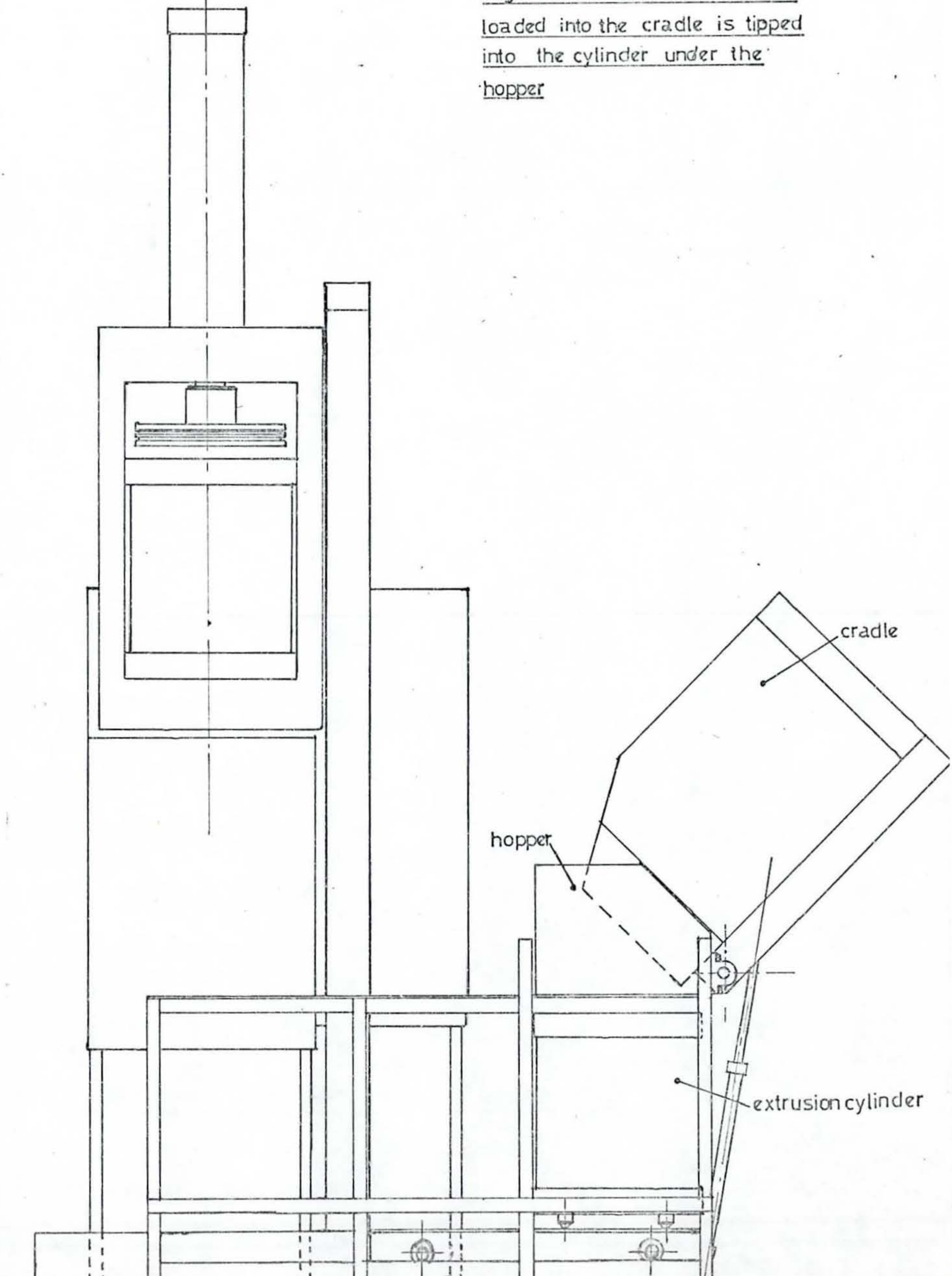
Step 1. The sliding table is actuated such that it uses one of its turned up lips in pushing the cylinder until it is aligned with the extrusion frame (Fig. 5.5a).

Step 2. The cylinder is locked in position by two lock solenoids, while the table is actuated such that it slides under the cylinder without the cylinder moving. This is achieved with the aid of the four ball transfer units on the base of the cylinder (Fig. 4.9). The table continues to slide until the catches on the opposite lip of the table latch under the cylinder (Fig. 5.5b).

Step 3. With the catches latched under the cylinder in Step 2 the table is actuated such that it moves the cylinder to the

FIG 5-3

Pigment contained in the skip loaded into the cradle is tipped into the cylinder under the hopper



waiting bay (Fig. 5.5c).

3. Wait

On the completion of the cylinder manipulation sequence in Step 3, the handling unit waits for the extrusion machine to withdraw its piston from the extrusion cylinder, pans out the extrusion frame and lowers it.

4. Cylinder ejection

After the extrusion machine has lowered its extrusion frame the transverse loading ram[10] Fig. 4.6 is actuated such that it pushes the empty cylinder in the frame onto the handling unit's sliding table (Fig. 5.6a).

5. Cylinder alignment

During this cycle, the charged cylinder which was in the waiting bay is aligned with the extrusion frame and the empty cylinder positioned under the hopper ready for the next cycle (Fig.5.6b).

6. Loading

When the charged cylinder has been aligned with the extrusion frame, it is then pulled into the frame by the transverse loading ram. The loading is achieved by actuating the pull solenoid carried on the push plate of the ram.

7. Idle

When the charged cylinder has been loaded into the frame the handling unit enters an idle state, waiting for the extrusion machine to complete another extrusion cycle.

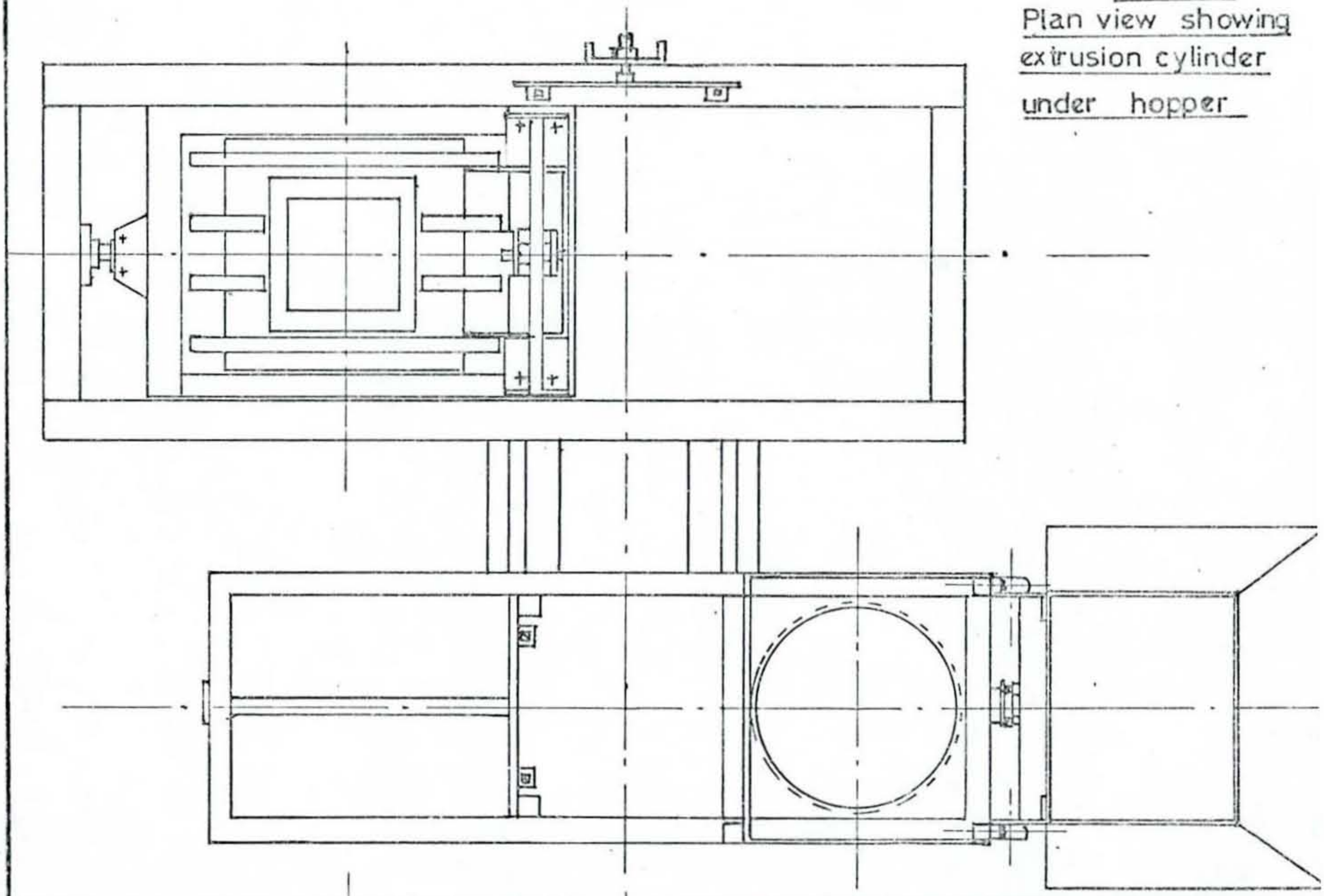


FIG 5-4
Plan view showing extrusion cylinder under hopper

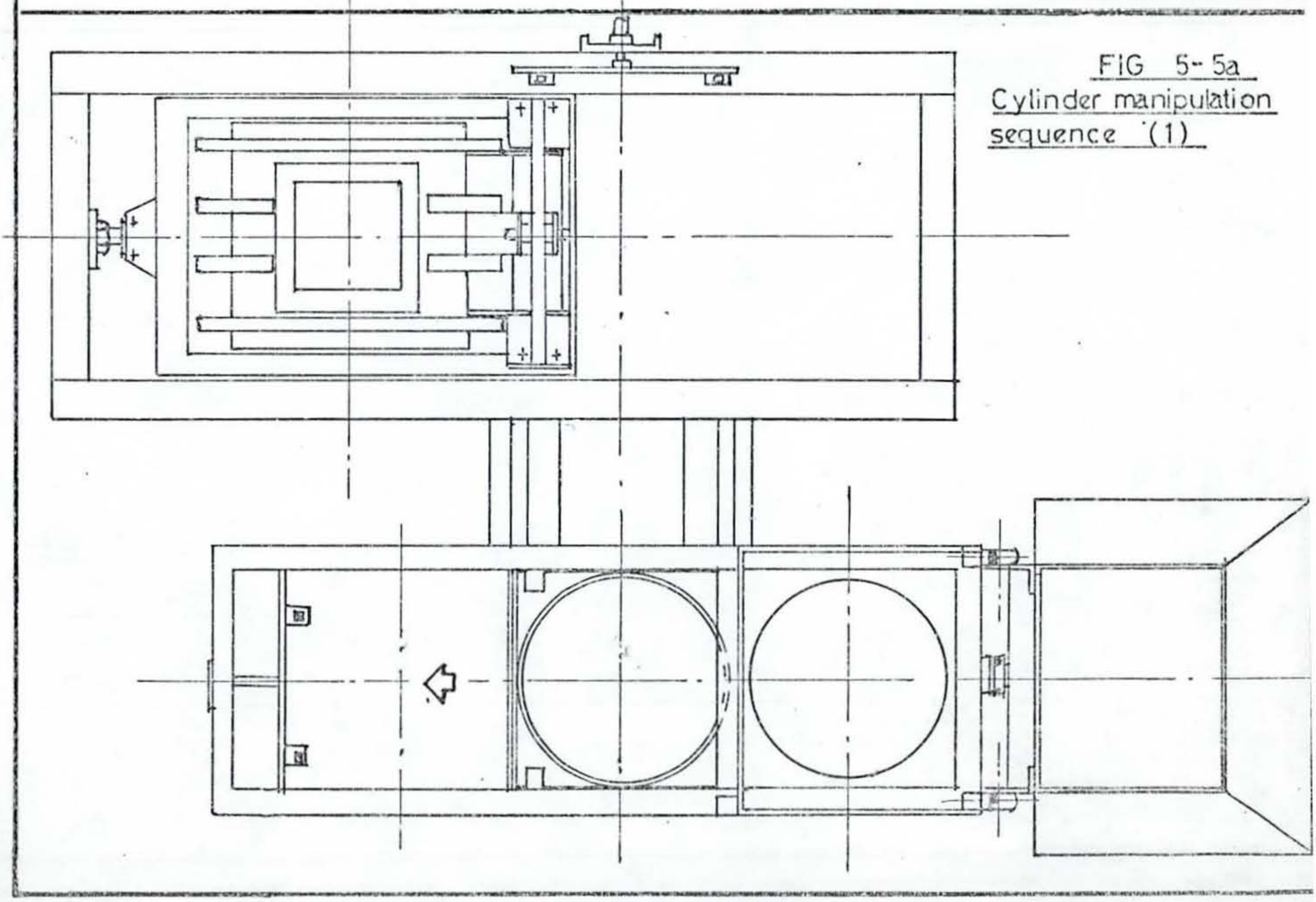


FIG 5-5a
Cylinder manipulation sequence (1)

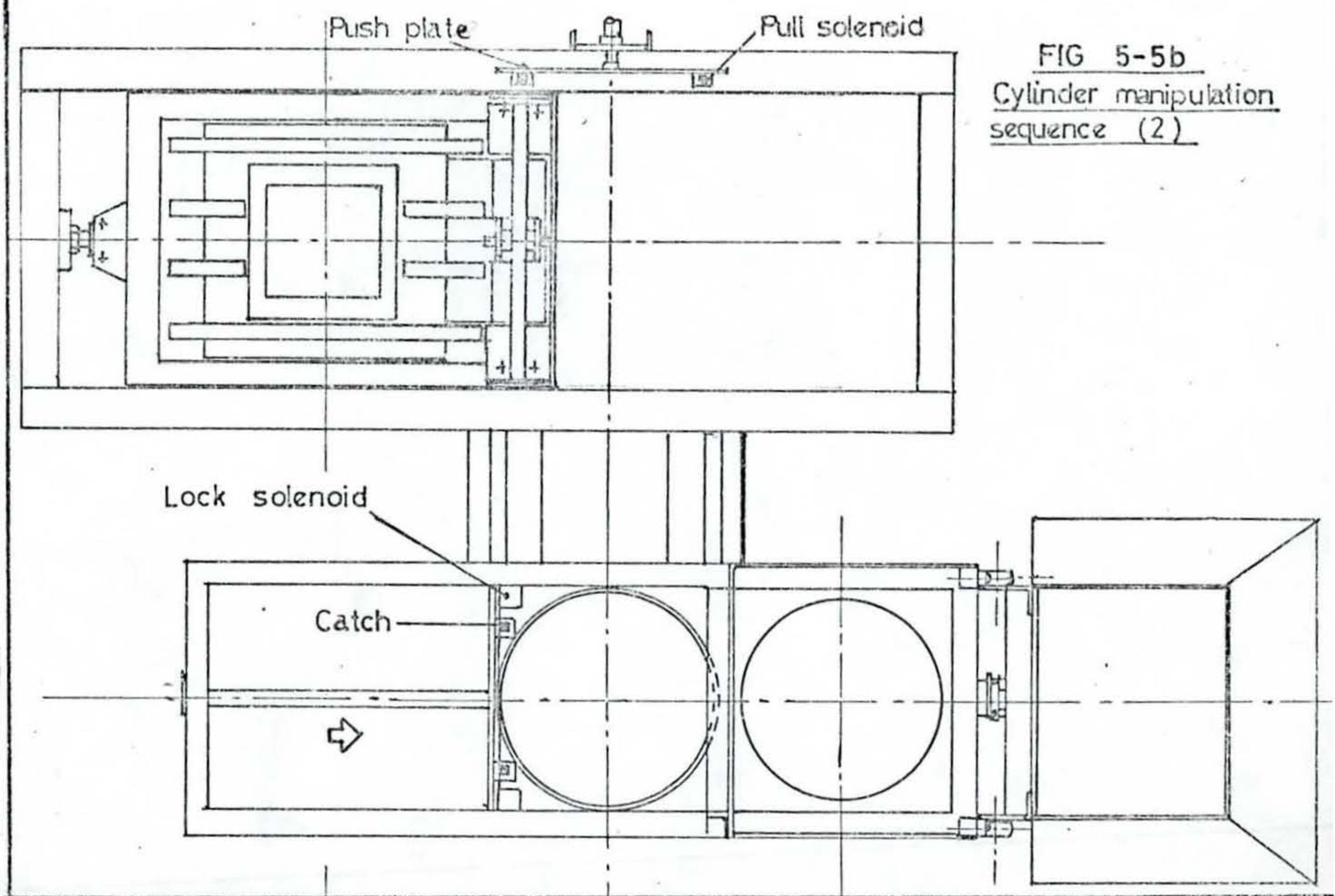


FIG 5-5b
Cylinder manipulation sequence (2)

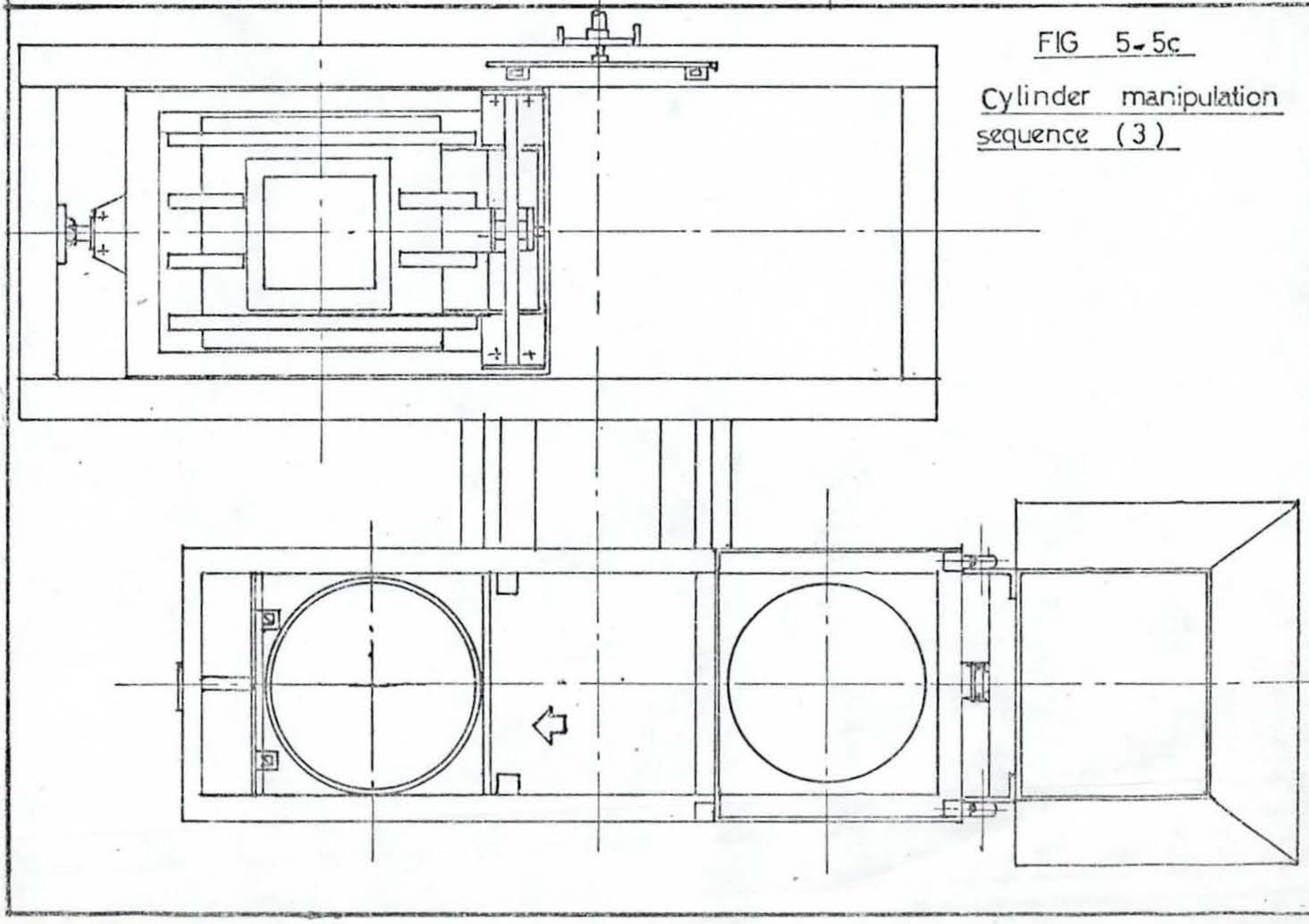


FIG 5-5c
Cylinder manipulation sequence (3)

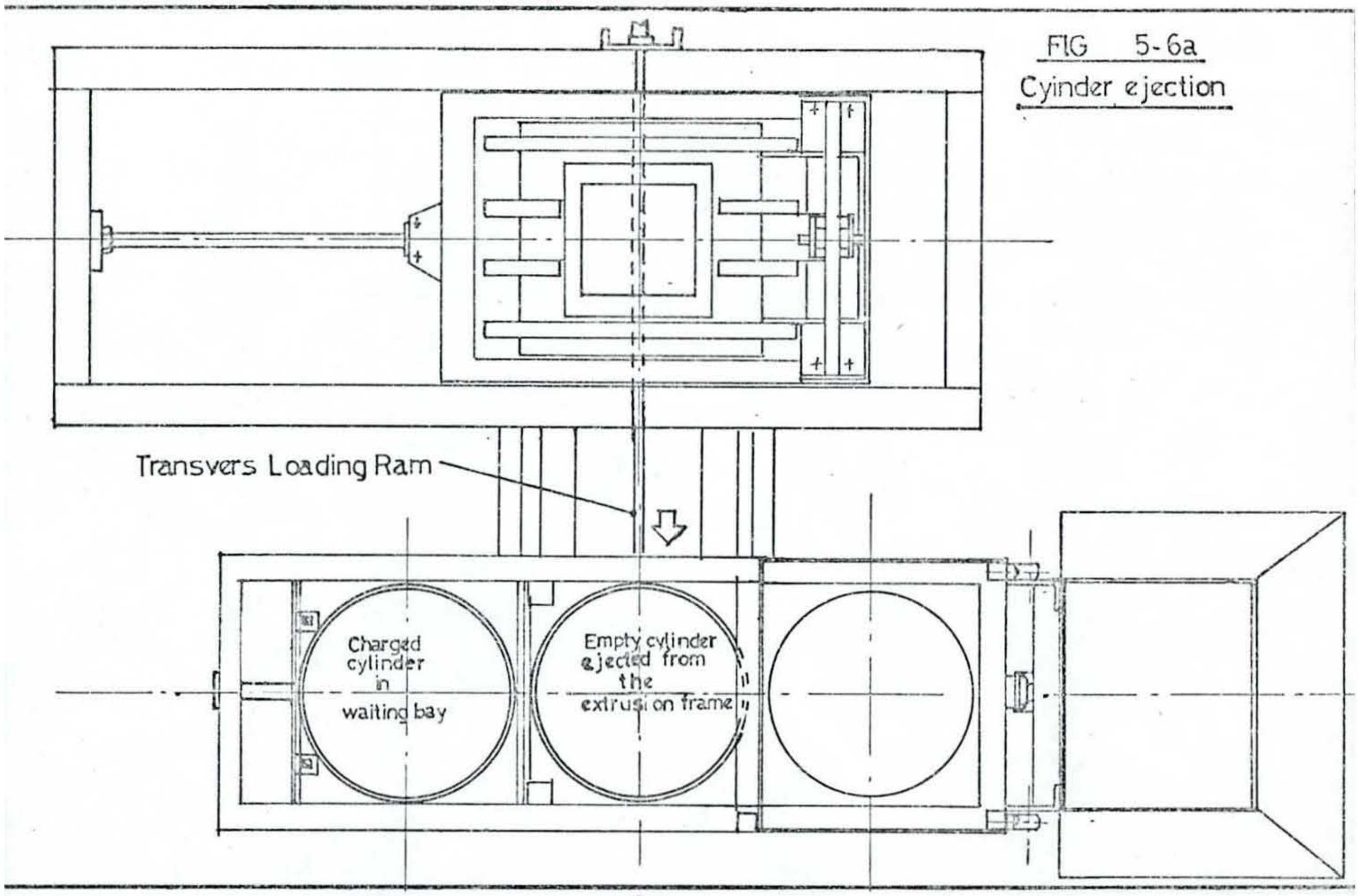


FIG 5-6a
Cyinder ejection

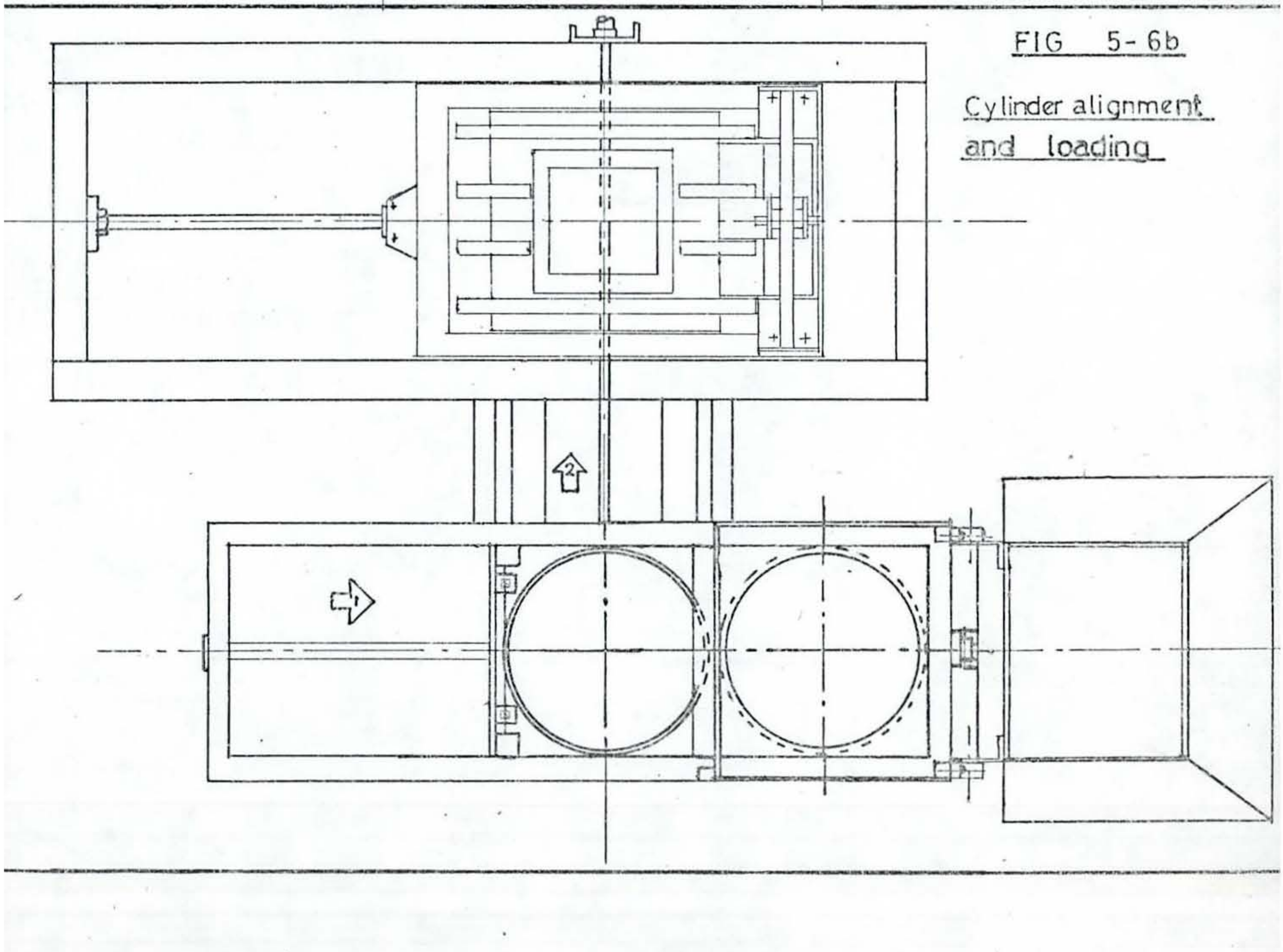


FIG 5-6b
Cylinder alignment and loading

CHAPTER 6

CONTROL

6.1 SYSTEM REQUIREMENTS

The extrusion plant has been designed to extrude pigment contained in a cylinder onto a band dryer in a spaghetti like form at a constant set rate. To perform the above task, the machine must fulfil the following requirements:

(a) Hold or contain the cylinder from which the pigment is being extruded.

(b) Endowed with sufficient power to enable the piston to force the pigment through the 16, 7mm diameter holes at the bottom of the cylinder.

(c) Capable of displacing the piston relative to the cylinder at a constant rate to maintain constant delivery onto the belt of band dryer. The displacement must be controlled with a degree of precision which will ensure uniform depth of pigment on the belt.

In addition to the main functions mentioned above, the machine must have provisions for performing ancillary functions such as loading the cylinder charged with pigment into the extrusion frame, lifting and lowering the extrusion frame onto the band dryer, lowering the piston into the cylinder, compacting the material at a fast piston speed, altering the piston speed to the extrusion rate as soon as the pigment is compacted. A hydraulic power pack is used to drive the machine.

The sequence of operation is controlled by a programmable sequence controller described in section 6.3.

6.2 HYDRAULIC CONTROL

The hydraulic circuit Fig. 6.1 is designed to accommodate the system drive requirements. It uses a tandem gear pump unit. The pump unit is continuously driven at constant speed. Thus, constant volume of fluid is delivered at constant pressure. Flow to various rams in the system are controlled by means of flow regulating valves in accordance with system demand. The unit can be switched off when there is no system demand.

As it is desired to have a compact power pack it was necessary to drive the pump unit at the highest speed possible which must be consistent with reliable performance. This does, however, increase fluid heating problems and may also tend to promote cavitation in the pumps. To minimize this adverse effect the fluid tank is sized to effectively dissipate the system heat.

The basic control elements which are involved in the hydraulic control system are shown in Fig. 6.1.

As the system is inherently a dual pressure system the pump unit is made up of two pumps; the high pressure (210 bar), low volume (2 ℓ/min) pump and the low pressure (70 bar) high volume (20 ℓ/min) pump. The low pressure pump has to be unloaded, that is, the output diverted back to the reservoir at as low a pressure as possible when only the high pressure low volume pump is required.

It is normally preferable to let the pump idle rather than to stop the driving motor, unless the demand is very infrequent.

6.2.1 Unloading valve

A self-contained unloading valve CV9 is arranged to open

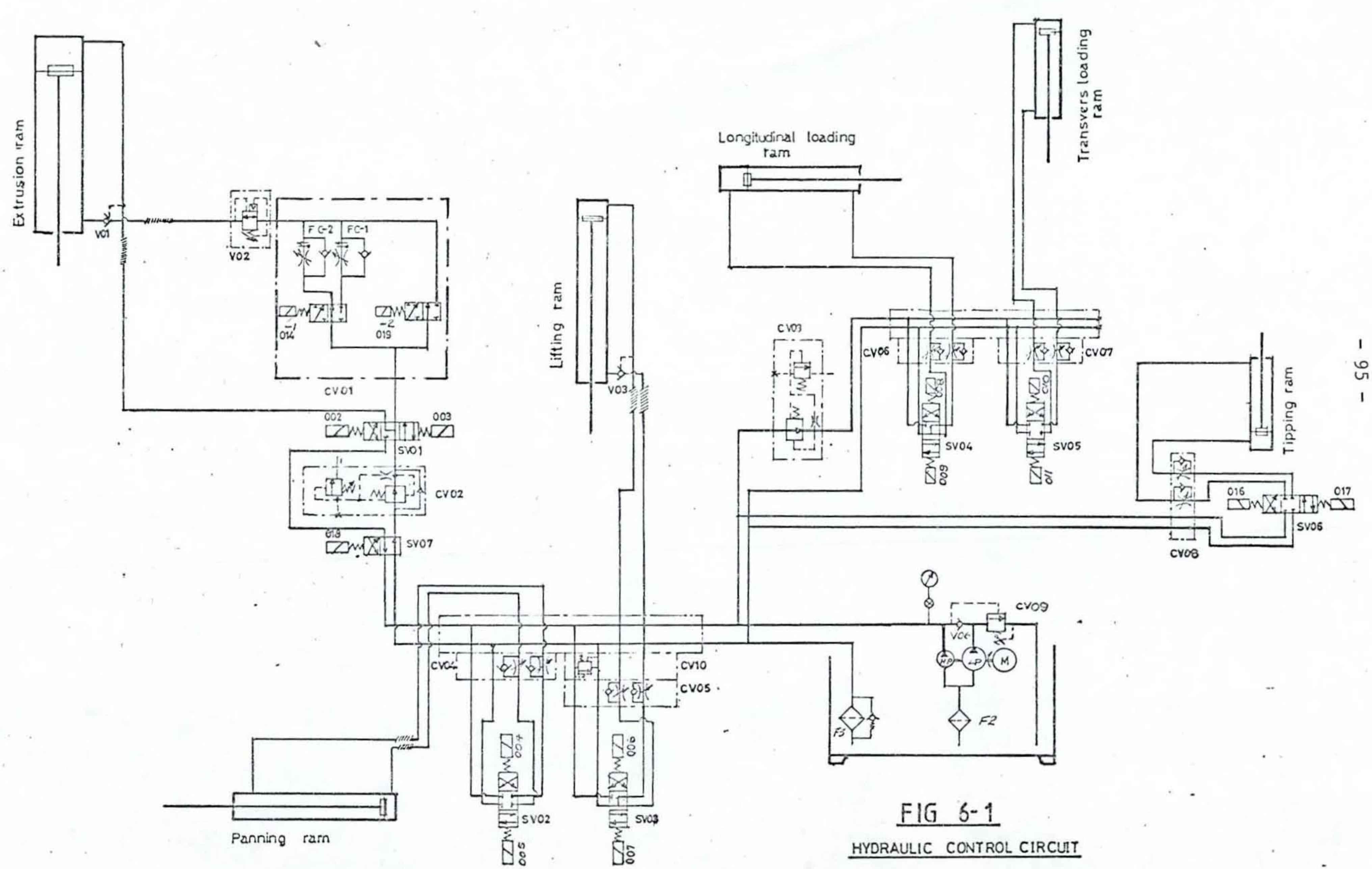


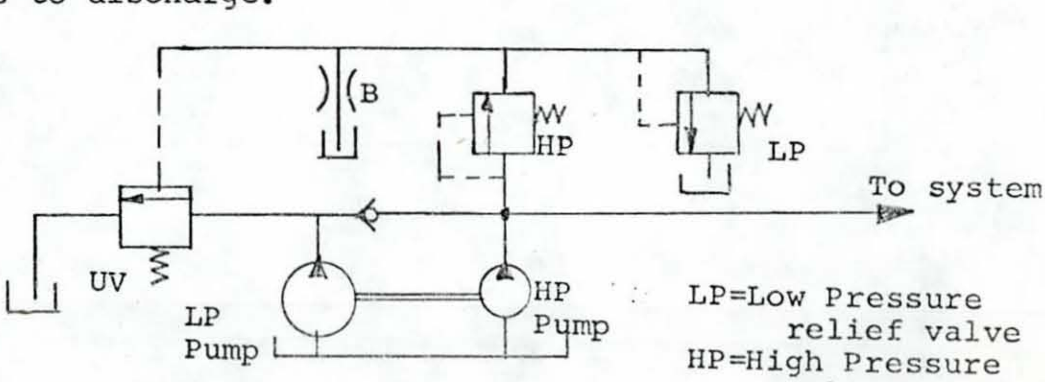
FIG 6-1

HYDRAULIC CONTROL CIRCUIT

as soon as the maximum set pressure is reached. The valve is similar to a relief valve. In addition to the normal pilot relief valves it has a plunger which is acted upon by the system pressure and forces the pilot valve off its seat when the required pressure is reached. This brings the pilot pressure to zero and so opens the main valve fully. A check valve V06 is essential to retain the system pressure whilst the pump is fully unloaded.

An alternative to this pilot unloading valve is the use of a solenoid operated unloading valve which can be controlled according to system demand.

It may be necessary to maintain pilot pressure continuously with the small pump whilst unloading the low pressure/high volume pump when it is not required. This can be arranged effectively by having two relief valves in series Fig. 6.2. One of the valves is set at a pressure sufficient for the pilot circuit and the other is set at the maximum working pressure. When the system demand ceases completely the main relief valve opens and discharges through the low pressure relief valve. This pressure is then applied to the unloading valve of the low pressure pump while the high pressure pump keeps the system pressurized. A permanent leak-off ensures that the pressure on the unloading valve falls quickly as soon as the relief valve ceases to discharge.



LP=Low Pressure relief valve
HP=High Pressure relief valve
UV=Unloading valve

FIG. 6.2

6.2.2 Directional control valves

Each ram is supplied through one or more directional valves, which is the control element for directing pressure to the appropriate side of the ram. These directional control valves are solenoid operated, two position, spring centred spool valves. Where check valves are connected to rams, the directional control valve provides a vent to tank in the 'off' position, otherwise they are close-centred in the 'off' position. The only exception is the direction control valve on the longitudinal loading ram which is 'vented off' in the 'off' position. This is to allow for self correction of small mis-alignment during extrusion cylinder loading.

6.2.3 Pressure reducing valves

In order to prevent excess force being applied to the extrusion cylinder during cylinder manipulation and loading, the feed line to the loading rams is provided with a pressure reducing valve CV03. This pressure reducing valve reduces the outlet pressure to a predetermined proportion of the inlet pressure (system pressure). This pressure is then fed to the loading rams. Thus allowing the system to stall without damage to any component.

Also the tank line of the extrusion ram is provided with a pressure reducing valve CV02. During the sequence in which the piston enters the cylinder after the cylinder has just been loaded into the extrusion frame, system pressure is applied to the inlet port of the reducing valve and its outlet pressure of about 6 bar is applied to both the full bore and annular sides of the extrusion ram. This enables the piston to drop under its own weight into the cylinder with the pressure from the relief valve used to maintain motion and to overcome friction that might be encountered during cylinder entry. This entry sequence operates on a regenerative principle in which the fluid supplied from the pump and the fluid displaced from the annular side of the extrusion ram are fed into the full bore side of the ram.

6.2.4 Ram speed control

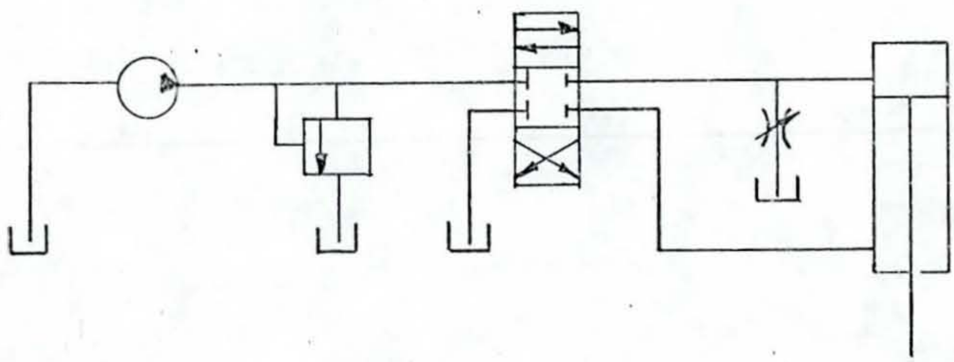
Additional elements are employed to control the speed of movement of the rams. They are basically metering valve CV01, CV04, CV05, CV06 and CV07, Fig. 6.1. They are all adjustable flow control valves. They are installed on both side lines following the directional control valves. By arranging the integral check valves in the flow control as shown in Fig. 6.1, they are essentially metering out devices. This type of speed control suffers from relatively high energy losses and high fluid heating since the pump is operating at maximum pressure all the time and excess flow is discharged through the relief valve. This type of losses can be minimized by adopting a bleed-off speed control, Fig. 6.3 or the bypass speed control, Fig. 6.4.

In the bleed-off circuit the throttle valve is located in the feed line to the ram bypassing to the tank. The valve is operative only when the feed line is under pressure. All the throttling losses are linked to this bleed flow and pump pressure automatically adjust to load. The main disadvantage of this type of flow control is that it is indirect and will vary if the pump delivery varies with the load.

The bypass speed control is commonly preferred where losses are to be minimized. A restrictor is used to monitor the flow rate and the pressure drop across the restrictor is used to adjust the bypass flow accordingly. This gives the same positive speed control as a meter-in or meter-out circuit.

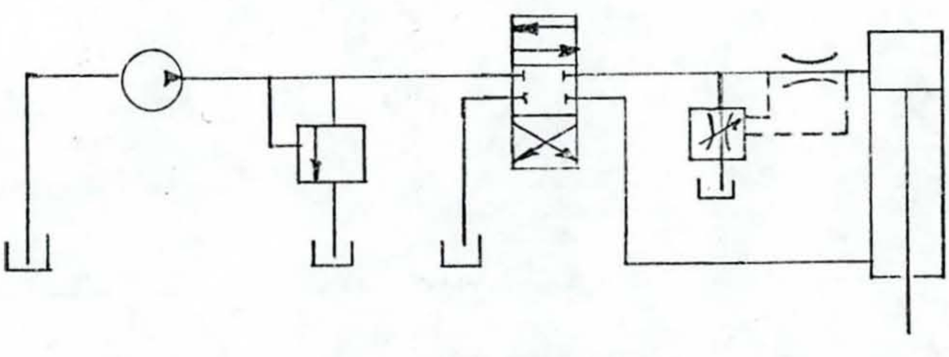
Both the bleed-off and bypass circuit are basically meter-in system. They would have no effect on ram speed if connected to the exhaust line from the cylinder.

The speed control system of the plant was assessed on merit, simplicity and cost. Since cost and simplicity were the dominant design criteria, simple meter-out circuit were used on all the rams.



Bleed-off speed control

FIG. 6.3



By-pass speed control

FIG. 6.4

6.2.5 Extrusion ram speed control

The speed control of the extrusion ram is the most critical in the system and its design is based on the same meter-out principles as for the other rams. Speed control is achieved with two flow control valves FC-1 and FC-2, Fig.6.1. These valves are built with temperature and pressure compensation to prevent change in preset values even if oil pressure and temperature changes.

For safety purposes the flow rates can be set and locked using set screws and accidental adjustment prevented using lock keys.

These flow control valves with the two miniature solenoid valves are arranged in a manner such that three forward speeds are obtainable; slow forward, very slow forward and rapid forward. There is also a rapid return speed. The slow forward speed is used during pigment compaction after cylinder entry with the extrusion frame panned onto the dryer. The very slow forward speed is set for extrusion. During extrusion a very slow speed is required in order to maintain uniform pigment depth on the band dryer. The fast forward is included as a feature of the design to enable the piston to be lowered at a speed very much faster than the previous speed settings for use during installation and maintenance. The rapid return is used during piston withdrawal to reduce the time between extrusion cylinder change to a minimum.

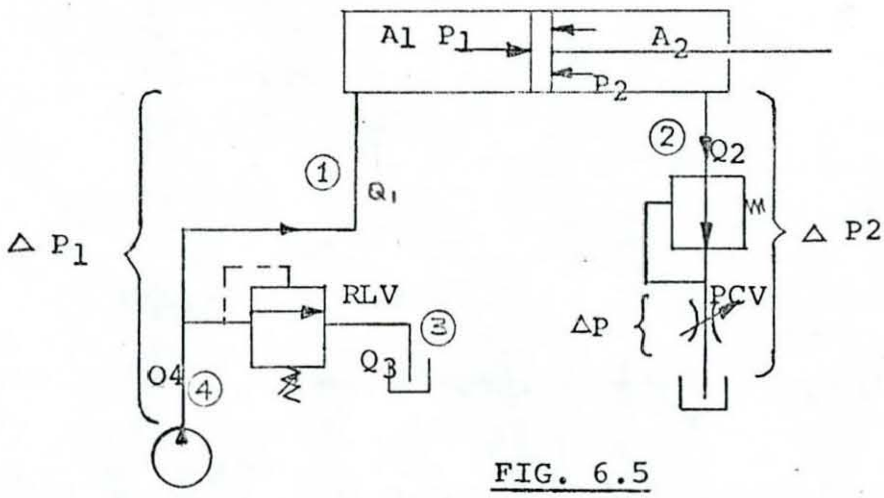


FIG. 6.5

6.2.6 COMPACTION TO EXTRUSION SPEED CHANGEOVER

The theoretical thrust developed by the cylinder shown in Fig. 6.5 is given by:

$$F = Pe\ A \quad \ldots\ldots\ldots \quad (1)$$

where Pe is the effective applied pressure and A is the effective piston area.

In Fig. 6.5,

$$Q_3 = Q_4 - Q_1$$

$$Q_2 = \frac{A2}{A1} Q_1$$

$$Q_3 = Q_4 - \frac{A1}{A2} Q_2$$

Q_2 stands for flow at point 2.

If $Q_3 \neq 0$

Then P_1 = constant since the relief valve RLV will not relieve at a pressure lower than the set pressure.

If ΔP_1 and ΔP_2 are the pressure drops in the input and output lines respectively, then the effective pressure Pe is given by:

$$Pe = P - \Delta P_1 - \frac{A2}{A1} \Delta P_2 \quad \ldots\ldots\ldots \quad (2)$$

where P is the system pressure set at the pump. A_1 is the ram full bore area and A2 is the annulus area.

$\Delta P_1 \ = \ P - P_1$

$\Delta P_2 \ = \ P_2 - 0$ using gauge pressure.

Substituting in equation 2:

$$Pe = P - P + P_1 - \frac{A_2}{A_1} P_2$$

$$= P_1 - \frac{A_2}{A_1} P_2$$

With a pressure compensated flow control valve installed as a meter-out system, the inlet and outlet theoretical flow rates are equal and constant. Thus the inlet pressure drop must be constant. Thus,

$$Pe = \frac{F}{A} = P_1 - \frac{A_2}{A_1} P_2$$

$$F = P_1 A_1 - A_2 P_2 \ \ .... \ \ (3)$$

Since $P_1 = P - P_1$ is a constant and P is assumed constant

P_1 must be constant,

thus we can say that P_2 is a function of the load F.

For a particular speed setting and due to the pressure compensating characteristic of the flow control valve the thrust F on the fall bore side of the ram will remain constant independent of load, but the actual load on the cylinder might vary as shown in Fig. 6.6.

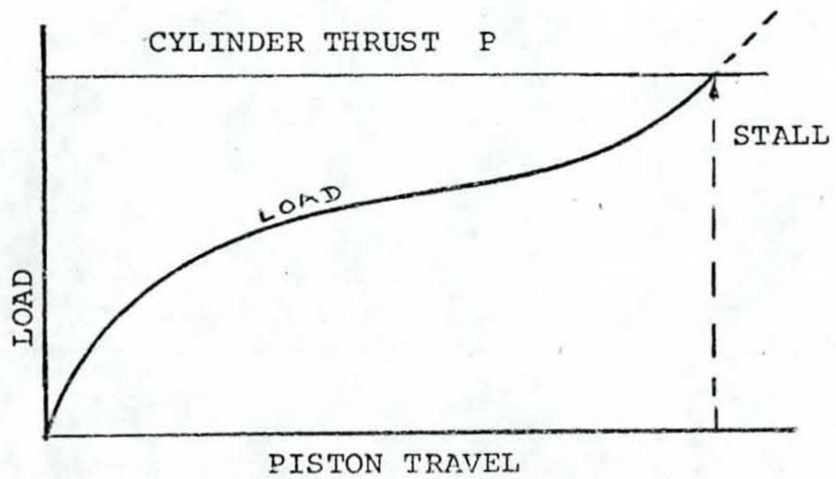


FIG. 6.6

Equation 3 represents condition where the load is zero. With a load L introduce to the ram, the force equation becomes:

$$F = A_1P_1 = A_2P_2 - L \quad \ldots\ldots\ldots \quad (4)$$

Since the cylinder thrust F, the Pressure P_1 the Area A_1 and A_2 are constants then P2 must vary in such a manner that $A2P2 + L$ = constant.

Thus, the changeover point between compaction and extrusion is obtained by monitoring P_2, using a pressure switch. This is the basis on which the plant changeover control is designed.

6.2.7 Counter-balancing

In order to prevent the piston against gravitation fall when it is withdrawn from the cylinder, a counter balancing valve VO2, Fig. 6.1 is connected to the annular side of the extrusion ram. The use of a pilot operated check valve alone would introduce the danger of cavitation in that the annulus fluid would tend to separate from the ram piston at the commencement of a downward stroke. A schematic diagram of the counter balancing valve is shown in Fig. 6.7. It basically consists of a pilot operated relief valve D and a plain check valve E in parallel with the relief valve. The relief valve is set to relieve at a pressure which will just balance the weight of the extrusion ram rod weight and the piston weight. Its pilot may be connected to the annulus or full bore side of the cylinder.

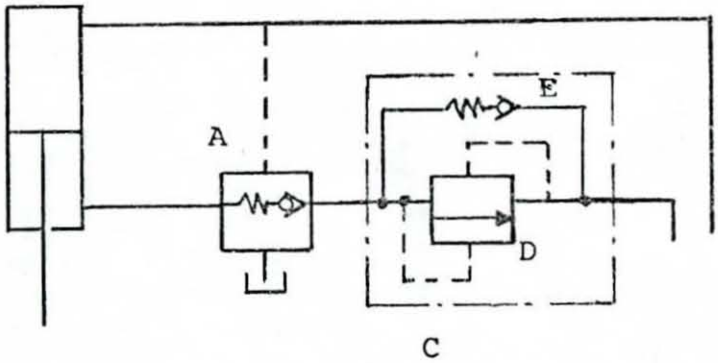


FIG. 6.7

6.2.8 Manufacture

As the hydraulic pack is to be a bought out item , a guide specification was prepared (Appendix B) to enable quotation to be obtained from suppliers. The specification covers all the essential requirements of the hydraulic system required for the plant.

6.3 SEQUENCE CONTROL

Sequential control of the plant is achieved by switching components (solenoid operated directional control valves). The plant is designed to operate as an automatic transfer machine going through its step advance sequence without operators attention. Sequence control of this nature can be any of the following:

(1) A conventional hardwired logic control system i.e. based on electro-magnetic or contactless relays.

(2) Mechanical systems with cam shafts and drums.

(3) Micro computer.

(4) Programmable sequence controller.

To realise hardwired logic control requires a great deal of design, manufacture and adjustment time since each component satisfies a single purpose. Also if specifications are changed or capabilities are expanded, hardware composed of assembled units such as used in wired logic can cause a lot of trouble.

With these considerations in mind the control requirements to be met were specified as follows:

(1) The controller has to be programmable with the program capable of being changed easily.

(2) Reliability must be better than that of a relay control board.

(3) The controller must be smaller in size than a relay control board.

(4) Cost must be competitive with those of wired logic control board.

(5) Basic unit must be capable of easy expansion.

(6) Must be easy to maintain and repair.

(7) Must be easy to integrate with other plant components.

Figure 6.8 shows cost as a function of performance of sequence controller based on wired logic with those stored programs i.e. minicomputers and programmable units with especially designed microcomputers.

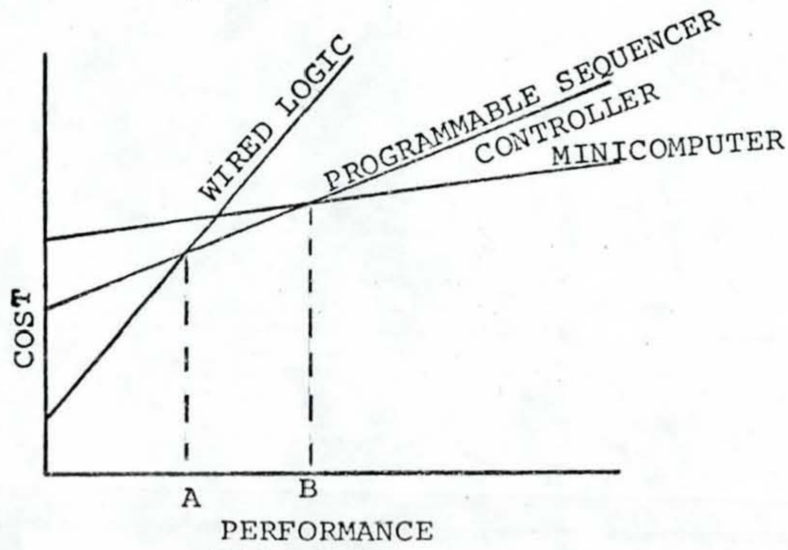


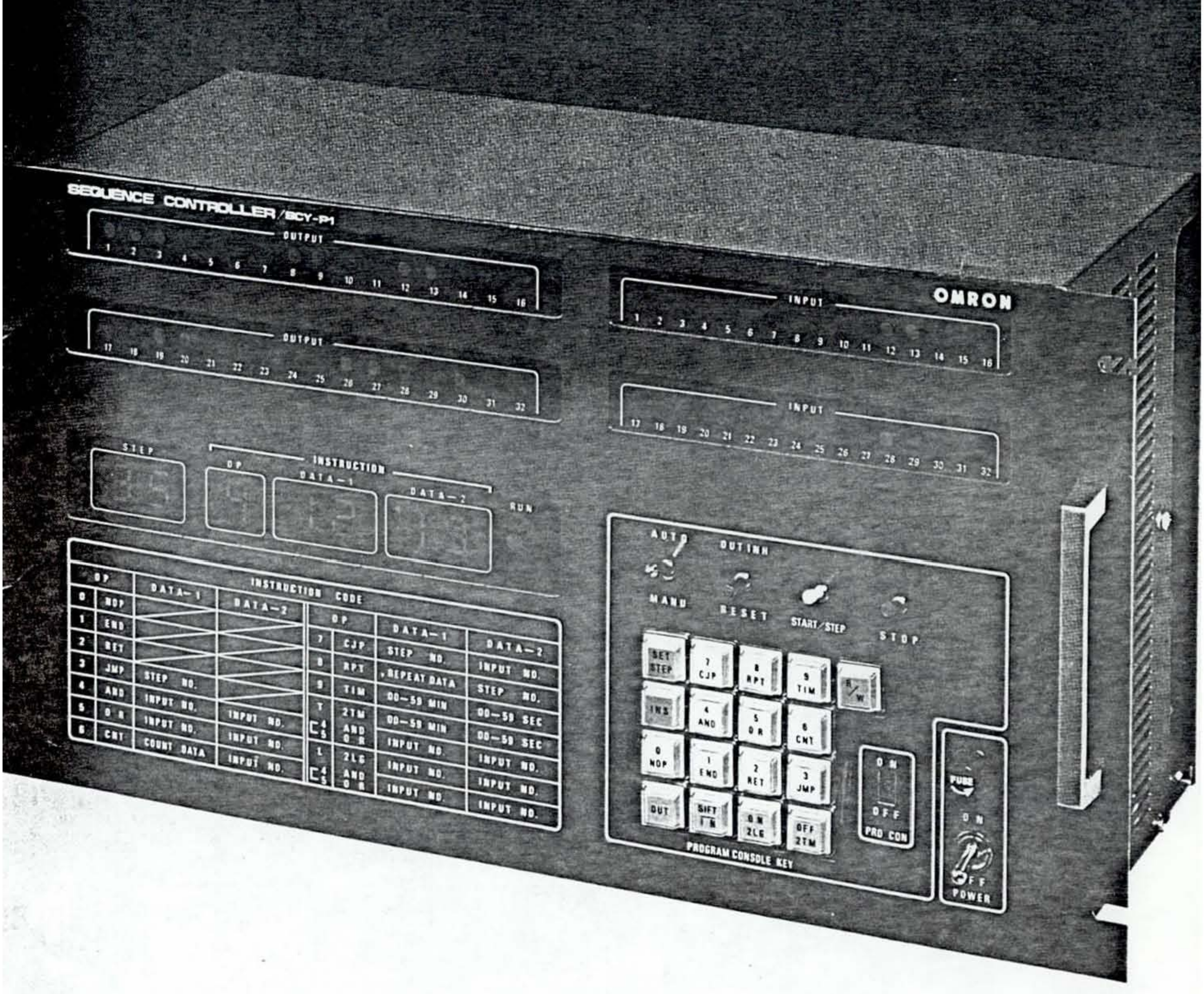
FIG. 6.8

If the function level is below point A, and involves simple control, a small scale wire logic (e.g. relay control board with say 30 relays) is relatively the least expensive. The function level between points A and B is best suited to a programmable sequence controller where timers, counters and shift register are abundantly used. The region of function level higher than point B is most adequately handled by a mini-computer where data processing is the main job e.g. for monitoring frequently changing data, for production control, and arithmetical operations.

It should be noted that decision made when selecting the control system was not based on initial cost alone. Cost was not considered only in terms of the number of relays that will be required, but account was also taken of such factors as the actual wiring, the number of necessary adjustments, reliability, flexibility, re-usability, ease of maintenance, space, standardisation and labour cost. Although the sequence controller selected cannot satisfy all the above requirements, it eliminates most of the difficulties.

The sequence controller used in the control system for the plant is an Omron "Sysmac - Pl" Programmable sequence controller, Fig. 6.9. This controller features a keyboard programming system with 12 kinds of instructions and a maximum of 63 programmable steps. Thus, it has a greater performance in relation to cost than sequence controllers of conventional pinboard-setting in terms of functions, steps and simplicity of programming. It performs a step advance type of control which has hitherto been regarded as impracticable with conventional sequence controller (diode matrix, pinboard-setting system)

STEP ADVANCE TYPE SEQUENCE CONTROLLER WITH KEYBOARD PROGRAMMING SYSTEM



OMRON® SEQUENCE CONTROLLER SERIES

SYSMAC-P1

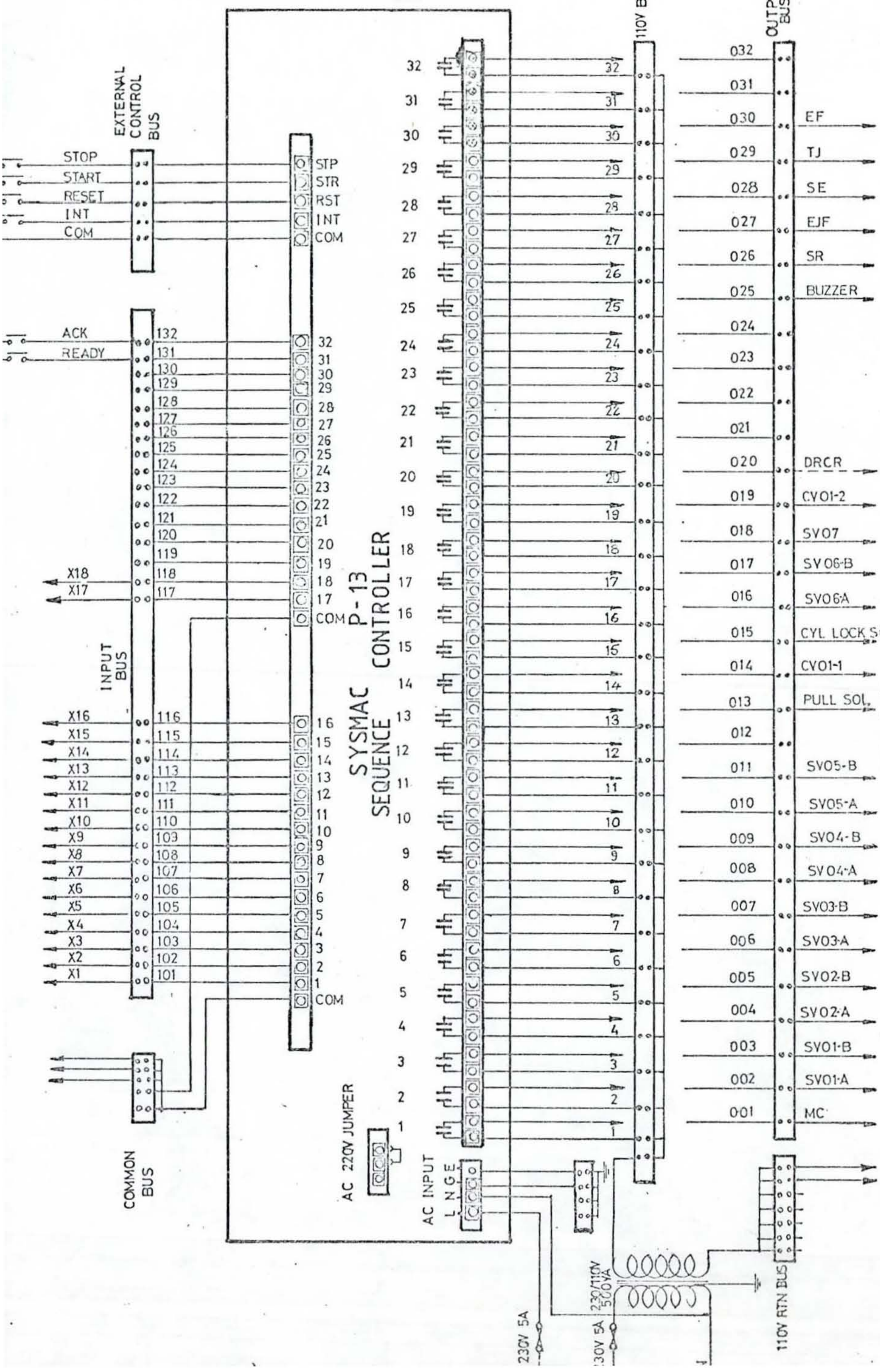
FIG. 6-9

A step advance type sequence control can be likened to an athletic relay race. In the relay race, when the first runner covers a specified portion of the entire course, he hands over the baton to the next runner who will cover another specified portion of the entire course. The baton pass is repeated by the remaining members of the relay team to complete the relay race. If the relay race is compared with a sequence control operation, the operation of each runner to cover a specified distance corresponds to the operation of each load which is being controlled (e.g. value, motor, etc.,). When input conditions (e.g. limit switch, proximity switch, pressure switch etc) become ready by the operation of the load, i.e. indicating the end of the current sequence which can be likened to a baton pass, the subsequent operation is carried out. The operation likened to a baton pass is expressed as "step advance condition".

The SYSMAC - P1 series sequence controller employs a stored program system which permits more sophisticated process control with ease.

Figure 6.10 shows the system wiring connection to the controller. Input and output connections are shown on Fig.6.11 and 6.12 respectively.

With this controller, programming is effected as easily as a desk-top electronic calculators merely by depressing the appropriate keys in a step sequence. The controller automatically checks key input errors during programming through the keyboard, flashes the instruction display and alerts the operator by means of a buzzer on detection of any program error. Input and output status are monitored and displayed using LED (light emitting Diodes) indicators, during operation, thus the status


EXTERNAL CONTROL BUS
STOP
START
RESET
INT
COM
STP
STR
RST
INT
COM
ACK
READY
INPUT BUS
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107
106
105
104
103
102
101
X18
X17
X16
X15
X14
X13
X12
X11
X10
X9
X8
X7
X6
X5
X4
X3
X2
X1
COMMON BUS
SYSMAC SEQUENCE P-13 CONTROLLER
AC 220V JUMPER
AC INPUT L N G E
110V BUS
OUTPUT BUS
032
031
030 EF
029 TJ
028 SE
027 EJF
026 SR
025 BUZZER
024
023
022
021
020 DRCR
019 CV01-2
018 SV07
017 SV06-B
016 SV06-A
015 CYL LOCK SOL
014 CV01-1
013 PULL SOL
012
011 SV05-B
010 SV05-A
009 SV04-B
008 SV04-A
007 SV03-B
006 SV03-A
005 SV02-B
004 SV02-A
003 SV01-B
002 SV01-A
001 MC
230/110V 500VA
110V RTN BUS
230V 5A
230V 5A

FIG 6-10

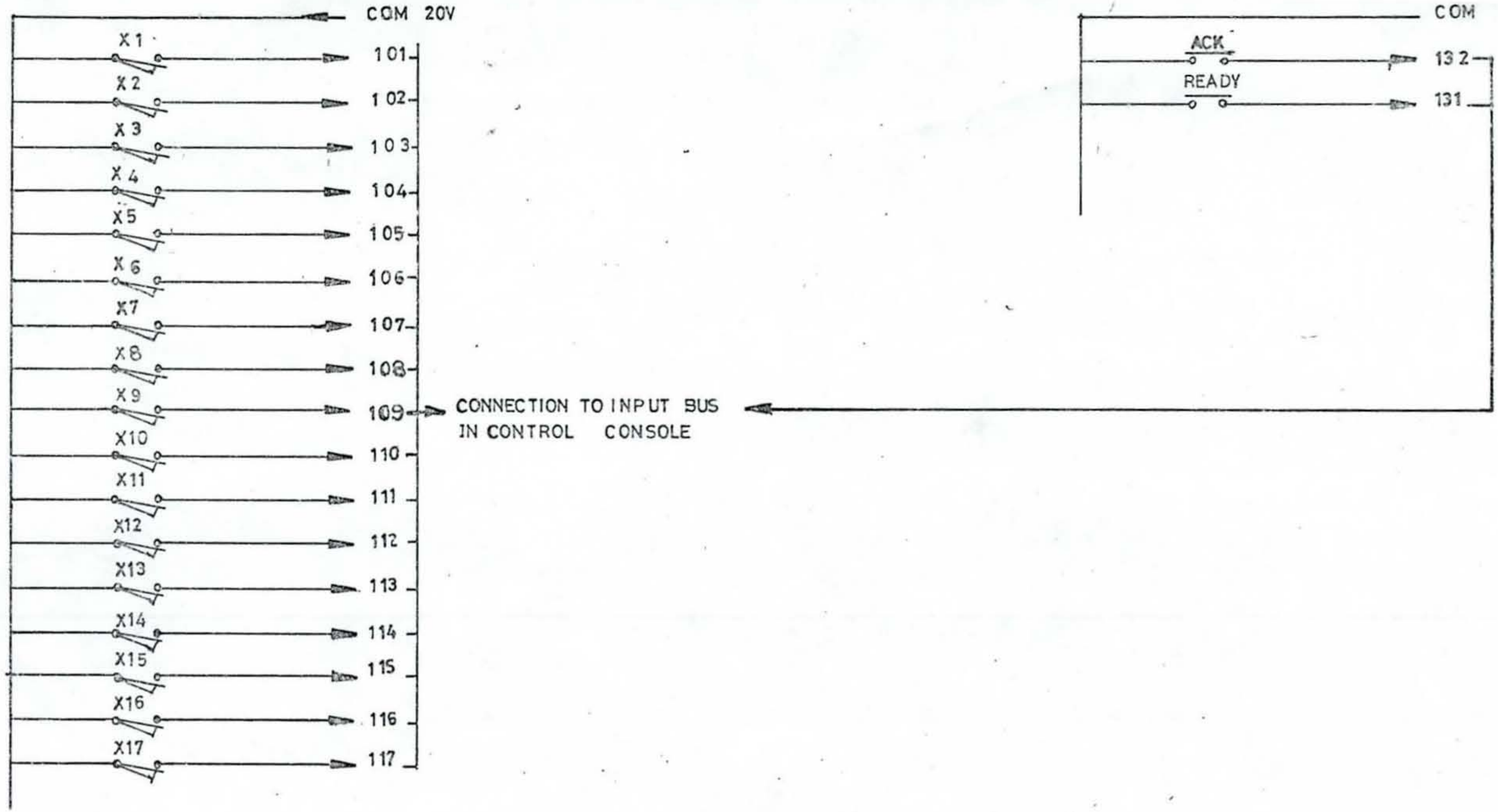
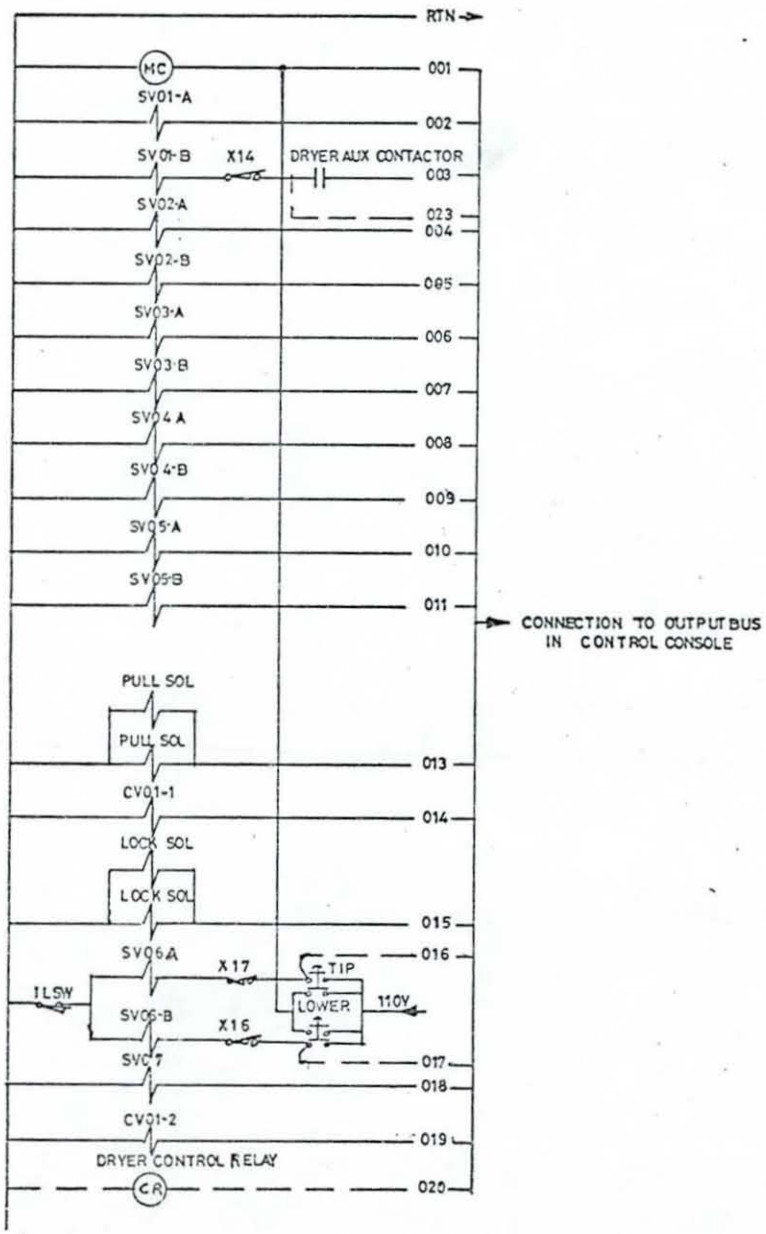


FIG 6-11

SYSTEMS CONTROL INPUT CONNECTION



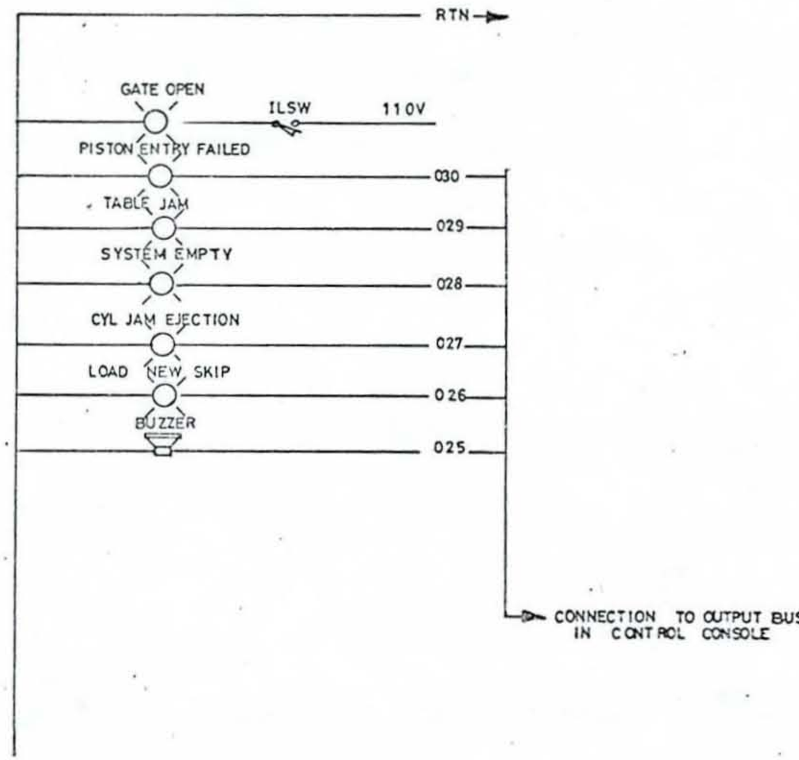


FIG 6-12

SYSTEM CONTROL OUTPUT CONNECTION

information of the current sequence in operation can be viewed by inspection of the display.

A step position (i.e. a step number in the process) can be monitored at any time by a step display, while a step-advance condition (i.e. an instruction) is indicated by OP, Data - 1 and Data - 2 displays.

The 12 kinds of instructions available includes Return, Unconditional jump, AND, OR, Counter, Conditional jump, Repeat, and Timer, thereby providing the sequence controller with complete processing functions to permit sophisticated control. The table of instruction code is given in Appendix D, together with descriptions of respective instructions.

As a counter-measure against power failure, should such a failure or a service interruption occur during operation of the controller, the process in progress will be held static. It will resume when the source of power is restored. This facility enables the plant to be shut down at any desired time without regards to the sequence in progress during the shut down.

The process flow chart covering all events required to control the plant is shown in Appendix D.

Each box in the flow chart represents a processing step. The diamond shape boxes are conditional jump processes in which the controller monitors the input condition and jumps to a specified step if the programmed condition is met.

Error or fault routines are entered at points E, F, G, H of the flow chart.

During the plant's operation there are four possible system faults that can develop. They are as follows:

(1) The extrusion cylinder can get stuck when being ejected from the extrusion frame.

(2) When a loading sequence commences the system can be empty or there may be no cylinder ready for loading into the extrusion frame.

(3) There could be misalignment during a cylinder entry sequence which will cause the piston to jam.

(4) The plunger in the pull solenoid could get stuck thus preventing the transverse loading ram to fully retract.

During an operation in which one of the above faults can occur the controller monitors the appropriate input or times the operation. If a fault occurred due to the operation being timed out or input requirement not fulfilled, the controller aborts the operation, calls the operator's attention by sounding an alarm and indicates the system status through appropriate indicator light on the control panel.

6.4 FUNCTIONAL DESCRIPTION SEQUENCE CONTROLLER

The sequence controller is housed in a fan cooled totally enclosed floor mounted control console.

6.4.1 Programming

A sequence flow chart, Appendix E was prepared to enable the sequence controller to be programmed.

6.4.2 Assigning input/output identifiers to input elements and controlled (output) elements

To prepare a system program, Table 6.1 each of the input and controlled elements in the flow chart is given a controller identifier number. An explanation of each elements identification begins with the manner in which input and output devices are connected to the sequence controller. Figure 6.10 shows how the elements in the flow chart of Appendix E are connected to the input and output bus of the controller.

Of the possible input connections, 1 to 17 and 31 and 32 were chosen (choice is generally arbitrary and depends upon available terminals).

Of the possible outputs connections, 1 to 11, 13 to 20, and 25 to 30 were chosen.

Each input, once identified can be referred to within the sequence as many times as deemed necessary to produce the desired control sequence.

6.4.3 Preparing system program

After each element has been assigned and identified as described above, a system program was prepared (see Table 6.1).

The program has six columns Step, Op, Data - 1, Data - 2, Output and Comment. The description of each column is as follows:

(1) Step: The step is the sequence step number in which the entered operation is to be performed. It is from 00 to 63.

(2) OP: Op represents the logical operation, ORing or ANDing to be performed on input present in the column DATA - 1 and DATA - 2, or a functional operation to be performed within the controller before control is transferred to the next step.

(3) DATA - 1: This column can contain one of the following:

(a) A input number to be monitored by the controller during the current step.

(b) The time in minutes for TIME operation.

(c) Numbers of repetions for REPEAT operation.

(d) A step to which control is to be transferred during any jump operation.

(4) DATA - 2: Data - 2 can contain one of the following:

(a) The second input setting if two or more input are to be monitored.

(b) A copy of Data - 1 if only one input is being monitored.

(c) The number of seconds setting for a TIME operation.

(d) The step number from which repetition is to start for a REPEAT operation.

(e) Input signal to be monitored for conditional JUMP.

(5) Output: Output indicates the output terminal corresponding to controlled element required which are to be switched on during the current sequential step.

(6) Comment: This column contains a brief explanation of the sequential step.

6.4.4 Programming

To program the controller, power is applied to it and program control 'PROCON' switch turned on. The controller is then initialized by depressing the INS and R/W keys simultaneously. This operation clears the memory and sets the step number to "00" (Appendix D contains definition for special function keys). For each step advance condition, the INS key is depressed and the step instruction entered in the following sequence:

OP → DATA - 1 → DATA - 2

If only one data is entered when an AND or OR operation is to be performed the content of DATA - 1 is automatically written into DATA - 2 when R/W key is depressed.

The output requirements are set by depressing the "OUT" key which flashes the LED(light emitting diode) in Output position 1 on the display, followed by an ON, OFF or SHIFT key according to the program. Depress ON, OFF or SHIFT key advances the output setting one terminal forward.

The instruction just entered is stored by depressing the R/W key. This automatically advances the step display one step forward. The program control (PRO CON) switch is turned off when all the program steps have been entered.

The program can then be editted by stepping through the program one step at a time. During program editting the PRO CON switch must be on, and only the STEP key needs to be pressed to advance the step one step forward.

TABLE 6.1

SYSTEM PROGRAMME

STEP	OP	DATA-1	DATA-2	OUTPUT	COMMENT
00	RET				Power failure recovery
A 01	OR	01	10	1,2,19	Withdraw piston from cylinder
02	OR	02		1,4	Pan out of dryer
03	TIM	00	02	1	Delay keep motor running
04	OR	03		1,6	Lower frame
05	OR	01		1,2,19	Withdraw piston from cylinder completely
06	CJP	F	06		If syst. is empty go to F
J 07	2TM	00	45		Cylinder ejection time limit
08	OR	04		1,10	Push empty cylinder onto table
09	CJP	E	04		If cylinder is jammed go to E
10	TIM	00	02	1	Delay
11	AND	01	15	1,8	Align full cylinder for loading
12	TIM	00	02	1	Delay
13	OR	08		1,11,13	Load full cylinder into frame
L 14	2TM	01	30		Piston entry time limit
15	OR	10		1,14, 18,19	Start piston entry
16	CJP	H	10		If entry fails go to H
K 17	TIM	00	00	1,10	Jerk push plate to release plugs
18	2TM	00	06		Push plate retraction time limit
19	OR	09		1,11	Retract push plate fully
20	CJP	6	09		If push plate retraction fails go to G

Table 6.1 (cont'd)

STEP	OP	DATA-1	DATA-2	OUTPUT	COMMENT
21	OR	11		1,7	Lift frame above dryer
22	TIM	00	02	1,	Delay
23	OR	12		1,5	Pan frame into dryer
24	TIM	00	10	1,3,14	Compaction pressure build up time
25	OR	13	14	1,3,14	Start compaction sequence
26	CJP	M^{54}	14		If cylinder is empty go to M
27	OR	14	32	1,23,(20) 25,26	Start extrusion
28	CJP	M^{54}	14		If extrusion complete go to M
29	OR	14	31	1,23,(20) 26	Otherwise continue extruding
30	CJP	M^{54}	14		If extrusion complete go to M
31	OR	14		1,23,(20)	Otherwise continue extruding
M 32	OR	17		1,16	Tip cradle
33	TIM	00	10		Wait for pigment to drop
34	OR	16		1,17	Lower the cradle
35	TIM	00	02	1	Delay
D 36	OR	18		1,9	Cylinder manipulation sequence 1
37	TIM	00	02	1,	Delay
38	OR	15		1,8,15	Cylinder manipulation sequence 2
39	TIM	00	02	1	Delay
40	OR	18		1,9	Cylinder manipulation final sequence
41	JMP	A			Return to A

Table 6.1 (cont'd)

STEP	OP	DATA-1	DATA-2	OUTPUT	COMMENT
E 42	OR	32		25,27	Buzz and indicate status as
43	OR	31		27	"cylinder stuck on ejection
44	JMP	J			Return to fault pointing and try again
F45	OR	32		25,28	Buzz and indicate status a
46	OR	31		28	"Loading table empty"
47	JMP	D			Return to fault point and try again
G 48	OR	32		25,29	Buzz and indicate status a
49	OR	32		29	"Pull sol stuck"
50	JMP	K			Return to fault point and try again
H 51	OR	32		25,30	Buzz and indicate fault as
52	OR	31		30	"Piston entry failure"
53	JMP	L			Return to fault point and try again
M 54	OR	32		25,26	Call operator request for new skip
55	OR	31		26	Skip request status
56	JMP	N			Return and tip skip
57	END				End of program
58	OR	14		1,3,19	Piston fast forward
59	END				
60	OR	01		1,2,19	Piston fast withdrawal
61	END				

CHAPTER 7

PLANT MANUFACTURE, INSTALLATION AND COMMISSIONING

7.1 MANUFACTURE

Detailed working drawings and system specifications for the plant were ready during the first quarter of 1980. Some known equipment manufacturers were invited to tender for the manufacture of the plant. The contract for the manufacture of the plant was awarded to a company in Newchapel, Stoke-on-Trent. The building and supply of the hydraulic system was subcontracted out by the main contractor.

In September 1980 the main contractor expressed some difficulty in finding suitable subcontractors to carry out the electrical/electronic system control wiring. In view of the time constraint on the project the author of this thesis volunteered to do the wiring. The labour and materials were supplied by the main contractor.

The final assembly of the plant was not on schedule due to the delay experienced on the supply of the 250 mm extrusion ram.

During the assembly it was observed that the perpendicularity required between the extrusion ram rod and the bottom plate of the extrusion frame could not be obtained. This was because during the fabrication of the extrusion frame, the sub-assembly procedure specified in the working drawings was not followed. The situation was remedied with the use of the shims under the extrusion ram flange.

Modification to the design is detailed in section 7.4.

The complete plant was assembled and tests were carried out to see that the performance requirements of the plant were met.

This includes stability tests and functional tests.

7.2 INSTALLATION

The plant was initially installed at the sponsor's works in Kidsgrove where performance tests were carried out (see Chapter 8).

Some problems were experienced with the check valves on the lifting ram circuit and the extrusion ram circuit. This was because the check valve supplied were supposed to be externally drained as opposed to the internally drained type specified in the hydraulic specification. The external drain required on the supplied valves were not provided for. The author then requested the main contractor to provide these external drains.

7.3 COMMISSIONING

On completion of the performance tests at Kidsgrove the plant was transported to Cowan Colours in London where it was commissioned.

During the installation of the plant in London the wiring was wrongly connected by the contractors, despite the fact that the cables were labelled. This caused the protective fuses in the control system to blow.

The complete wiring had to be stripped down by the author and reconnected.

Wrong piping connections on the panning and lifting system by the contractor caused the equipment to malfunction on start-up. This fault caused the loss of some seals on the panning ram's directional control valve, which were later replaced.

7.4 MODIFICATIONS TO THE PLANT

During the course of the manufacture of the plant a number of components e.g. the lock solenoid (17) Fig. 4.17, the pull solenoid, Fig. 4.15 were not standard items and had to be proved operational before standard detailed drawings and material selection could be made. The components for these items were made from mild steel. It will be necessary to make these components from stainless steel as specified in their manufacturing drawings, especially for those plants to be used in processing cadmium based pigment. This type of pigment have a corrosive effect on mild steel.

During the commissioning of the plant at Cowan's Colour Limited where it is now being used to produce chrome based pigment, some difficulties were experienced in maintaining continuous extrusion throughout the complete extrusion stroke on the machine. The machine had to be stopped and started three or four times during a complete extrusion stroke. The reason for this is discussed in Chapter 8. To overcome this problem the number of holes on the extrusion cylinder has now been increased from 16 to 26. This arrangement also gives a better spread on the band dryer, but did not solve the stop/start problem.

The problem was overcome by inserting a mouthpiece (see Fig. 7.1) over the die plate. This mouthpiece reduces the die angle from 90° to 60°. As mentioned by Hodginson[2] this has the effect of reducing the amount of redundant work required within the conical dead zone. The extrusion pressure required to extrude pigment with the mouthpiece insert was not determined but it was noted that the presence of the mouthpiece improved the performance of the plant considerably, e.g. the extrusion rate was observed to be constant, the extrudate distribution on the band dryer was uniform and the plant could run in its designed automatic mode without unnecessary operator's attention.

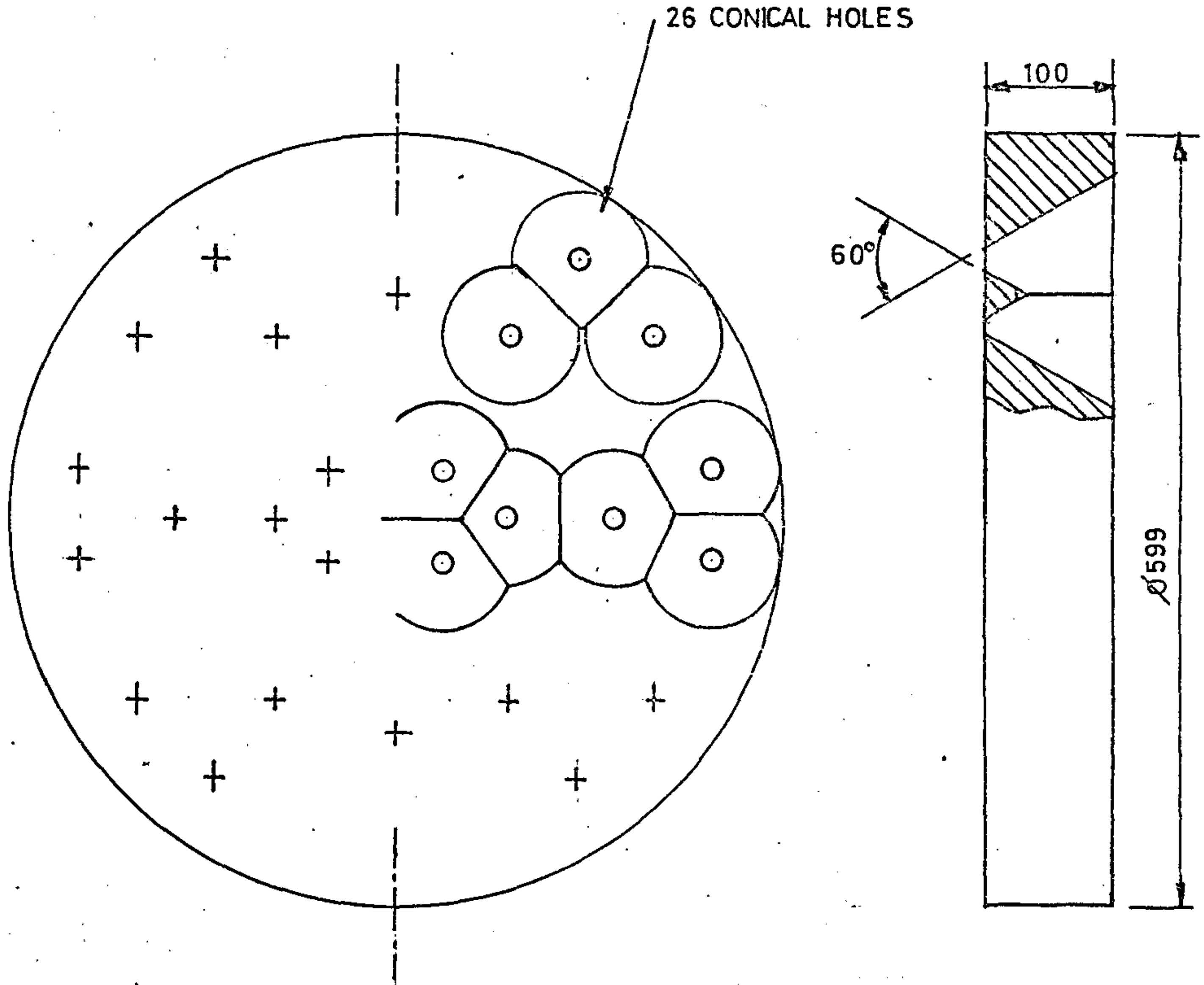


FIG 7-1

DIE MOUTHPIECE

CHAPTER 8

EXTRUSION PLANT TEST

The justification of many of the assumptions made for the design of the plant can only come through its use.

A test specification, Appendix C was prepared. The extrusion plant was tested to this specification at the manufacturer's works.

When the equipment was installed at the sponsors' works in Kidsgrove a performance test was carried out on it. The test carried out are discussed below. The test done on various pigments indicated that the plant is capable of extruding all the pigment currently being produced by the sponsors. There are variations to the thickness of pigment left over at the end of the extrusion cycle. This thickness depends on the pigment being extruded. When an extrusion cylinder is refilled with pigment without the left over from previous extrusion removed, it was observed that there was no build-up effect in the cylinder after each successive extrusion.

Difficulties were however experienced during the extrusion of chrome base pigment a material being produced at Cowan's Colour Limited (a sister company of the sponsors). The material was introduced into the project towards the end. These difficulties will be discussed in section 8.3.

8.1 PRESSURE TEST

Pressure measurements were made to check the behaviour of the extrusion process against the empirical equations derived on the Laboratory model on which the design of the plant was based. Pressure measurements were made during the extrusion of some pigments supplied by the sponsors within the limited time allocated for the test.

The pressures on the piston face and that on the bottom of the extrusion cylinder were taken at various piston displacements from the bottom of the cylinder. This was done by drilling and tapping holes on the piston and the cylinder bottom as shown in Fig. 8.1.

Two Kistler Piezoresistive pressure transducers type 4043 A50 were fitted as shown. The drilled holes not instrumented were plugged off. Each transducer was connected to a Kistler Piezoresistive amplifier type 4601. When it is desired to read the pressure on any one of the transducers it is connected to the amplifier as shown in Fig. 8.2. Output from the amplifier is read with an AVO digital multimeter.

Only two readings, one on the piston and the other on the cylinder could be taken during each extrusion stroke. This was because only two transducers and one amplifier were made available by the sponsors.

8.2 TEST RESULT

The amount of pressure testing carried out was severely limited as not all the pigments being produced by the sponsors were available for test at the time.

Pressure testing was carried out without seals on the extrusion piston grooves. Although there were some back extrusion between the cylinder walls and the piston this was not appreciable. It was observed that after each extrusion the cylinder walls were wiped clean by the piston during its withdrawal.

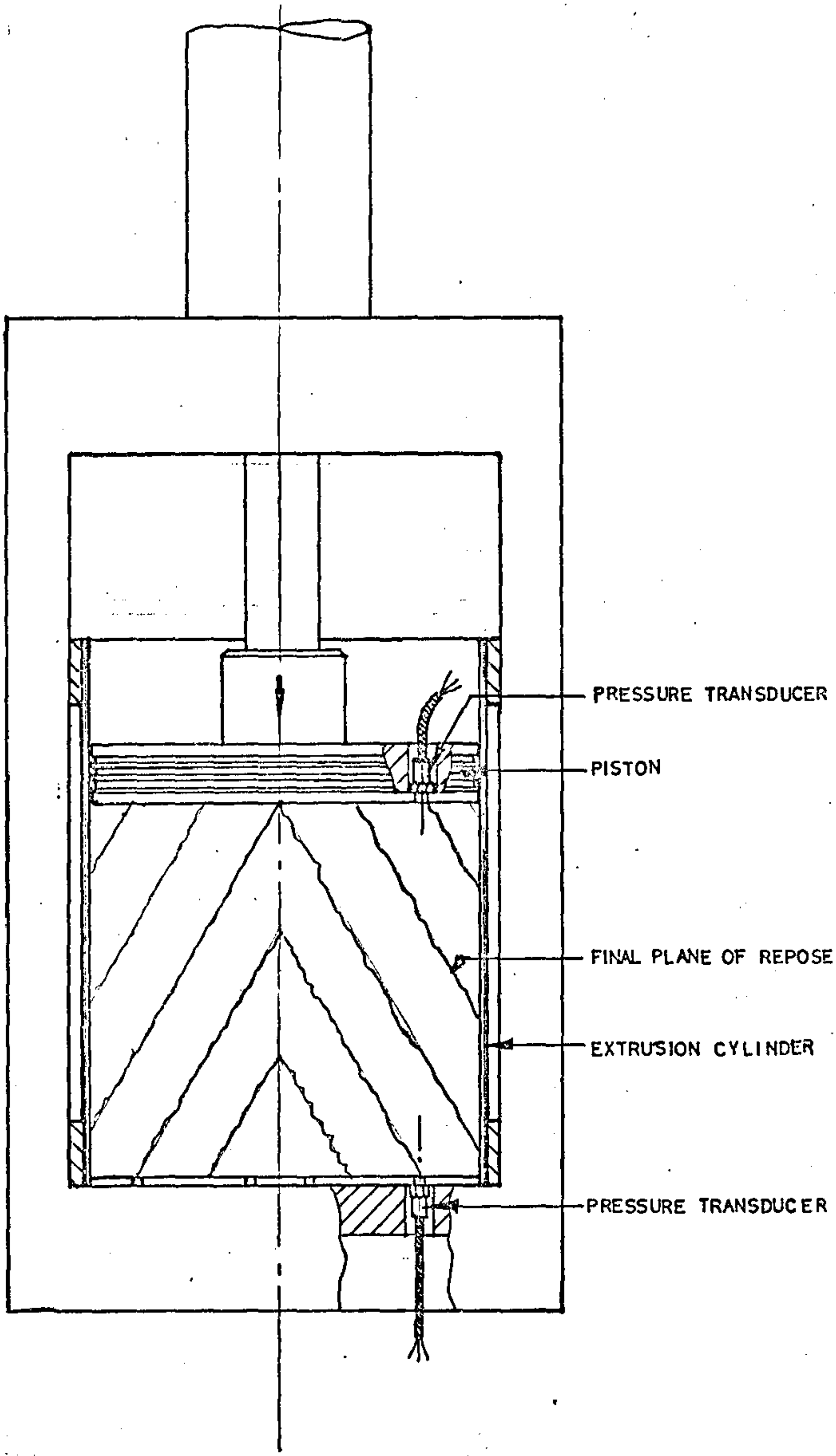
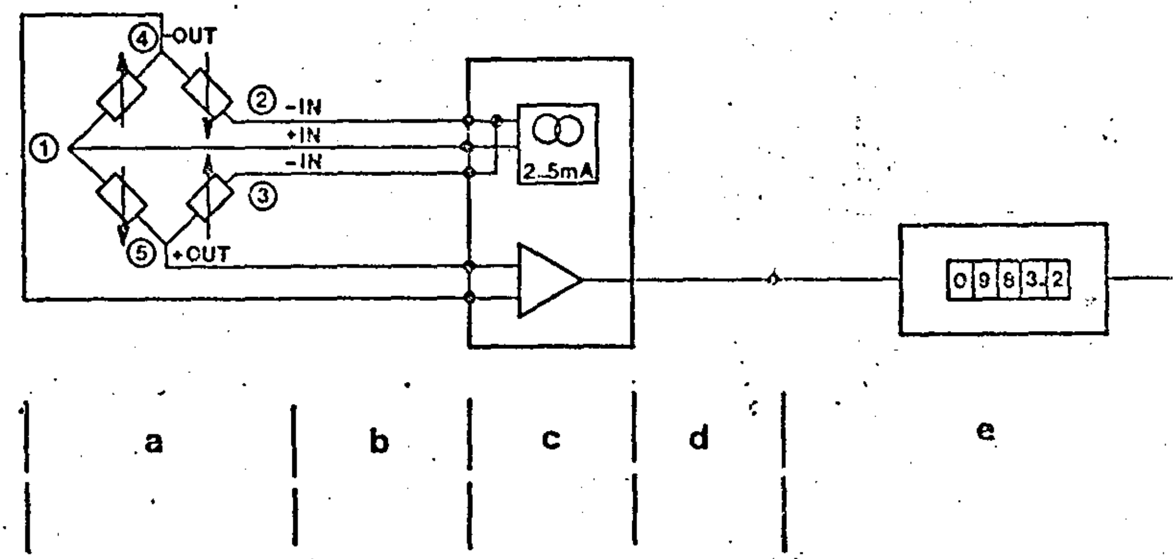


FIG 8-1

TRANSDUCER LOCATIONS DURING EXTRUSION PRESSURE MEASUREMENT



a: transducer (with open measuring bridge), e.g. 4043/45A...

b: 5-conductor connecting cable

c: piezoresistive amplifier with integral constant current source 2 ... 5 mA

d: connecting cable(s)

e: displays electronics

FIG. 8.2

Block diagram of measuring system

The pressure reading taken during the tests were plotted against piston distance from the bottom of the cylinder. The results are shown graphically in Figs. 8.3 to 8.7.

At least two measurements were taken using the same type and group of pigment. The curves obtained from each set of measurement are depicted as A and B in each figure.

8.3 DISCUSSION OF RESULTS

From the test results it can be observed that the pressure reading at the piston face is lower than that at the bottom of the cylinder. These results do not agree with the theories of extrusion in which the total extrusion pressure, (i.e. piston pressure) is the sum of the pressure due to cylinder wall friction plus the pressure at the cylinder bottom.

It is believed that the reason for some of the piston pressure readings being lower than those at the bottom of the extrusion cylinder were due to pressure distribution on the piston surface. The behaviour can be attributed to final angle of repose of the pigment after it has attained its extrusion density (see Fig. 8.1) which allows the central portion of the pigment to form a heap capable of supporting the applied force. This hypothesis could not be verified due to the timescale allocated to the tests.

The pressure at 10 mm from the bottom of the cylinder for unfired deep Yellow Y77 and fired Red R05 were in close agreement with those predicted by the empirical equation obtained in Chapter 3, (see Table 8.1). The predicted pressure for chromate (0.42MPa) is less than the observed value (4.4MPa) because the pigment used in the laboratory test was filtered using a pack filter with 60% moisture content compared to the vacuum filtered pigment used in the performance test of 30% moisture content.

Pigment	Extrusion Pressure MPa	
	Predicted	Observed
RO4 Unfired	0.9	Not available
Y77 Unfired	1.23	1.2 average
YO6 Unfired	1.4	Not available
RO1 Unfired	1.5	Not available
RO1 Fired	3.5	1.87 average
Y77 Fired	2.0	Not available
M59 Fired	4.1	Not available
RO5 Fired	4.45	4.43 average
Chromate	0.42	4.40 average

TABLE 8.1

Observed/predicted extrusion pressure

The extrusion pressure from tests on the laboratory model used in deriving the empirical equations were obtained by dividing the total applied load of the compression tester during extrusion by the extrusion cylinder area, while those obtained during the extrusion plant test were pressure within the pigments.

This difference in method of pressure measurement might have an effect on the correlation between the predicted pressures and those observed.

The stop/start phenomena exhibited by chrome base pigment whereby the extrusion pressure builds up until the extrusion ram stalls and when the plant is stopped and restarted the extrusion pressure drops and as extrusion continues the pressure builds up again until it stalls, can be likened to the behaviour of clay as explained by Capper and Cassie[14] and depicted in Fig. 8.8. The situation was remedied by inserting a mouthpiece on the die plate as explained in Chapter 7.

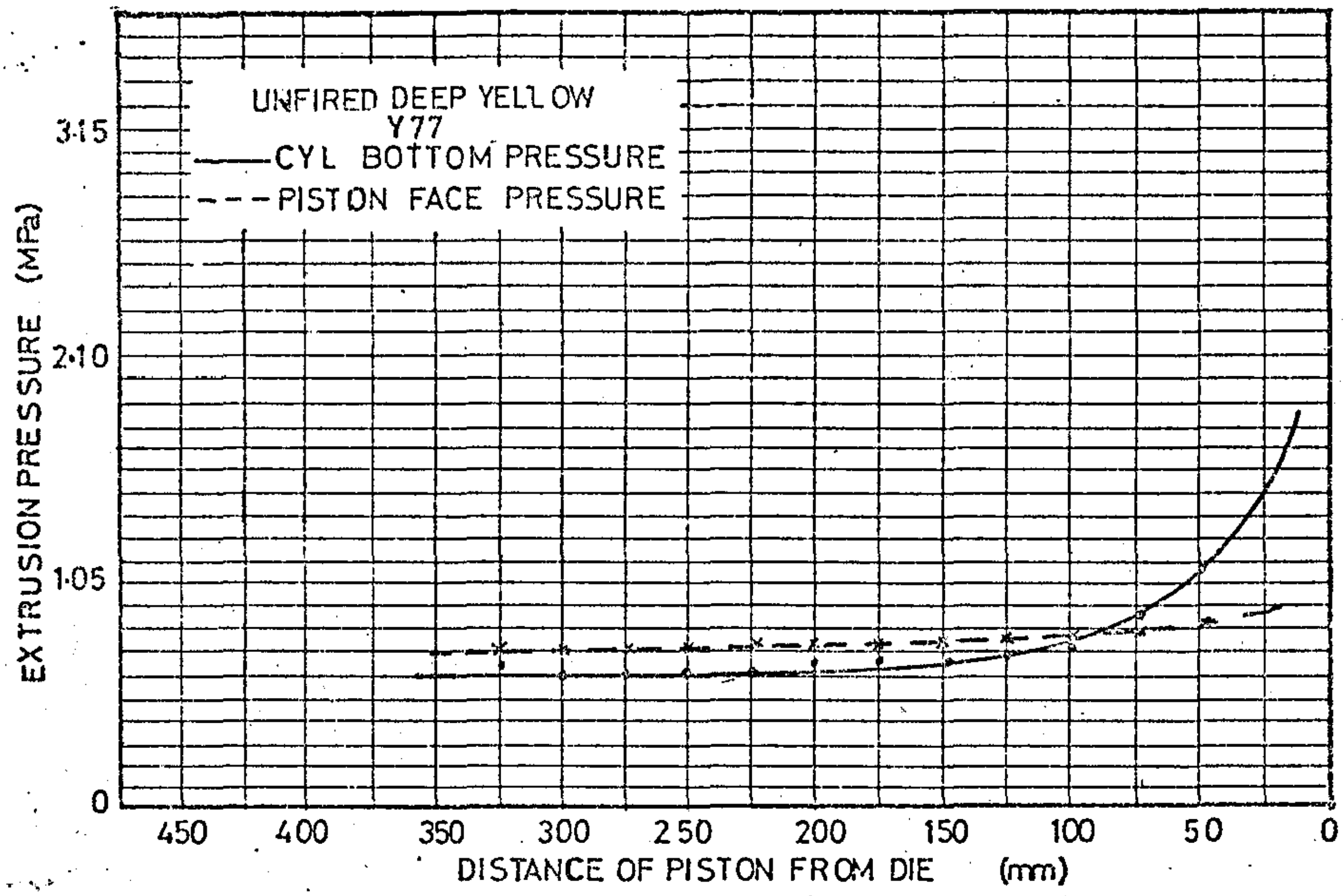


FIG 8-3A

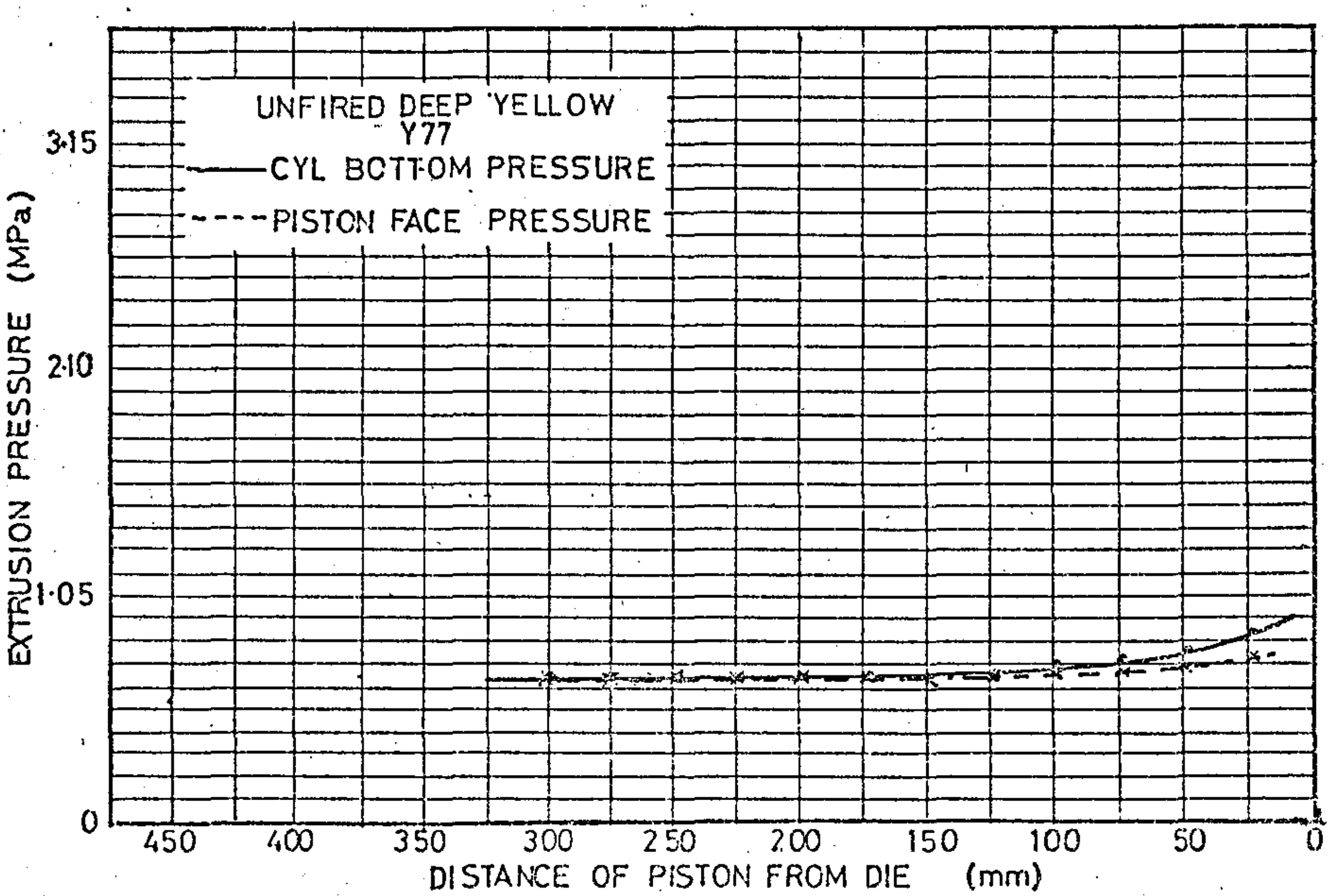


FIG 8-3B

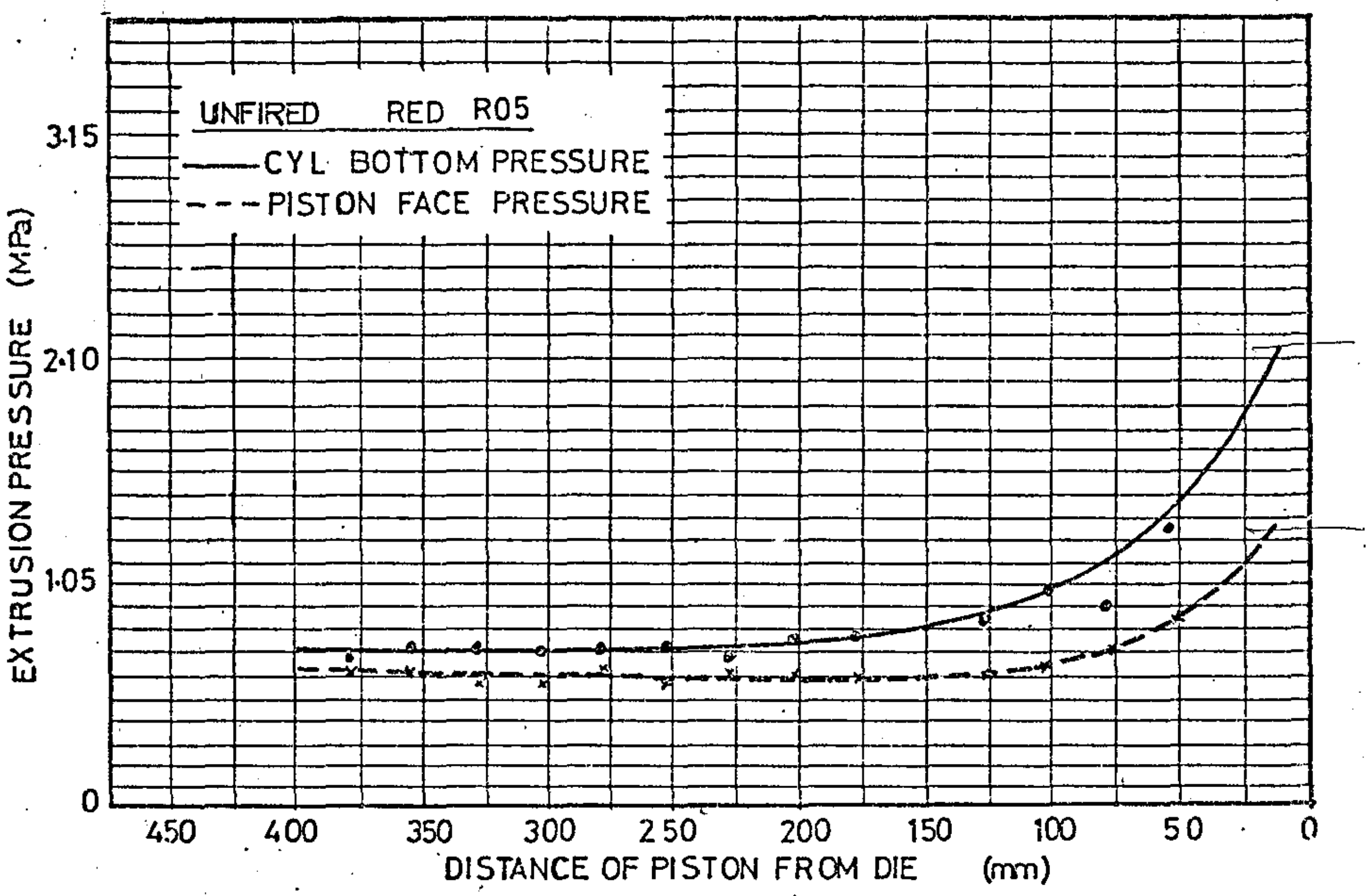


FIG 8-4A

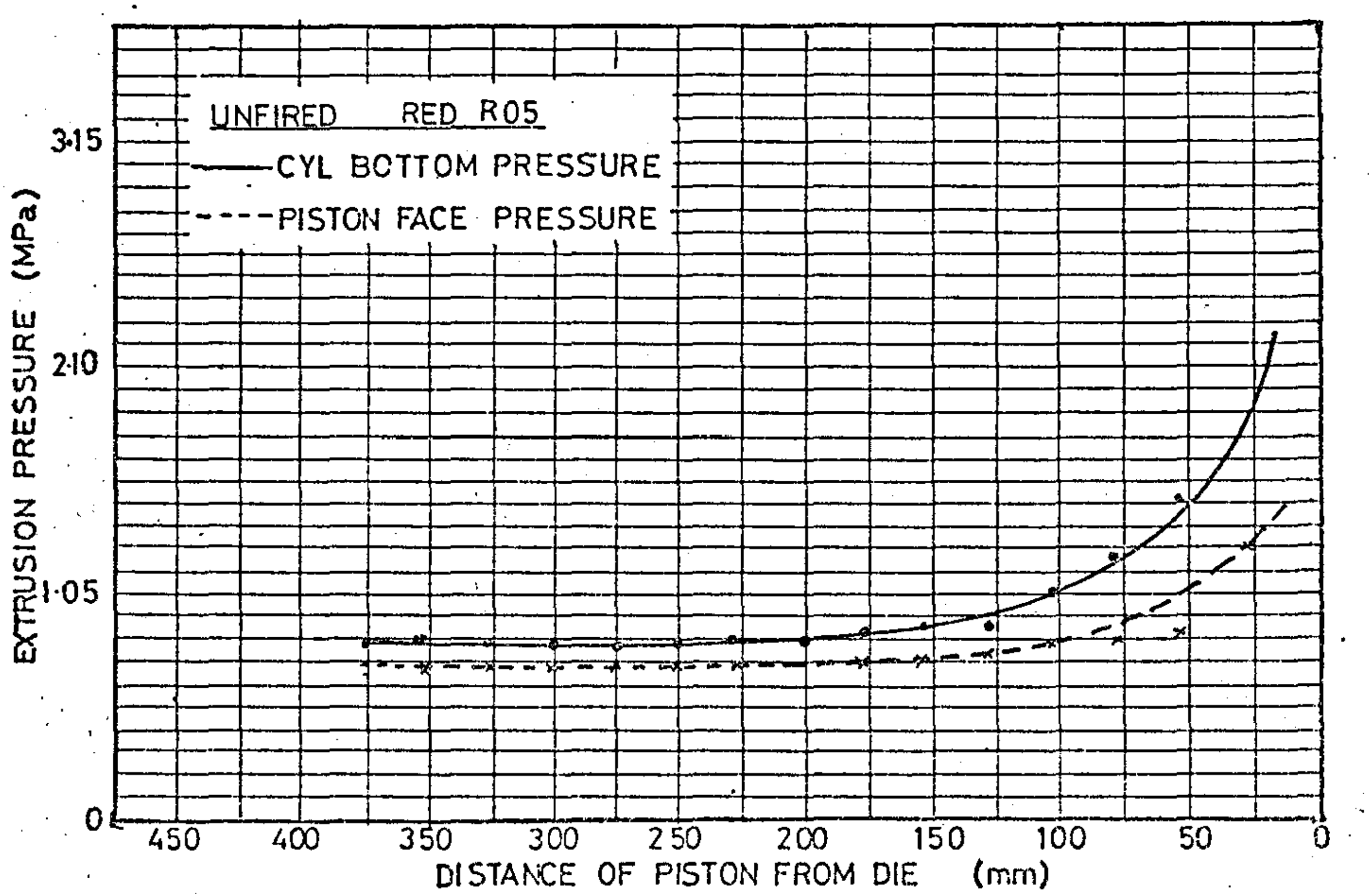


FIG 8-4B

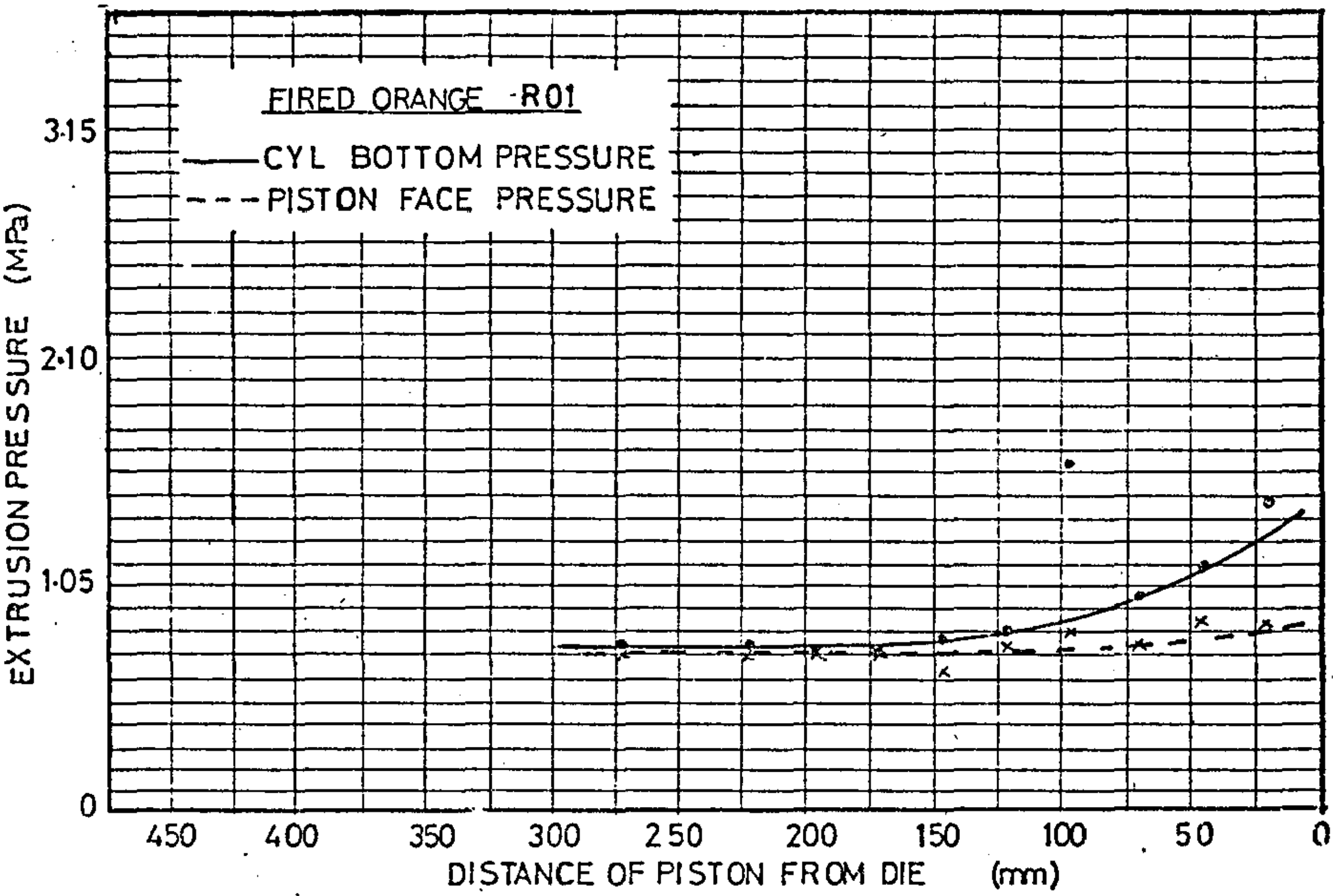


FIG 8-5A

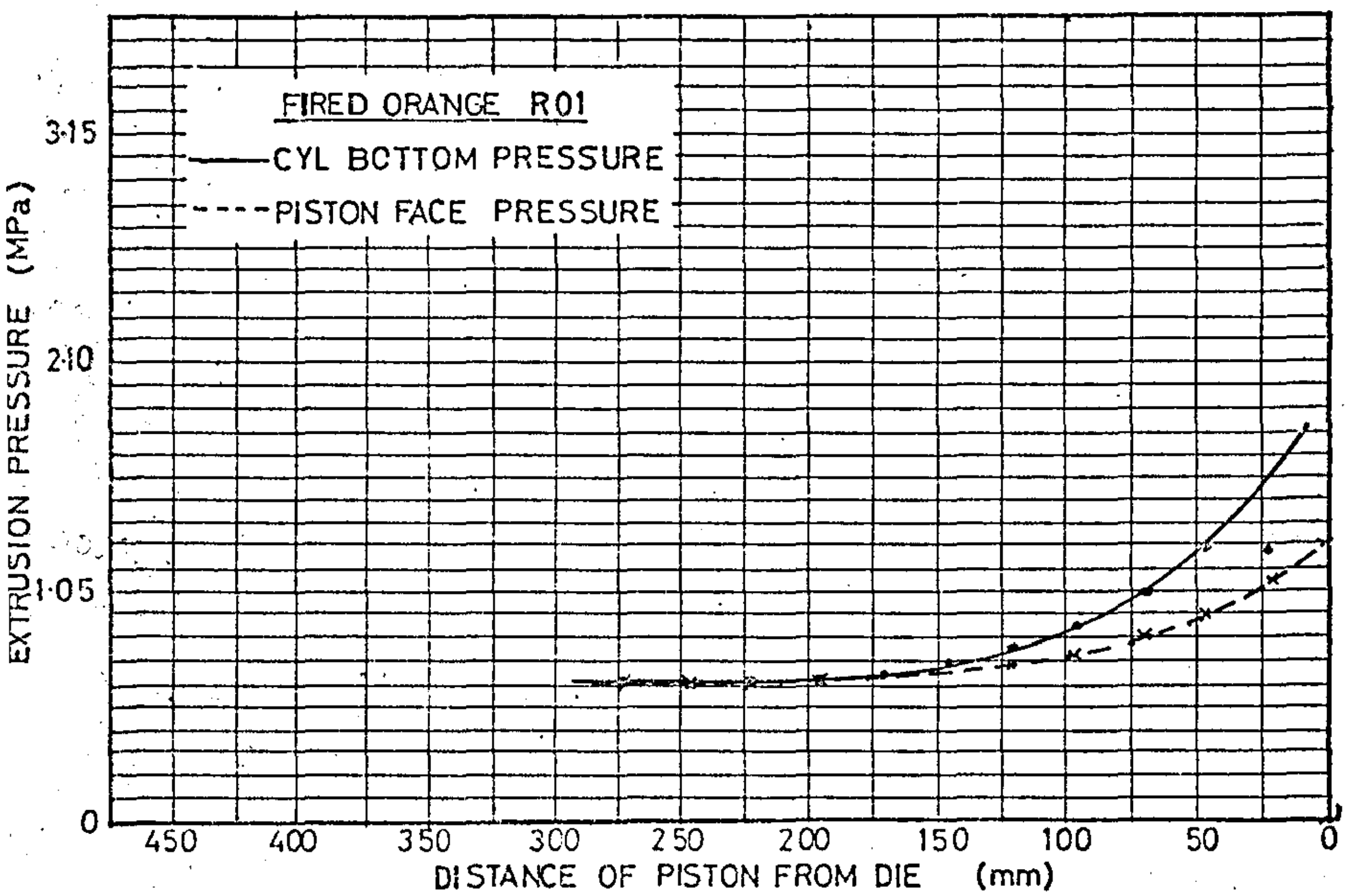


FIG 8-5B

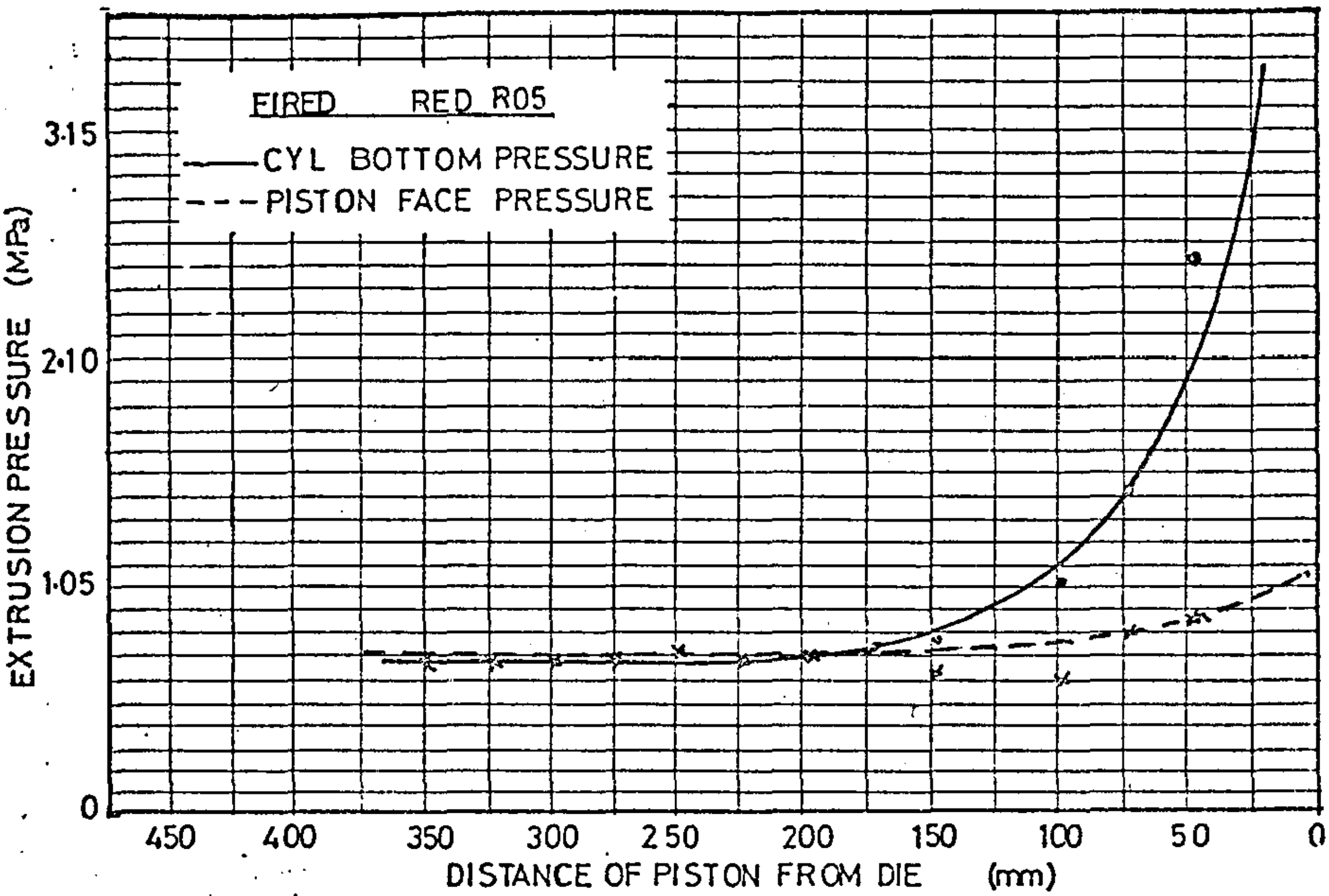


FIG 8.-6A

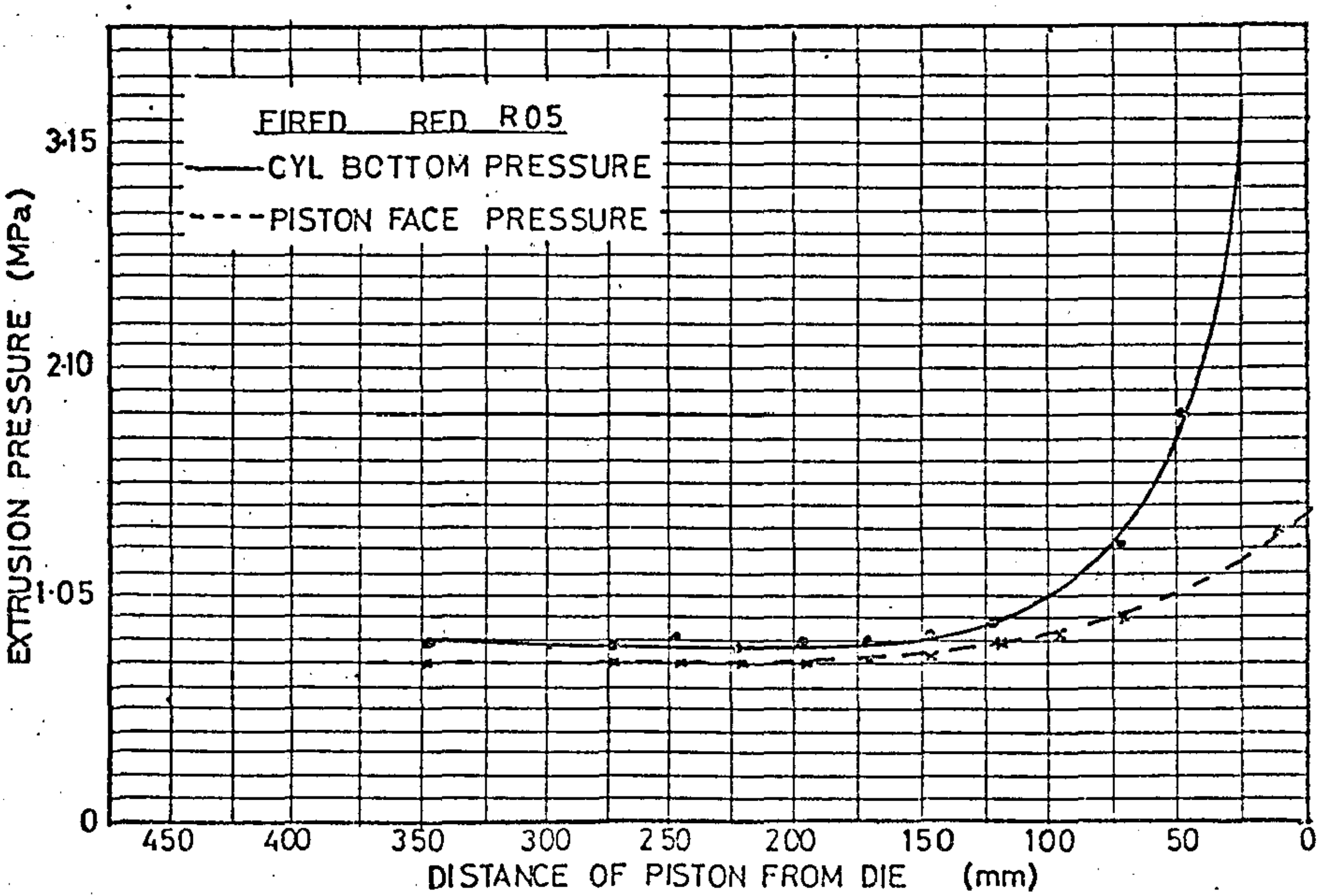


FIG: 8-6B

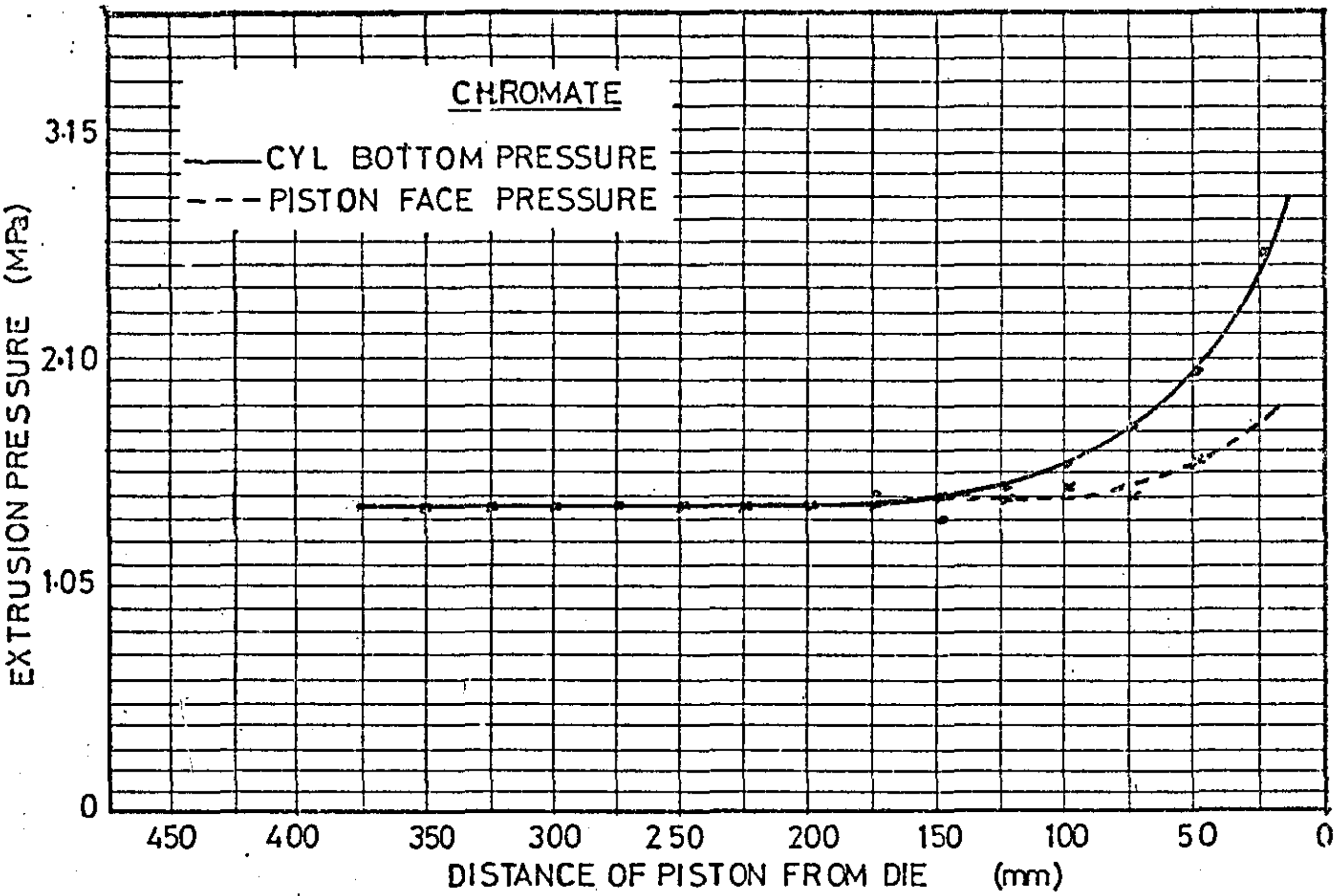


FIG 8-7A

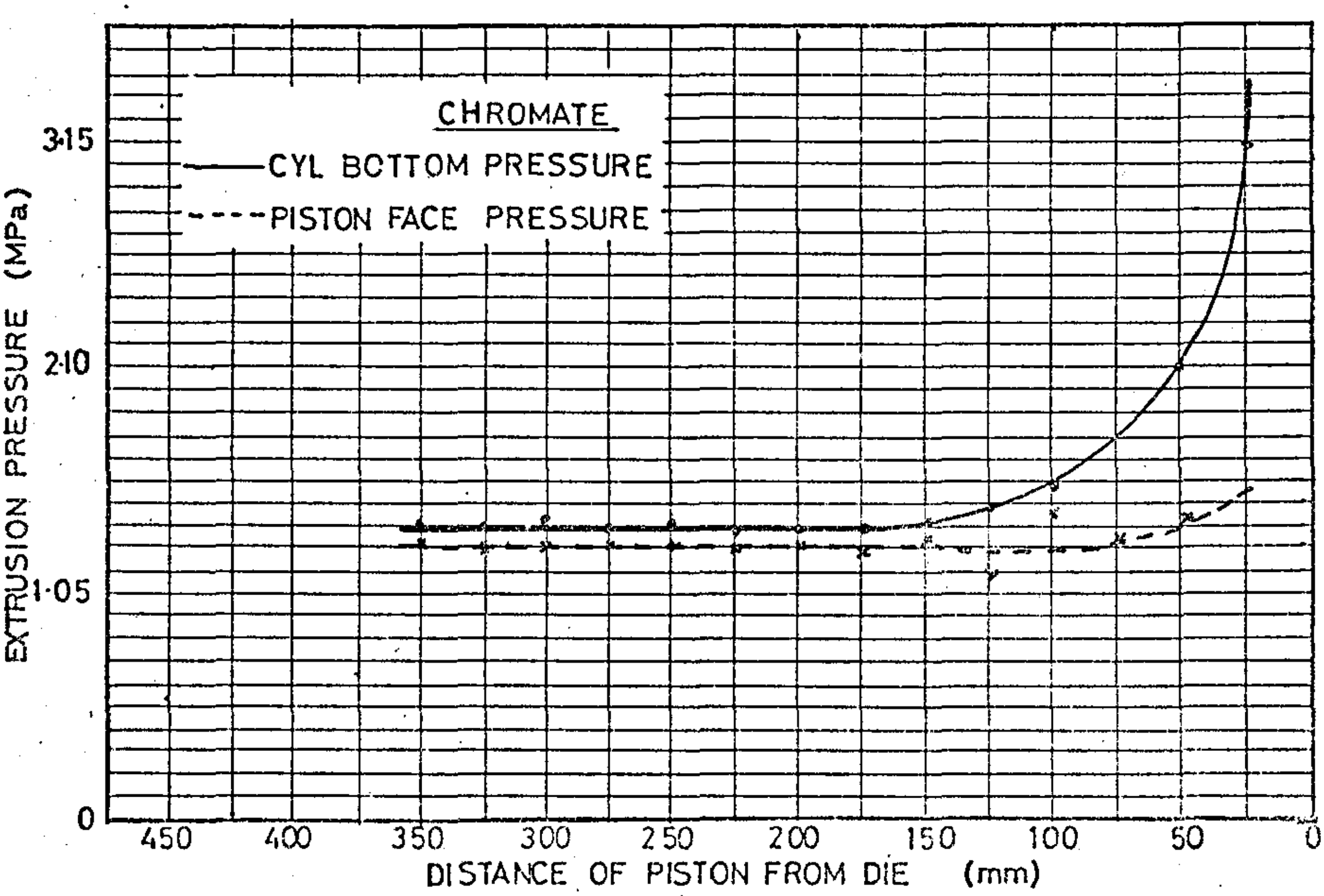


FIG 8-7 B

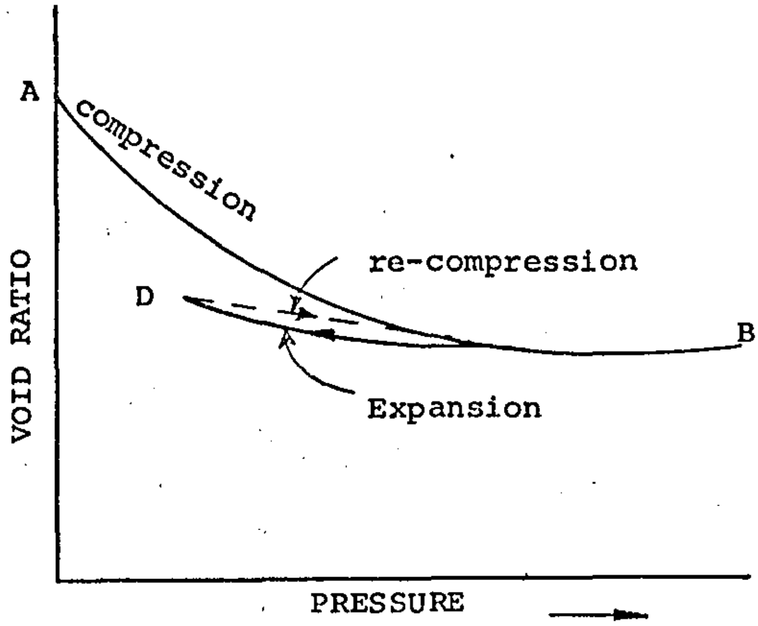


FIG. 8.8

8.4 CONCLUSIONS

The product from the designed extrusion plant is of better quality as compared with those produced from screw extruder. Figure 8.9 shows some products from the plant.

Drying tests done on some chromate pigment showed that the extrudate can be dried to 0.5 percent moisture content in a three bay convective dryer. Drying tests were not carried out on cadmium based pigment because the plant could not be installed over a cadmium pigment processing dryer since this would involve the removal of the existing extruder and its ancillary components long shutdown time and loss of production. However, cadmium pigment produced from the earlier prototype ram extruder showed a much better dryness quality than from the screw extruder[1].

The thixotropic nature of the pigment has no effect on the process and it can be rightly concluded that the designed plant can handle all the pigment in production by the sponsors.

For future work it would be advantageous to carry out a thorough study of chromate pigment flow characteristics during extrusion as was done for cadmium pigment.

It will be of interest not only academically but also to the pigment producing industries if a thorough study of the deformation behaviour of wet pigment particulate under stress could be carried out, the pressure distribution during extrusion and the flow characteristic of the pigment established.

Application for a British Patent was filed by Johnson Matthey, the parent company of the sponsors to cover the design of the plant on the 2nd of July 1981 and was accorded application Number 8120513, and is given in Appendix F.

The designed plant is working full-time on the chromate pigment production line at Cowan Colours Limited, London after mouthpieces (see section 7.4) were inserted in the extrusion cylinders.

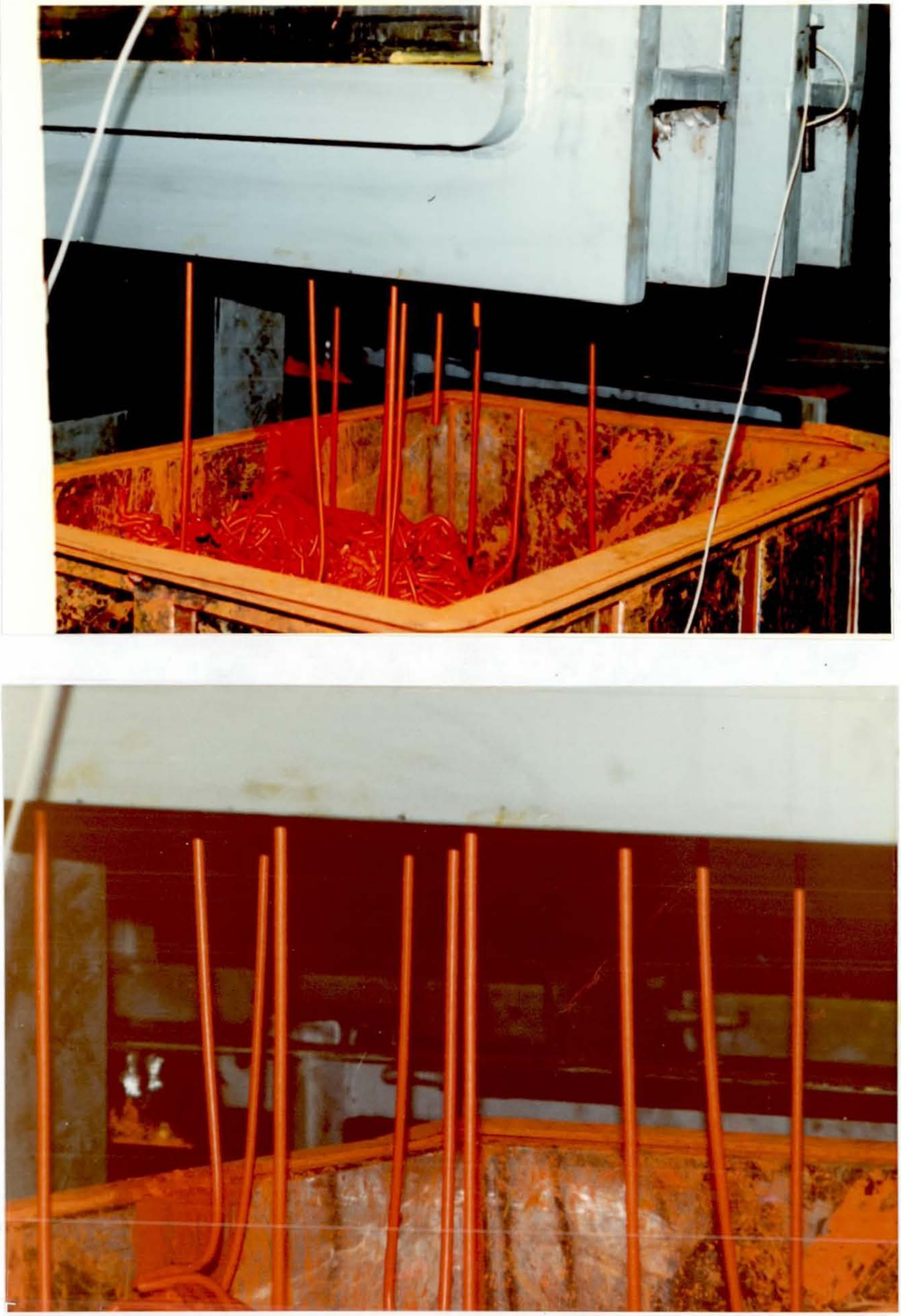


FIG 8-9

Some extrudate from the extrusion plant.

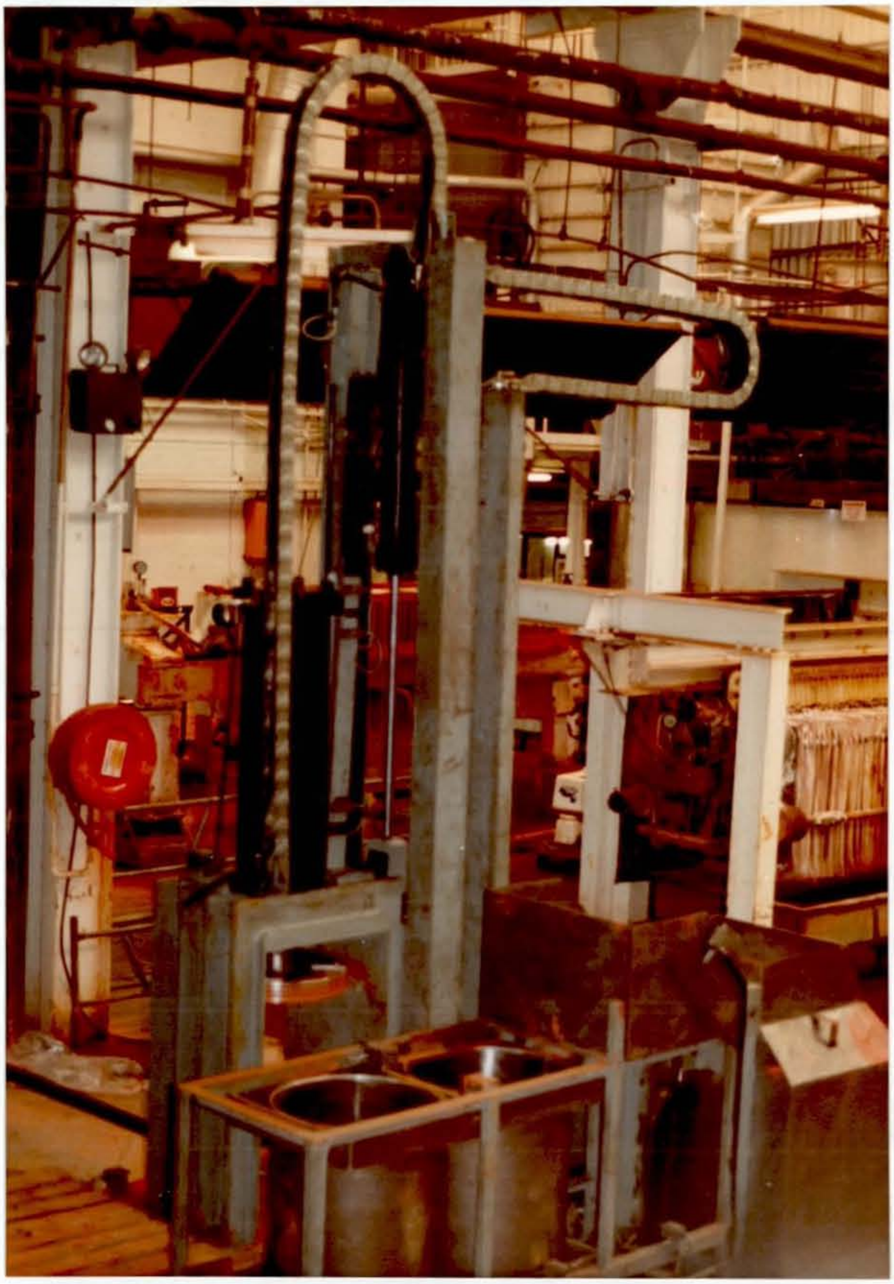


FIG 8-10
EXTRUSION PLANT

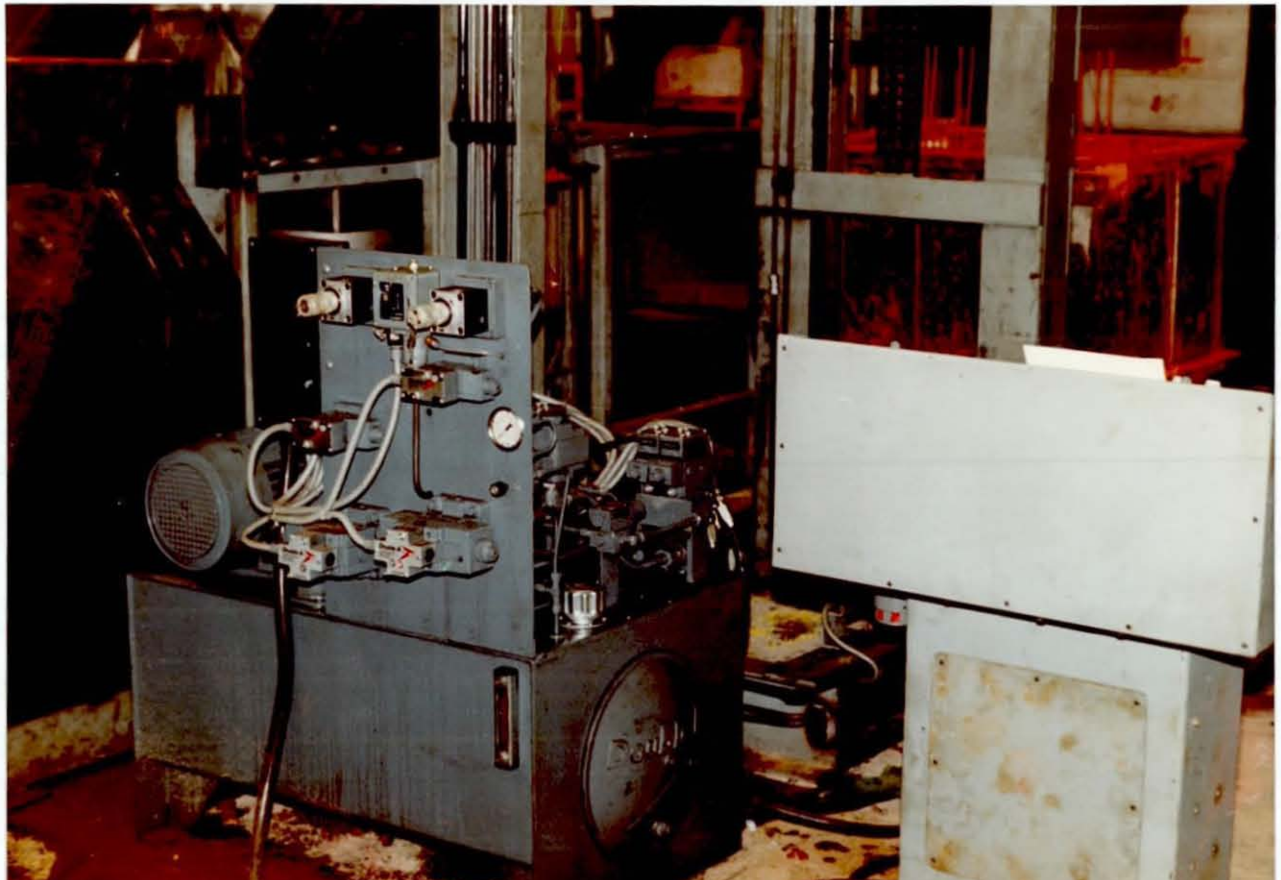


FIG 8-11

HYDRAULIC POWER PACK & BACK VIEW OF CONTROL CONSOLE

APPENDIX 'A'

EXTRUSION PLANT DESIGN SPECIFICATION

2.5.1 INTRODUCTION

This specification concerns the design of a new machine to preform the pigment paste delivered from the filter presses into a worm shape and load it on to the band conveyor of an industrial band dryer.

The input shall consist of filter cakes of pigment delivered to the machine in the currently used skips and the output shall be a preformed worm shaped paste laid down on the band with a depth and pattern having the best possible drying characteristics.

2.5.2 PERFORMANCE

The machine shall be capable of handling 240 kg/hr of pigment (wet weight) or 170 kg/hr (dry weight) with the possibility of a 25 percent increase in processing capacity.

The extrusion rate of the machine shall be adjustable to accommodate the various pigment in production. The speed shall be variable between 25 mm/min to 200 mm/min.

The machine shall incorporate a transfer unit which will transfer the filter cake in the skips into the extrusion cylinder used on the main machine.

2.5.3 ENVIRONMENT

High relative humidity due to vapour from drying pigment (20 - 100 percent RH). Temperature between 0°C and 30°C corrosive due to the material being processed.

2.5.4 LIFE EXPECTANCY

Ten years. Component parts may be maintained or replaced as necessary.

Recommended spares list required.

2.5.5 MIANTENANCE

Planned preventive maintenance shall be carried out.

The annual shut down is for two weeks during which major overhaul will be done.

All partS in contact with pigment paste will require cleaning at regular intervals, thus the equipment must therefore afford ease of access for cleaning which may be done manually with or without hoses.

Where possible in-situ cleaning is desirable.

Re-entrant features, grooves etc., which might trap pigment and give rise to undesirable mixing of pastes must be avoided.

Modular replacement of exchange parts and ease of access for critical parts should be features of the system.

All machine must be capable of being hosed down or washed.

2.5.6 TARGET COST

Capital cost £20,000 per unit.

2.5.7 QUANTITY AND MANUFACTURE

One prototype followed by four units, one for each production line will be required.

Conventional milling, turning, drilling, welding and fitting services are available in-house, but sub-contracting of parts will be considered if these facilities are inadequate.

2.5.8 SIZE AND WEIGHT

Within the limitations of space available for manoeuvreability of transporting equipment. See Drawing No. RG/K204 - L - 518A.

Pigment paste should preferably be introduced at a lower level than on existing system to reduce labour cost and loading time.

2.5.9 AESTHETICS AND APPEARANCE

The equipment shall have clean and pleasing lines and surfaces coloured in contrast with the system and must be free of pockets and ledges.

2.5.10 MATERIALS

The materials used must be resistant to the corrosive and erosive effect of the pigment, Stainless steel is considered to be a suitable material. Copper and alloy should be avoided.

2.5.11 STANDARDS AND SPECIFICATIONS

(i) H.M. factory Inspectorate technical data note 11 "Cadmium, Health and Safety Precautions".

(ii) H.M. factory Inspectorate technical data note 14 "Health, Dust in Industry".

(iii) Deposit of poisonous waste Act 1972.

(iv) Insurance regulations.

(v) Noise regulation.

2.5.12 ERGONOMICS

All manually operated items required for the operation of the plant shall be located at standard levels.

2.5.13 OPERATION OF PLANT

Six operators shall be made available to run four machines on the drying floor, two per shift.

The four machines can be attended to by a single operator.

No special qualifications are needed for the operators.

There shall be a plant engineer with a knowledge of programming the SYSMAC - P1 programmable sequence used as a controller in the plant control system.

APPENDIX 'B'

EXTRUSION PLANT HYDRAULIC SYSTEM SPECIFICATION

Issue No. 2:

1. INTRODUCTION

This specification amplifies and clarifies some points set out in BS 4575 Part 1 1979 "British Standard Guide for application of fluid power equipment to transmissions and control systems" - Part 1 Hydraulic Systems.

A hydraulic system to power and control an extrusion plant is required. Solenoid valves shall be remotely controlled by the output of a programmable sequencer.

The initial requirement shall be one off, with a view to purchasing at least a further three after the plant has been proven satisfactory.

2. EXTENT OF SUPPLY

2.1 Design

The design shall be as depicted on drawing No. 79W0041/1 issue 1 of 3rd March 1980.

2.2 Manufacture

The manufacture of component parts and assembly will be put in the hands of the supplier. Components shall be as specified below or approved equal. The power unit and control valves should be supplied preferably as a single assembly.

CUSTOMER

The customer shall be Blythe Colours Limited, Albion Works, Liverpool Road East, Stoke-on-Trent.

TESTS

The system shall be tested to ensure that it conforms to the designer's performance requirement.

3. GENERAL

3.1 Specifications

Design submitted will comply with ISO 4413 - 1978, which is identical to BS 4575 Part 1 - 1979.

3.2 Safety

3.2.1 Failsafe

The extrusion ram and lifting ram subcircuit shall be provided with counterbalancing valves and pilot operated check valves. A pilot operated check valve shall also be provided on the tipping ram subcircuits. These check valves shall be located on or close to the rams. All components shall be selected, applied , fitted and adjusted to ensure that the system is failsafe.

3.2.2 Application concept

(a) All components within the system shall operate within their manufacturers' specifications, and must meet the system specification requirement.

(b) All parts of the system shall be protected against over-pressure.

(c) The control system should be constructed as a single unit, with all valves or valve panels mounted on the power unit. Components shall be located in such a manner that they are accessible, and can be safely adjusted and serviced.

(d) Circuits shall be constructed to minimize surge pressure.

(e) Surge pressure or lack of pressure shall not cause hazards.

3.3 System specification requirements

3.3.1 Valves

(a) V01 - Check valve on extrusion ram subcircuit

Nominal flow capacity	15 gpm
Nominal valve size	½"
Rated pressure	3000 psi
Type	Double A type AA-04-10A1 or approved equal

V03 and V04 - Check valves

Nominal flow capacity	10 gpm
Nominal valve size	⅜"
Rated pressure	3000 psi
Type	Double A type AA-03-10A1 or approved equal

(b) V02 and V03 - Counterbalancing valves

Max operating pressure	3000 psi
Adjustment range	50 to 3000 psi
Adjustment sensitivity	700 psi/turn
Internal leakage	7 cipm/1000 psi
Repeatability	½% of setting
Nominal flow	10 gpm
Envelope pressure rating*	
Fatigue	3300 psi
Static	8000 psi
Nominal valve size	⅜"

* Varification of fatigue and static pressure of the pressure containing envelope shall conform to NFPA recommended standard NFPA/T2.61 - 1974 category 1/90

Type ..... Double A type BQP-03 10A1 or approved equal

(c) CV01-Control manifold with 3 selectable flow rates

This unit should consist of two flow control valves and two solenoid operated directional valves. The flow control valves shall conform to the following specification and must be pressure and temperature compensated.

Controlled flow minimum	0.008 l/min
maximum	18 l/min
Free reverse flow	36 l/min
Operating pressure	3000 psi

Pressure compensation shall be within ± 0.5% to ± 3% of setting with lock and key adjustment combined.

Type .... Double A type QXA-005-LC---T--10A1 or approved equal

The solenoid operated directional valves shall conform to the following specification.

Two position spring-offset spool

Nominal flow capacity	5 gpm
Max. flow without malfunction	7 gpm
Max. operating pressure	3000 psi
Response time	0.008 sec.
Solenoid type	220V 5¼Hz
Inrush/holding current	1.1/0.23 amp.

Type .... Double A type QG-005-P-10B1-220/50 or approved equal

(d) CV02 Pressure reducing valve

Operating pressure	3000 psi
Adjustment range (rated flow)	50-3000 psi

Nominal flow capacity	50 gpm
Type	Double A type WOP-03-C-10A3 or approved equal

(e) CV03 Pressure reducing valve

Rated operating pressure	3000 psi
Adjustment range	50-3000 psi
Nominal flow capacity	10 gpm
Type	Double A type WQP-03-10A1 or approved equal

<u>(f) SV1 to SV7 Solenoid operated directional valves</u>

	SV01 & SV07	Others
Operating pressure	3000 psi	3000 psi
Max flow without malfunction	19 gpm	7 gpm
Nominal flow	12 gpm	5 gpm
Solenoid type	220V 50Hz	220V/50V
Inrush holding current	1.62/0.47 amp.	1.1/0.23 amp
Response time	0.015 sec.	0.009 sec.

Type	Double A-
SV01	QF-01-FF-10F1-220/50
SV02	QF-005-C-10B1-220/50
SV03	QF-005-FF-10B1-220/50
SV04	QF-005-C110B1-220/50
SV05	QF-005-C-10B1-220/50
SV06	QF-005-FF-10B1-220/50
SV07	QF-01-C-10F1-220/50

(g) CV04 to CV08 Dual flow regulator

Operating pressure	3000 psi
Check cracking pressure	20 psi
Max. flow	12 gpm
Type	Double A type NNYYC-01-10A1 or approved equal

(h) V05 Lifting subcircuit counterbalancing valve

Max. operating pressure	3000 psi
Flow rate	12 gpm
Adjustment per rev.	650 psi
Repeatability	0.5% of full range
Pressure adjustment range	70 - 3000 psi
Type	Double A type NNCCC-01-3K--10A1 or approved equal

(i) CV9 Unloading valve

Max. operating pressure	3300 psi
Adjustment range	75 to 3000 psi
Adjustment sensitivity	700 psi/turn
Internal leakage	7 in^3/min/1000 psi
Repeatability	0.5% of setting
Type	Double A type B-06-H1-10A3 or approved equal

(j) V06 Check valve - direct acting in-line

Nominal flow capacity	15 gpm
Rated pressure	3000 psi
Nominal size	½"
Type	Double A type DL-04-10A1 or approved equal

3.3.2 Hydraulic rams.

3.3.2.1. Ram requirements.

	Extrusion ram	Lifting ram	Positioning ram	Transverse loading ram	Longitudinal positioning ram	Tipping ram
Cylinder bore dia.	250mm (10")	100mm (4")	100mm (4")	38mm (1½")	38mm (1½")	100mm (4")
Piston rod dia.	140mm (5½")	45mm (1¾")	45mm (1¾")	25mm (1")	25mm (1")	45mm (1¾")
Length of stroke	1000mm (39½")	1100mm (43½")	1000mm (43½")	1400mm (55")	853mm (34")	550mm (22")
Operating pressure	21 MPa (3000 psi)	21 MPa (3000 psi)	21 MPa (3000 psi)	7 MPa (1000 psi)	7 MPa (1000 psi)	21 MPa (3000 psi)
Type of mounting rod end	Square flange	-	Side tapped	Rectangular flange	-	-
Type of mounting at cap	-	Fixed clevis	Side tapped	-	Rectangular cap	Fixed clevis
Length of stop tube	-	-	-	75mm (3")	75mm (3")	-
No. of required cushions	2	2	2	2	2	2
Accessories	-	-		-	-	Female eye rod end
Selected rams or approved equal	Double A * N2J 10/5½" X 1000mm	Double A N2C 4/1¾" X 1100mm	Double A N2B 4/1¾" X 1100mm	Double A R2F 1½/1" X 1400mm	Double A R2B 1½/1" X 853mm	Double A N2C 4/1¾" X 550mm

* Fitted with flared lip urethane piston seals.

Location of feed port on each ram shall be such that will permit easy access when system is fully assembled - see dwg. 79W0077 for detail.

(k) CV10 Relief valve

Max. operating pressure	3000 psi
Adjustment range @ rated flow	75-3000 psi
Adjustment sensitivity	700 psi per rev. of adjustment screw
Internal leakage	4.5 in^3/min/1000 psi
Repeatability	0.5%
Rated flow	50 gpm
Type	Double A type B06-10A3 or approved equal

3.3.2.2 Protection

Each ram shall be provided with rod wiper to provide dirt protection for the rod bearing and rod seal.

Piston rods shall be chrome plated and the surface polished to a 6-10 micro-inch finish.

Cylinders shall be made from high strength steel honed and polished internally to a 10-15 micro-inch finish.

3.3.3 Hydraulic power unit

The hydraulic power unit shall comprise:

Low pressure pump 20 l/min @ 1000 psi, coupled to a High pressure pump 2 l/min @ 3000 psi

Motor - 4hp, 415V, 50Hz running @ pump speed

Suction strainer

Air breather and filler cap

Temperature indicator

Pressure indicator

Level indicator

Clean out cover

Return line filter, 1 micron, with electrical clogging indicator.

3.3.4 Maintenance data

The supplier shall provide maintenance data for all hydraulic equipment which clearly:

(a) Describes start up and shut down procedure.

(b) Describes adjustment procedures.

(c) Indicates external lubrication points and the type of lubricant required.

(d) State maintenance procedures for unique assemblies.

(e) Locates flüid level indicators, full points, drains, filters, test points, strainers, magnets etc., that require regularly scheduled maintenance.

(f) Gives instructions for fluid maintenance.

(g) Gives further identification of parts in the hydraulic components supplied which are commercially available or manufactured to an internation standard that provides for uniform coding; the identification shall be the part manufacturer's Part Number , or as provided by the Standards Code.

(h) List recommended spare parts.

3.3.5 Data to be provided by the supplier

(a) Final diagrams, drawings and text, including the Maintenance Data, shall conform to the equipment shipped and forwarded to the purchaser not later than the time of delivery.

(b) Final diagram of the system shall be supplied to the purchaser on reproducible material which shall not be folded.

APPENDIX 'C'

EXTRUSION PLANT TEST SPECIFICATION

Issue No. 1

Test shall be carried out to ensure that the plant satisfies the product specification.

The test shall be made by visual inspection and physical measurements as detailed below.

<u>Visual inspection</u>

Visual inspection of the machine shall be carried out to ensure that it satisfies the maintainability, ergonomic and aesthetic as specified in the product specification.

<u>Functional test</u>

The programmable sequence controller shall be programmed for the control sequence required as shown in the process flow-chart (page162)and the operation of the machine observed. The following tests shall be carried out.

(i) <u>Control sequence simulation</u>

Prior to fitting the sequence controller in the control panel, limit switches shall be connected to the input of the controller and system program (as shown on page 117) shall be entered into the controller. By activating the limit switches in accordance with the process flow diagram (page162)the output LED (light emitting diodes) on the controller shall be observed and shall follow the required output, as stipulated in the process flow diagram under control output activated.

(ii) <u>Dynamic test</u>

With the plant completely assembled and the control system wired as shown in the circuit diagram 79W0079, the operating program shall again be entered into controller, and the response of each ancillary part of the machine shall be observed. All moving parts of the machine shall move without jamming or judder and shall operate as required in the process flow diagram. Each ram speed shall be set to the optimum level of operation.

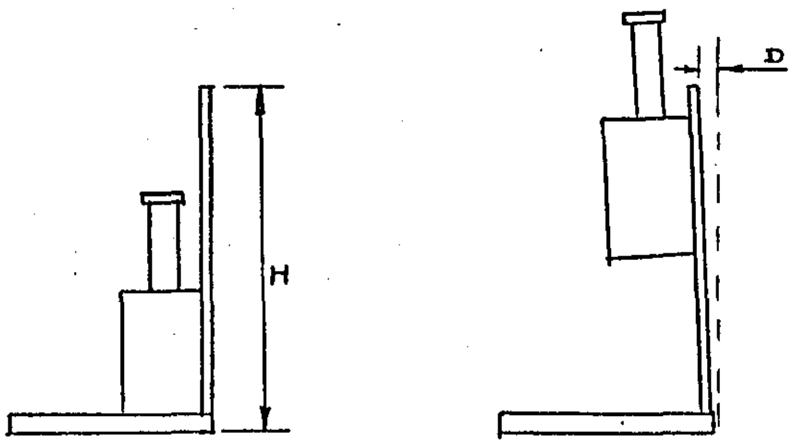
(iii) Safety test

The cradle in the handling system shall be activated to simulate a tipping operation and the interlocking switch 'ILSW' shown in drawing no. 79W0076 deactivated to simulate the opening of the lock gate. This action must stop the movement of the cradle.

A switch shall be inserted in place of the band dryer belt interlock contactor. When this switch is opened, it should put the machine into a state of suspended animation only during the extrusion stroke, other systems functions shall remain operational.

Static test

With the extrusion frame fully lowered, the position of the mast shall be noted (as shown in the Figure below. The extrusion frame shall then be lifted to the maximum height with a weight of 250 kg attached to the frame, or loaded into it. The mast position shall again be noted. The ratio of the deflection D and the height of the mast H shall not exceed 0.001.



Performance test

The performance test shall be carried out with the machine installed over a band dryer.

Prior to loading a cylinder charged with pigment into the extrusion frame, two empty cylinders shall be placed in the handling system. The system program (Table 6.1) should be now entered into the controller, the controller put in Auto Mode and started. The machine shall be observed to follow the necessary operating sequence.

The machine shall be allowed to perform one hundred full operations and the number and type of failures noted.

Possible failures are:

(a) Cylinder stuck whilst being pushed out of the extrusion frame.

(b) Cylinder not well aligned for loading into extrusion frame.

(c) Piston entry into cylinder failure.

If any of these failures should occur, the controller shall be observed to carry out the necessary safety routine, as outlined in sections E,F,G and H of the process flowchart.

TEST CHART

EXTRUDER

Run no. ....

Product .... Batch no..............

Extruder speed setting ....

Extrusion speed ....

PISTON DISPLACEMENT	EXTRUSION PRESSURE			COMMENTS ON QUALITY, LEAKS, ETC.
	INLET	OUTLET	DIFFERENCE	

SPEED SETTINGS

Longitudinal Ram Speed Setting

Forward setting	CVO 6 - A ____	Average ram speed ____
Reverse setting	CVO 6 - B ____	Average ram speed ____

Transversing Ram Speed Setting

Push setting	CVO 7 - A ____	Average ram speed ____
Pull setting	CVO 7 - B ____	Average ram speed ____

Tipping Ram Speed Setting

Lift setting	CVO 8 - A ____	Average ram speed ____
Lowering setting	CVO 8 - B ____	Average ram speed ____

Lifting Ram Speed Setting

Lift setting	CVO 4 - A ____	Average lifting speed ____
Lowering setting	CVO 4 - B ____	Average lowering speed ____

Panning Ram Speed Setting

Pan out setting	CVO 5 - A ____	Average out speed ____
Pan in setting	CVO 5 - B ____	Average in speed ____

APPENDIX 'D'

DEFINITION OF CONTROLLER INSTRUCTION CODE AND OPERATING SWITCHES

The following are definitions of the controller OP (instruction) codes together with descriptions of respective instructions.

NOP (NO - OPERATION)

This instruction instructs the sequence controller to do nothing, except to proceed to the next step. Use of this instruction is convenient for steps which become unnecessary due to changes in the process.

END (END)

This instruction indicates the completion of one processing cycle.

RET (RETURN)

In the event of a power failure (or external interruption) this instruction causes the sequence controller to memorize the step being executed. Upon depression of the START switch the step before the power failure (or external interruption) restarts.

JMP (UNCONDITIONAL JUMP)

This instruction causes the program to jump to the step specified by DATA - 1 to resume the program execution from that step.

AND (AND)

When two input signals specified by DATA - 1 and DATA 1 2 are present, the program proceeds to the next step.

OR (OR)

When either of two input signals specified by DATA - 1 and DATA - 2, whichever comes first is present, the program proceeds to the next step.

CNT (COUNTER)

When the counting is performed up to the count value specified by DATA - 1 (a maximum of 63 counts) at the input specified by DATA - 2, the program proceeds to the next step.

CJP (CONDITIONAL JUMP)

When the input signal condition specified by DATA - 2 is satisfied the program proceeds to the step specified by DATA - 1. When input signal condition is not satisfied the program proceeds to the next step.

RPT (REPEAT)

The program is repeated as many times as that specified by DATA - 1 (a maximum of 63 times) from the step specified by DATA - 2 to the present step.

TIM (TIMER)

The program proceeds to the next step after the lapse of the time specified by DATA - 1 (in units of minutes) and by DATA - 2 (in units of seconds) respectively.

2TM AND (TIME TOGETHER WITH AND)

When the input specified at the second step following the 2TM instruction is present after the lapse of time specified at the first step, 2TM instruction, the program proceeds to the next step.

2TM OR (TIME TOGETHER WITH OR)

When the time specified at the first step, 2TM instruction, has lapsed, or when any of the input specified in the second step following the 2TM instruction, whichever comes first, is present, the program proceeds to the next step.

2LG AND (4 INPUT AND)

When both the two input specified at the first step (2LG instruction) are present and both the two input specified in the second step following the 2LG instruction are present, the program proceeds to the next step.

2LG OR (4 INPUT OR)

When any of the input specified in the first step (2LG instruction) is present or any of those specified in the second step present, the program proceeds to the next step.

NAME AND FUNCTIONS OF OPERATING SWITCHES

On the front panel of the controller operating switches are provided for writing, reading, and executing programs and operating the sequence controller, in the automatic or manual mode. These switches are also wired to the front panel of the control console so that they can be remotely operated.

AUTO/MANU selector switch

AUTO ...... Automatic operation mode

MANU ...... Manual operation mode.

OUT INH/RESET Selector switch

OUT INH ...... Used to inhibit output in program checking.

RESET

(1) With the PRO CON switch turned on setting the selector

switch to the "RESET" position causes the controller to reset to step 00.

(2) With the PRO CON switch turned off, setting the selector switch to the "RESET" position causes the controller to reset to step 01. The resetting function becomes effective only when the STOP switch is ON.

START/STEP switch

In the automatic mode, turning this switch on causes the program step execution to start, whereas in the normal mode, one program step is executed each time the switch is turned on.

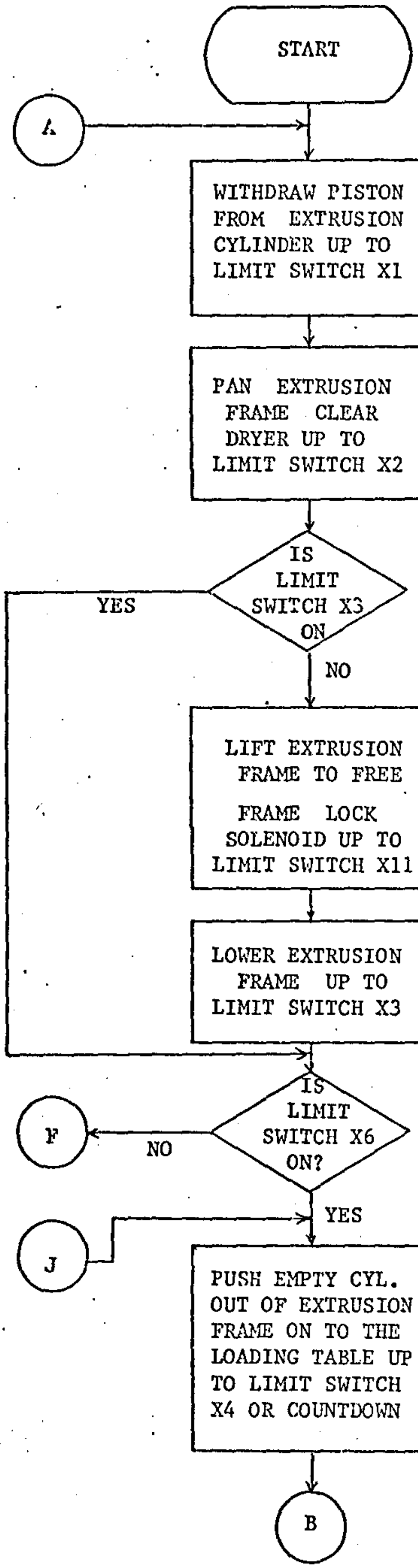
STOP switch

Used to stop the program execution and prevent output transfer to an external device.

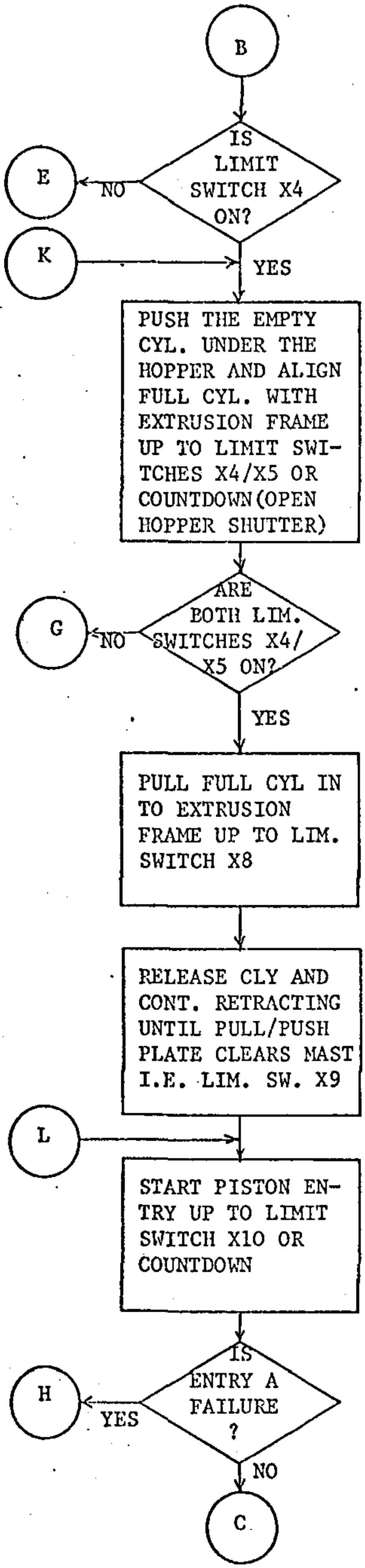
NOTE: In the manual operating mode the program does not advance even when all input conditions are met unless the STEP switch is actuated.

APPENDIX 'E'

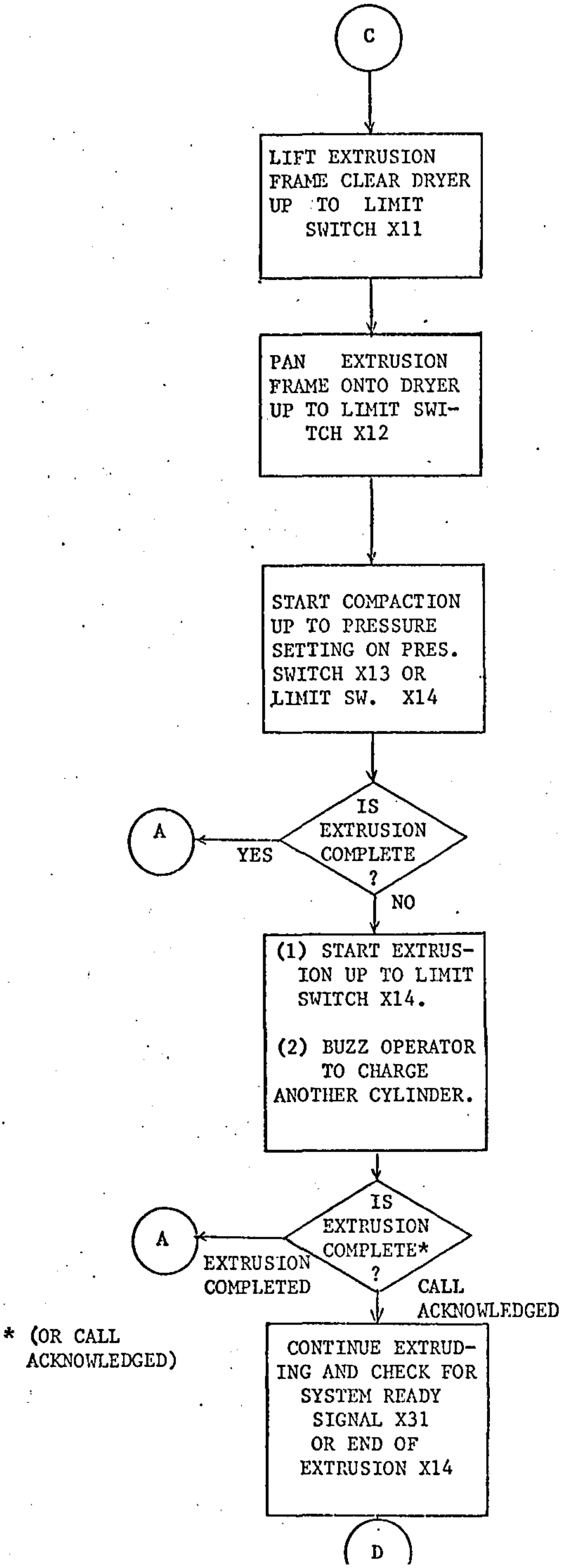
PROCESS FLOW DIAGRAM



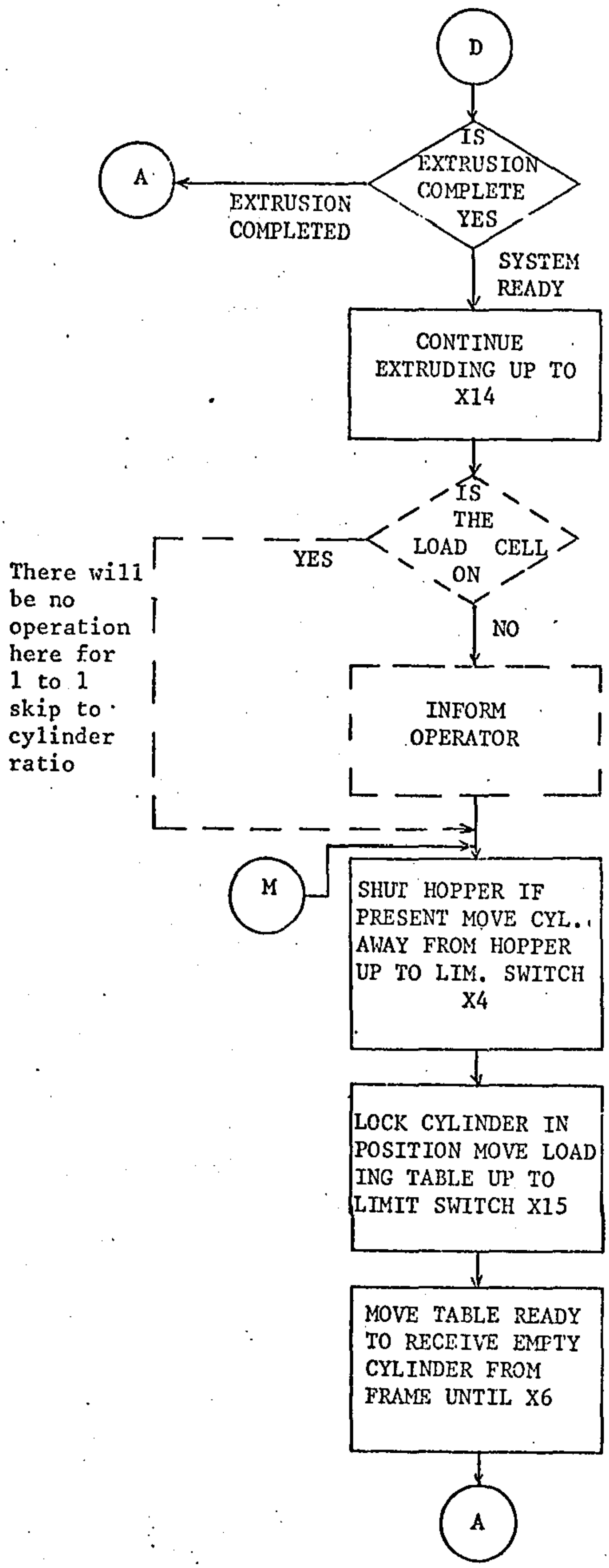
CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
1	Hydraulic pump
2	Sol. valve SV01-A
1	Hydraulic pump
4	Sol. valve SV02-A
1	Hyd. pump
7	Sol. valve SV03-B
12	Frame lock solenoids
1	Hyd. pump
6	Sol. valve SV03-A
12	Frame lock solenoids
1	Hyd. pump
10	Sol. valve SV05-A



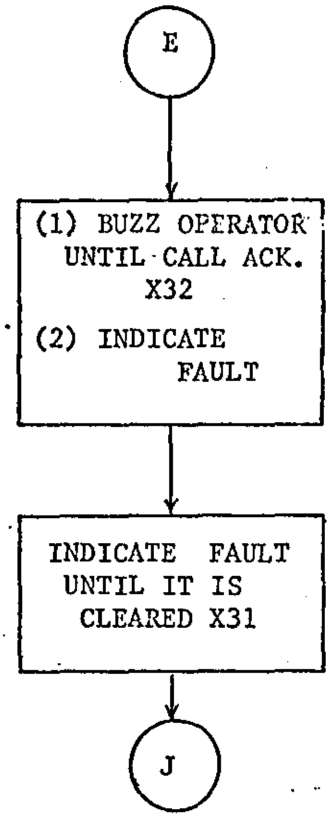
CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
1	Hydraulic pump
8	Sol. valve SV04-A
13	Pull Solenoids
1	Hydraulic pump
11	Sol. valve SV05-B
1	Hydraulic pump
11	Sol. valve SOV5-B
13	Pull solenoids
1	Hydraulic pump
18.	Sol. valve SOV7-B
14	Sol. valve CV01-A

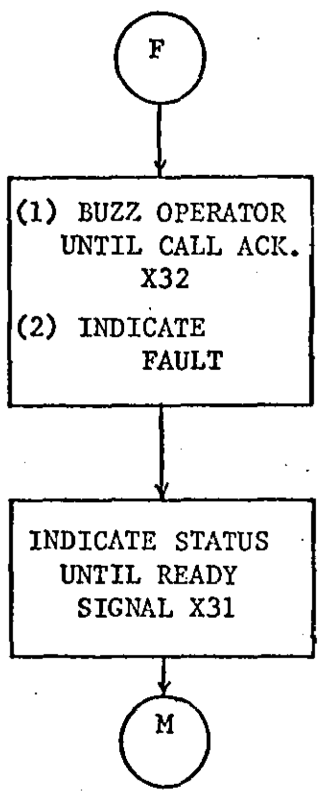


CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
1	Hyd. pump
7	Sol valve SV03-B
12	Frame lock solenoids
1	Hyd. pump
9	Sol. valve SV02-B
1	Hyd. pump
3	Sol. valve SV01-B
14	Sol. valve CV01-A
1	Hyd. pump
3	Sol. valve SV01-B
25	Buzzer
26	Cyl charge request light
1	Hyd. pump
3	Sol. valve SV01-B
26	Cyl. charge request light

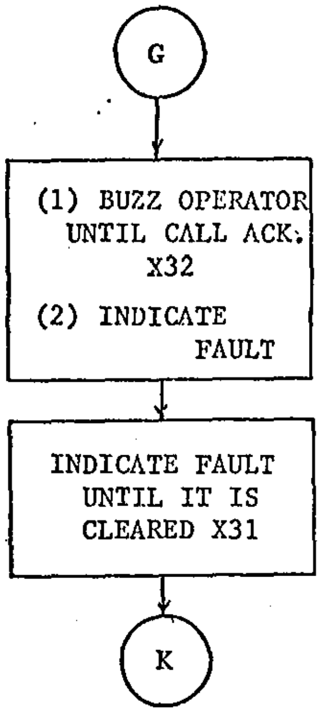


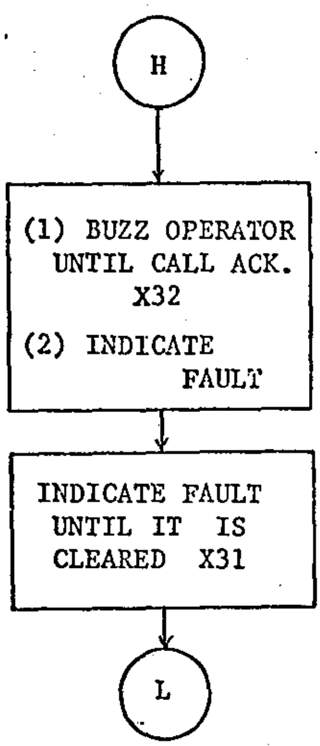
CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
1 3	Hyd. pump Sol. valve SV01-B
1 9	Hyd. pump Sol. valve SV04-B
1 8 15	Hyd. pump Sol. valve SV04-A Cyl. lock solenoids
1 9	Hyd. pump Sol. valve SV04-B





CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
25	Buzzer
27	Indicator light, cyl. stuck on ejection
27	Indicator light, cyl. stuck on ejection
25	Buzzer
28	Loading table empty ind. light
28	Loading table empty ind. light





CONTROLLER OUTPUT ACTIVATED	CORRESPONDING CONTROL ELEMENT ACTIVATED
25	Buzzer
29	Cyl's not well aligned indicator light
29	Cyl's not well aligned indicator light
25	Buzzer
30	Piston entry failure indicator
30	Piston entry failure indicator

APPENDIX 'F'

PATENT SPECIFICATION

Issue No. 2

"EXTRUSION PROCESS AND APPARATUS"

This invention relates to means for extrusion of a plastic material and particularly provides means for extrusion of such a material comprising a pigment or a precursor thereof and water on to the moving conveyor belt of a belt drying oven.

In the manufacture of pigments and particularly inorganic pigments such as cadmium sulphide pigments, one or more filtration and drying operations are required. In the drying operation, it is the usual practice to extrude filter cake containing generally between 40% and 60% by weight of water by means of a screw extruder and to allow the extrudate, which has the form of a filamentary or cord-like plastic substance, to settle under the influence of gravity on to the moving conveyor belt of a belt drying oven. Ideally, the consistency of the extrudate is such that it retains its three dimensional form and settles on to the belt in a randomly-orientated mass of filament or cords, thus providing a high surface area and air being thus able to circulate readily through the mass to effect efficient drying. The speed of the belt may be adjusted relative to the speed of extrusion to allow control to be exercised over the depth of the extrudate on the belt.

One disadvantage of screw extruders is that extrusion pressure is applied only to that portion of material actually in the barrel of the extruder and in consequence any local zones of inhomogeneity in respect of water content of the material affect the quality of the extrudate, leading to poor drying, or the efficiency of the extrusion operation. Thus, a zone of excessive wetness will be extruded as a flowable material, or even as a slurry, which will not retain its three-dimensional form on the conveyor belt and will in consequence not be properly dried. A zone of excessive dryness, on the other hand, will tend to block the extrusion holes of the extruder.

We have now found that this disadvantage may be overcome by applying extrusion pressure to a larger volume of material by means of a ram, any local zones of inhomogeneity thus being eradicated before the extrusion operation is performed.

According to one aspect of the invention, therefore, we provide a process for extrusion of a plastic material comprising supplying the material to a loading/unloading station in a container a wall of which has one or more holes for extrusion formed therein, moving the container to an extrusion station and, thereafter, applying extrusion pressure to the material by means of a ram.

Preferably, pressure is applied in two stages, in which a lower pressure than that required for extrusion is first applied to compress the material and to cause any excess wetness, for example, to be exuded, and in which a higher pressure is then applied for extrusion.

We have found that pressure exerted by the extrusion ram is sufficient to compress substantially the entire charge of plastic material in the container prior to extrusion to an extent sufficient to eradicate any local zones inhomogeneity with respect to water content in the charge. Any excess water in local zones is either distributed substantially throughout and taken up by the remainder of the charge or is expelled through extrusion holes prior to extrusion of the plastic material. The remaining plastic material, on extrusion, has a consistency such that it retains its three diemsnional form and settles on the belt in a randomly-oriented mass of filamentary or cord-like material which provides a high surface area for drying air to circulate readily throughout the mass. A further advantage is that higher extrusion pressures obtained with apparatus according to the invention compared with prior art extruders such as screw extruders result in extrudate being more compact and hence stronger and less prone to collapse or breakage on the conveyor belt.

According to a second aspect of the invention, apparatus for extrusion of a plastic material comprises a container for holding a quantity of material and having one or more extrusion holes formed in a wall thereof and being adapted for location in a cage movable between a loading/unloading station and an extrusion station, and ram means which can be entered into the container for exerting pressure on the material at least when the container is at the extrusion station.

Preferably, apparatus according to the invention is used in combination with a conveyor belt or other carriage means for receiving extruded material, for example, the belt of a belt drying oven, and the loading/unloading station is located at or near floor level and the extrusion station is located above the belt so that the extrudate settles under the influence of gravity on to the belt.

The container may have for convenience the form of a hollow right circular cylinder closed at one end, extrusion holes being formed substantially longitudinally through the closed end, holes additionally or instead being formed radially through the cylindrical wall. One or more dowels are preferably provided on the underside of the container for location of the container in the cage. The ram preferably comprises a piston which can be entered into the cylinder through the open end and which is a sliding fit within the cylinder, suitable sealing means such as one or more spring rings being provided circumferentially around the piston. The piston is connected via a piston rod to activating means which may be screw-operated, hydraulically operated or the like. We prefer to use a double-acting hydraulic cylinder and piston assembly which may act directly or indirectly on the ram.

The cage preferably comprises a reinforced framework having a base and a roof section and at least one open side for facilitating loading with and unloading of the container. The base of the cage is provided with one or more holes generally larger in diameter than the extrusion holes of the container and positioned to be in registration with the said extrusion holes when the container is correctly located on the base of the cage and, when locating dowels are fixed to the underside of the container, is further provided with one or more corresponding holes for receiving the dowels.

One way of providing movement between loading/

unloading and extrusion stations is to mount the cage on a pylon for longitudinal sliding movement relative thereto, in a substantially vertical plane, the pylon being itself carried on a chassis for longitudinal sliding movement relative thereto in a substantially horizontal plane. Movement of the pylon and the cage relative to the pylon is each preferably provided by means of a respective ram, for example, a hydraulic ram, which may act either directly or indirectly. Alternatively and preferably, movement of the cage on the pylon is controlled by means of a hydraulically-operated piston mounted substantially parallel to the longitudinal axis of the pylon and in the region of the upper end thereof, the lower end of the piston having attached thereto a pulley, one end of a chain or other flexible support means being attached to a mounting point towards the lower end of the pylon and the other end being passed over the pulley and attached to the cage, thus imparting a mechanical advantage to the movement of the cage relative to the movement of the piston.

Means for activating the extrusion ram may be mounted either on a structure fast with the upper end of the pylon so that the activating means is in registration with the ram when the container in the cage is at the extrusion station or, alternatively, activating means may be mounted directly on the cage. The latter arrangement is to be preferred due to the ram thus being capable of being securely attached to the ram activating means irrespective of the presence or absence of a container in the cage and irrespective of whether the cage is at the extrusion station or at some other location.

To facilitate loading and unloading of the cage, locating dowels when fixed to the underside of the container are each provided at the lower end with a spherical castor or other bearing means and the pylon base section is provided with upstanding pegs corresponding in number and relative position with the container dowel locating holes in the base of the cage. Thus, with the cage at the loading/unloading station at the lower end of the pylon so that the underside of the cage rests on the pylon base section, the pegs fit into the said locating holes and thereby displace the locating dowels of a container in the cage. Each peg is adapted to have a substantially flat upper surface which is flush with the floor of the cage when the latter is at the loading/unloading station so that a container can be rolled on its spherical castors either in to or out of position relative to the pegs and hence to the locating holes.

The apparatus is suitable for use with a plurality of containers to minimize downtime during container charging and handling operations. Thus, a container handling system suitable for use with apparatus according to the invention may include a charging station for charging an empty container with material to be extruded, and a holding station for holding a charged container pending loading into the cage of the apparatus, together with means for simultaneously removing an empty container at the loading/unloading station and transporting it to the charging station, transporting a charged container from the charging station to the holding station and transporting a further charged container from the holding station to the loading/unloading station.

Apparatus according to the invention will now be described by way of example with reference to the accompanying drawings, of which:-

Fig. 1 is a perspective view;

Fig. 2 is a section along the line II - II of Fig. 1;

Fig. 3 is a section along the line III - III of Fig. 1

Fig. 4 is a diagrammatic sectional view of the container located in the base of the cage;

Fig. 5 is a diagrammatic sectional view of the container at the loading/unloading station;

Fig. 6 is a diagrammatic illustration of the loading/unloading and extrusion stations, and

Figs. 7 and 8 show the location of limit switches on the apparatus.

Referring to Fig.1, apparatus according to the invention is shown consisting essentially of a chassis 11, a pylon comprising an upstanding section 12 and a base section 13, and a cage 14. Chassis 11 comprises a pair of longitudinal channel girders 15 suitably end-braced by girders 16 and 17. The inwardly-facing web surfaces of girders 15 are each provided with a runner 18 (one side only shown) for sliding movement of the pylon thereon (see also Fig. 2). The runners extend longitudinally between end girder 16 and an intermediate cross-element 19.

The pylon upstanding section 12 comprises a pair of fabricated structures 20 suitably cross-braced at their ends (21 and 22) and at intermediate locations (23 and 24).

The upstanding section is rigidly secured to base section 13 which comprises a girder framework consisting of a pair of longitudinal angle girders 25 cross-braced at their ends, cross-brace girder 26 being remote from the upstanding section and cross-brace girder 22 being common with the lower end cross bracing girder of the upstanding section. The base section (see also Fig.2) is adapted to slide longitudinally between chassis girders 15 and is carried for this purpose on runners 18. Wheels or rollers 27 (shown in dotted outline in Fig.1) are provided on the outside of angle girders 25 for facilitating such sliding movement, which is controlled by means of piston rod 28 acting on cross-element 19 and powered hydraulically by two-way hydraulic cylinder 29.

The cage 14 consists essentially of a base member 30 and a roof member 31 held in spaced-apart relationship by means of a reinforced framework comprising end members 32 and intermediate reinforcing ribs 33. The cage is open-sided on at least one side for providing access for loading and unloading containers. The base is provided with four holes 34 (three only visible in Fig.1) for receiving locating dowels on the underside of the container. Further holes 35 are provided for passage therethrough of extruded material. A double-acting hydraulic cylinder 36 is secured to the roof of the cage and is connected with piston 37 for exerting ram extrusion pressure on the material in the container. The cage is mounted for longitudinal sliding movement with respect to the pylon upstanding section by means of rollers adapted to roll on the inner sides of the channel sections of the longitudinal fabricated structures, the roller axles being secured by nuts 38 to plates 39 attached to the cage. Sliding movement is controlled by double-acting hydraulic cylinder 40 the piston rod of which is connected to a pulley 41 over which passes chain 42 secured at one end to the pylon at 43 and at the other end to the base of the cage.

Fig. 2 is a cross-section through the chassis and pylon base member to show the arrangement of the runners and the wheels. In addition to elements 15, 18, 25 and 27 already referred to, Fig.2 illustrates a longitudinal plate 44 secured to the upper surface of each girder 15 for acting as a cover for the runners and longitudinal bearing strip 45 secured to the inward-facing edge of each runner to prevent skewing of the pylon base section between the chassis longitudinal girders with consequential interruption to smooth running. The material of the bearing strip may be, for example, white metal or nylon.

Fig. 3 is a cross-section through the pylon showing part of the cage and the means by which sliding movement of the cage relative to the pylon is facilitated. The fabricated structures 20 each comprise a box girder 46 to which is attached a pair of longitudinal plates 47 to create longitudinal channel sections which are arranged to be inwardly facing. To the cage 14 is attached a pair of plates 39 on which there are rotatably mounted, by means of nuts 38, rollers 48 which bear on the inner sides of the channel sections. Elements 24 and 25 are respectively a pylon cross-brace and pylon base section longitudinal girders (see Fig.1).

Figures 4 and 5 are schematic representations of the containers. In Fig.4, the container 49 is located in and is supported by the base 30 of the cage, locating dowels 50 being positioned in holes 34 (see Fig.1). Extrusion holes 51 are in registration with larger diameter holes 35 formed in the base of the cage. The dowels are equipped with spherical castors 52.

In Fig.5, the container is shown at the loading/unloading station standing with spherical castors 52 on upstanding pegs 53 located in a member itself secured to the base section of the pylon, the pegs having displaced the locating dowels 50 from holes 34 as the cage was lowered on to the said base section, the upper surface of pegs 53 being essentially flush with the floor (i.e. the upper surface of the base 30) of the cage to facilitate loading and unloading of the cage by rolling the container on castors 53.

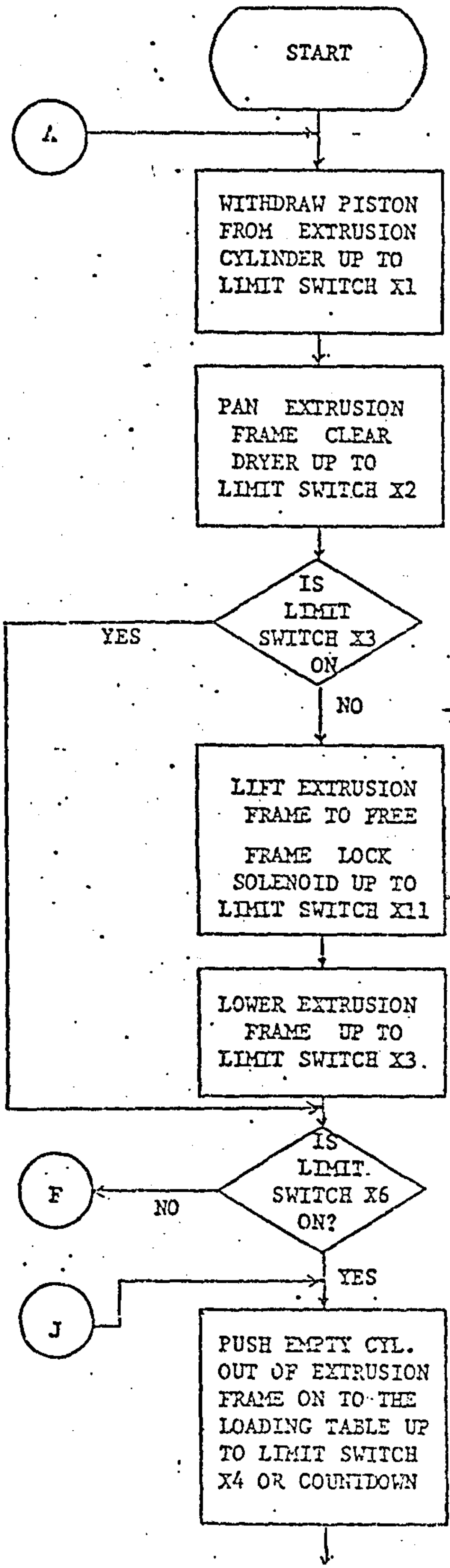
Figure 6 comprises two diagrams 6A and 6B showing the apparatus schematically in the loading/unloading station and the extruding station respectively in relation to the belt drying oven shown in cross-section at 54.

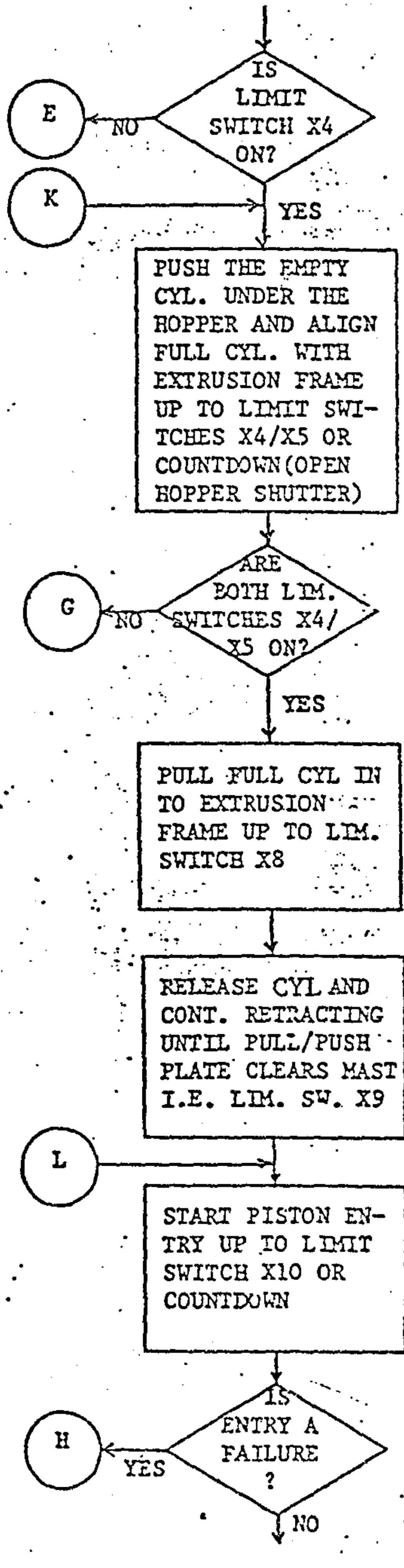
In a process according to the invention for extrusion of a plastic material, extrusion rate is controlled by controlling the extrusion ram pressure. Where extruded material is allowed to settle on a moving conveyor belt, for example, the belt of a belt drying oven, the depth of material on the belt may be controlled either by controlling the extrusion rate and/or by controlling the speed of the conveyor belt.

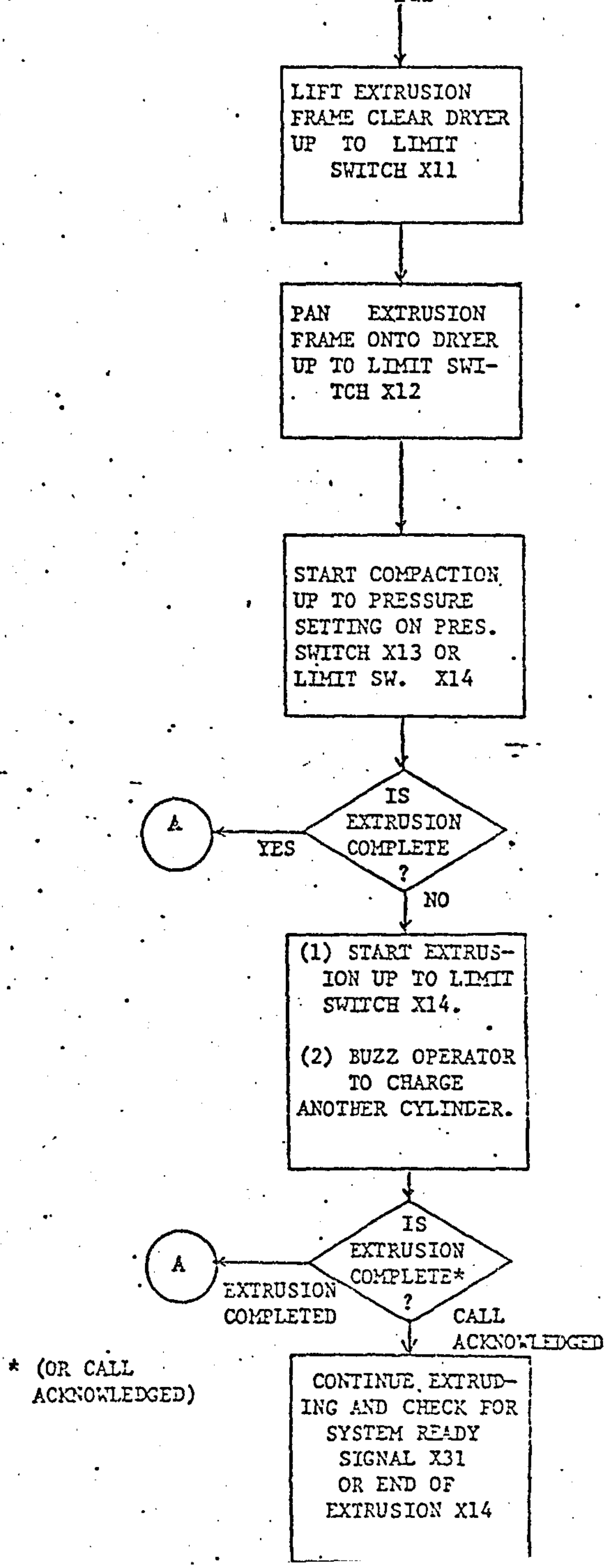
For the purpose of drying a pigment or a precursor thereof in a belt drying oven, the optimum depth of extrudate on the belt is normally about four inches.

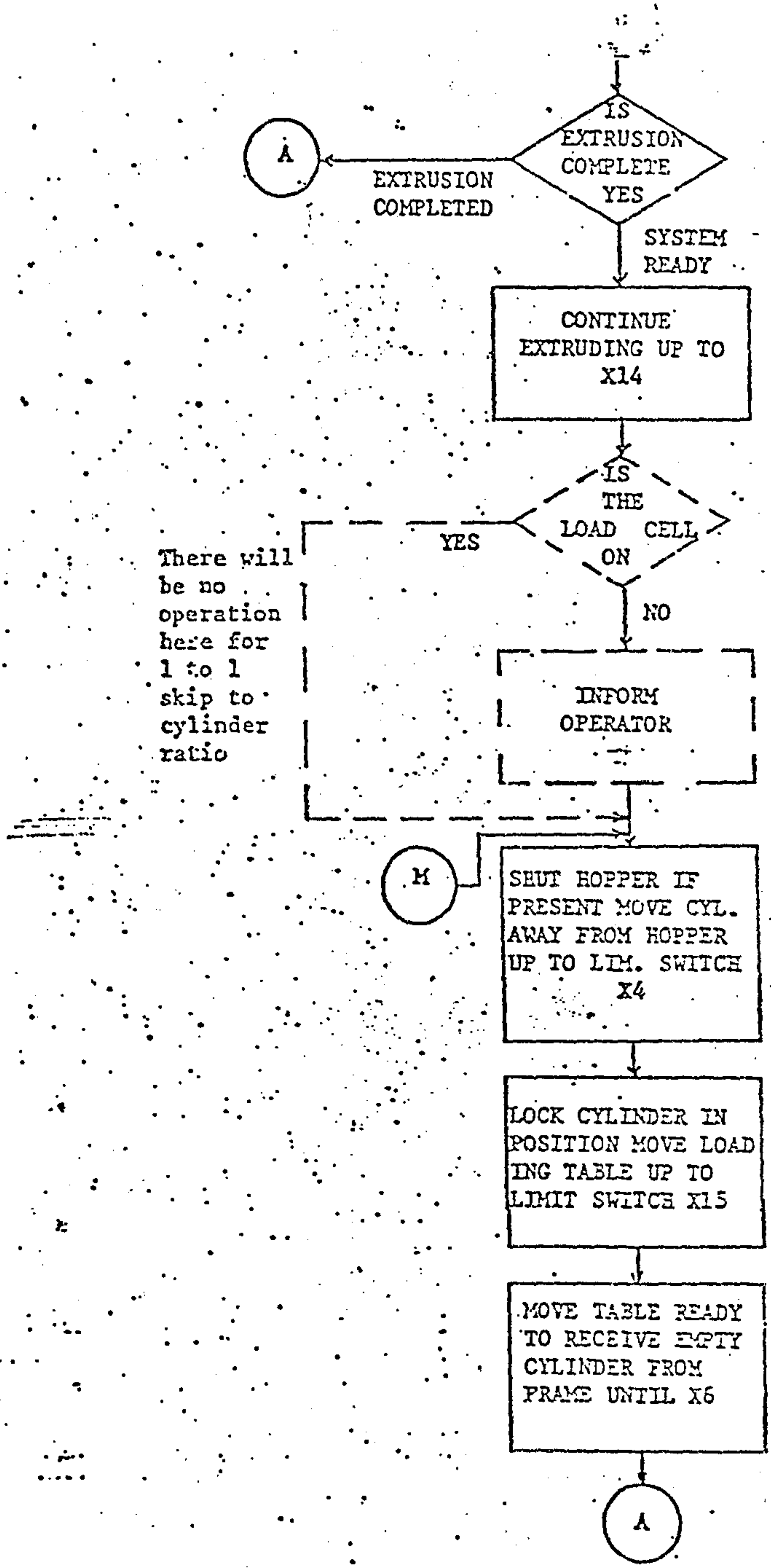
Apparatus according to the invention may be controlled by hydraulic control means in standard manner and its operation is facilitated by use of limit switches to indicate the position of various components of the apparatus at various stages in the process.

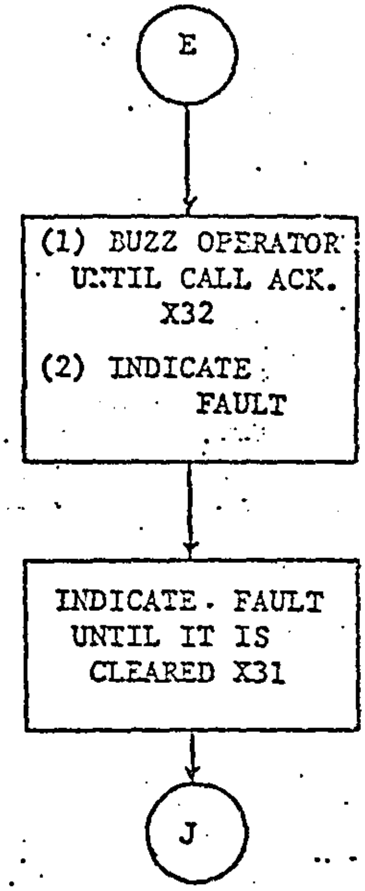
Figures 7 and 8 indicate the positions of limit switches X1 to X6 and X8 to X15 on the apparatus illustrated in Fig.1, the switches being involved in the various stages of the process of operating the apparatus as follows:

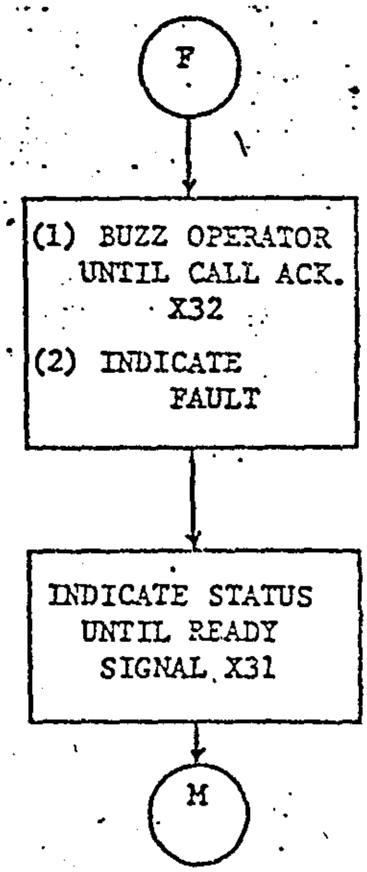

START
A
WITHDRAW PISTON FROM EXTRUSION CYLINDER UP TO LIMIT SWITCH X1
PAN EXTRUSION FRAME CLEAR DRYER UP TO LIMIT SWITCH X2
IS LIMIT SWITCH X3 ON
YES
NO
LIFT EXTRUSION FRAME TO FREE FRAME LOCK SOLENOID UP TO LIMIT SWITCH X11
LOWER EXTRUSION FRAME UP TO LIMIT SWITCH X3.
IS LIMIT SWITCH X6 ON?
F
NO
YES
J
PUSH EMPTY CYL. OUT OF EXTRUSION FRAME ON TO THE LOADING TABLE UP TO LIMIT SWITCH X4 OR COUNTDOWN

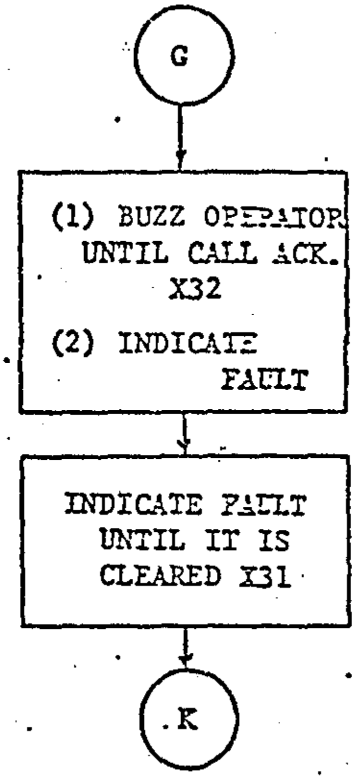

IS LIMIT SWITCH X4 ON?
E
NO
K
YES
PUSH THE EMPTY CYL. UNDER THE HOPPER AND ALIGN FULL CYL. WITH EXTRUSION FRAME UP TO LIMIT SWITCHES X4/X5 OR COUNTDOWN (OPEN HOPPER SHUTTER)
ARE BOTH LIM. SWITCHES X4/X5 ON?
G
NO
YES
PULL FULL CYL IN TO EXTRUSION FRAME UP TO LIM. SWITCH X8
RELEASE CYL AND CONT. RETRACTING UNTIL PULL/PUSH PLATE CLEARS MAST I.E. LIM. SW. X9
L
START PISTON ENTRY UP TO LIMIT SWITCH X10 OR COUNTDOWN
IS ENTRY A FAILURE ?
H
YES
NO

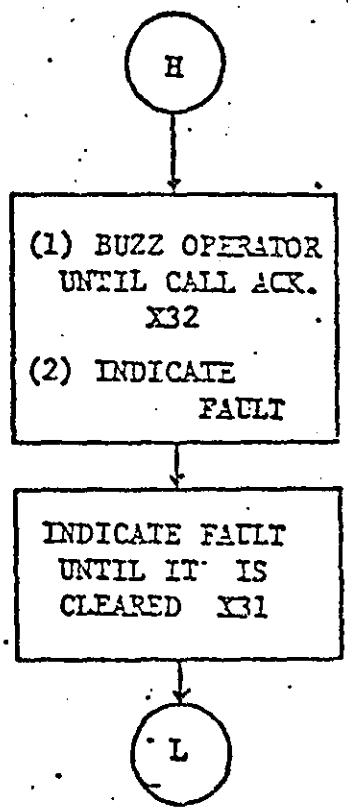

LIFT EXTRUSION FRAME CLEAR DRYER UP TO LIMIT SWITCH X11
PAN EXTRUSION FRAME ONTO DRYER UP TO LIMIT SWITCH X12
START COMPACTION UP TO PRESSURE SETTING ON PRES. SWITCH X13 OR LIMIT SW. X14
IS EXTRUSION COMPLETE ?
YES
A
NO
(1) START EXTRUSION UP TO LIMIT SWITCH X14.
(2) BUZZ OPERATOR TO CHARGE ANOTHER CYLINDER.
IS EXTRUSION COMPLETE* ?
EXTRUSION COMPLETED
A
CALL ACKNOWLEDGED
* (OR CALL ACKNOWLEDGED)
CONTINUE EXTRUDING AND CHECK FOR SYSTEM READY SIGNAL X31 OR END OF EXTRUSION X14


IS EXTRUSION COMPLETE YES
EXTRUSION COMPLETED
A
SYSTEM READY
CONTINUE EXTRUDING UP TO X14
IS THE LOAD CELL ON
YES
NO
There will be no operation here for 1 to 1 skip to cylinder ratio
INFORM OPERATOR
M
SHUT HOPPER IF PRESENT MOVE CYL. AWAY FROM HOPPER UP TO LIM. SWITCH X4
LOCK CYLINDER IN POSITION MOVE LOADING TABLE UP TO LIMIT SWITCH X15
MOVE TABLE READY TO RECEIVE EMPTY CYLINDER FROM FRAME UNTIL X6
A


E
(1) BUZZ OPERATOR UNTIL CALL ACK. X32
(2) INDICATE FAULT
INDICATE FAULT UNTIL IT IS CLEARED X31
J


F
(1) BUZZ OPERATOR UNTIL CALL ACK. X32
(2) INDICATE FAULT
INDICATE STATUS UNTIL READY SIGNAL X31
M


G
(1) BUZZ OPERATOR UNTIL CALL ACK. X32
(2) INDICATE FAULT
INDICATE FAULT UNTIL IT IS CLEARED X31
K


H
(1) BUZZ OPERATOR UNTIL CALL ACK. X32
(2) INDICATE FAULT
INDICATE FAULT UNTIL IT IS CLEARED X31
L

CLAIMS:

1. A process for extrusion of a plastic material comprising supplying the material to a loading/unloading station in a container a wall of which has one or more holes for extrusion formed therein, moving the container to an extrusion station and, thereafter, applying extrusion pressure to the material by means of a ram.

2. A process as claimed in Claim 1 in which pressure is applied in two stages in which a lower pressure than that required for extrusion is first applied to compress the material and to cause any excess wetness, for example, to be exuded, and in which a higher pressure is then applied for extrusion.

3. Apparatus for extrusion of a plastic material comprises a container for holding a quantity of material and having one or more extrusion holes formed in a wall thereof and being adapted for location in a cage movable between a loading/unloading station and an extrusion station, and ram means which can be entered into the container for exerting pressure on the material at least when the container is at the extrusion station.

4. Apparatus as claimed in Claim 3 in combination with a conveyor belt or other carriage means for receiving extruded material, ... the loading/unloading station being located at or near floor level and the extrusion station being

located above the belt so that the extrudate settles under the influence of gravity on to the belt.

5. Apparatus as claimed in Claim 3 or 4 in which the cage is mounted on a vertical pylon for longitudinal sliding movement relative thereto, in a substantially vertical plane, the pylon being itself carried on a chassis for longitudinal sliding movement relative thereto in a substantially horizontal plane.

ABSTRACT

Plastic material such as pigment filter cake is extruded in filamentary form for drying by means of a ram extruder which eradicates local zones of inhomogeneity. Pressure may be applied by the ram in two stages; a lower pressure to homogenise the material followed by a higher pressure to extrude it.

Apparatus for carrying out the process comprises a container transportable in cage between a loading/unloading station and an extrusion station.

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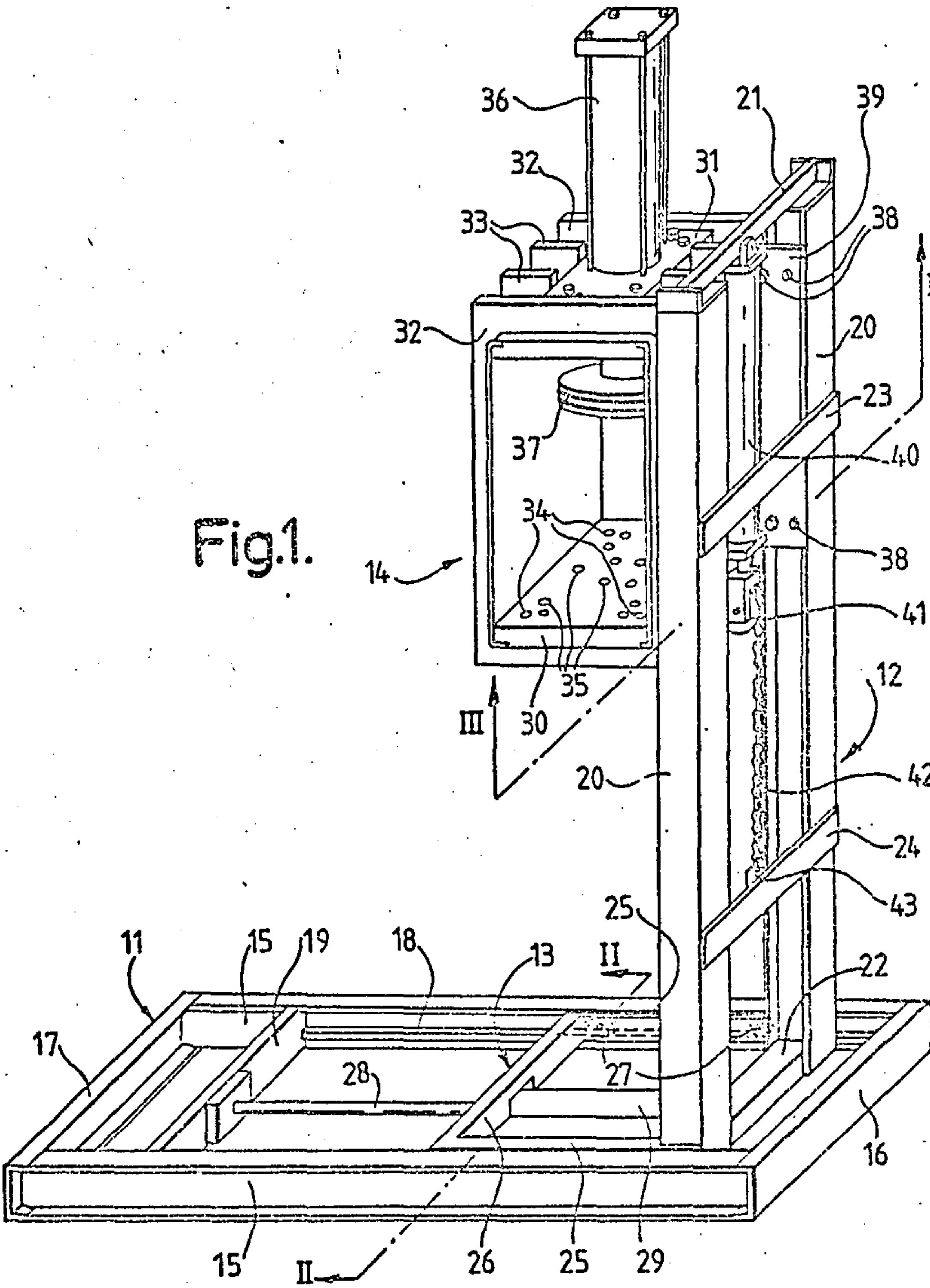

36
32
31
21
39
38
33
III
32
20
23
37
40
34
38
14
41
12
35
30
III
20
42
24
43
25
11
15
19
18
13
II
22
17
28
27
16
15
II
26
25
29

Fig.1.

Fig.2.

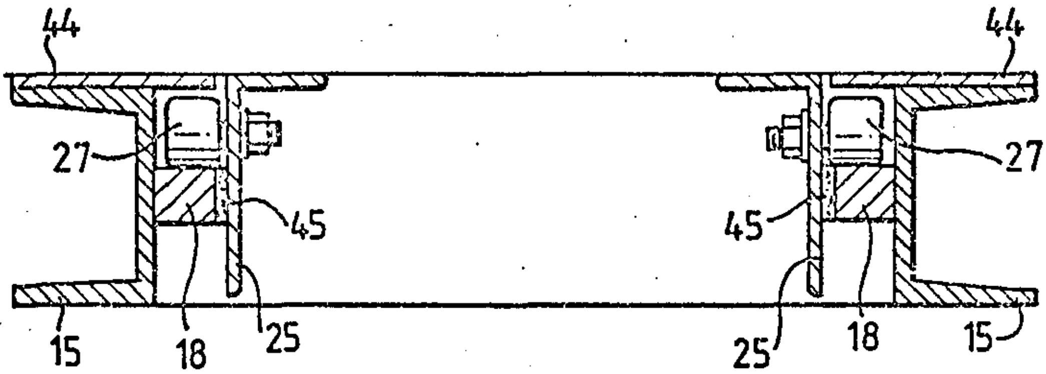
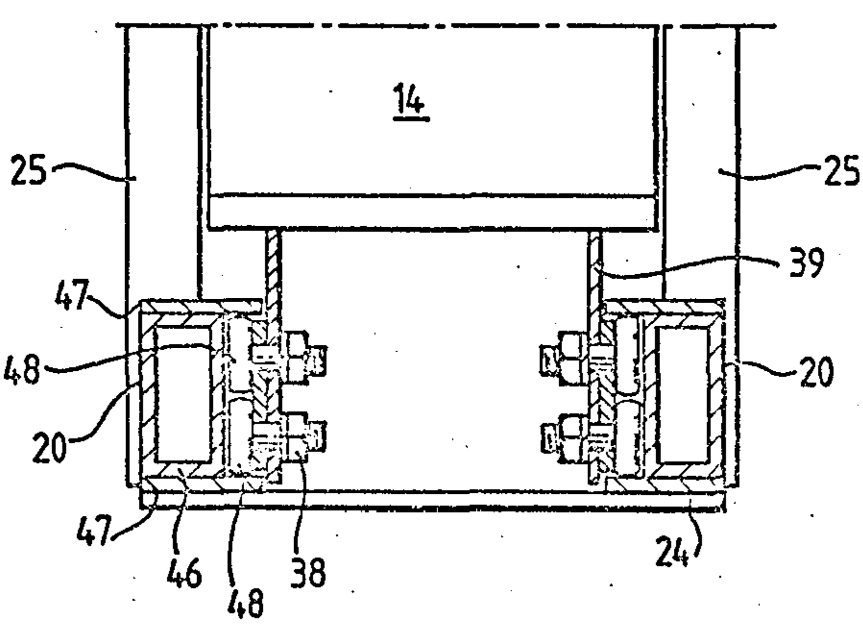

44
44
27
27
45
45
15
18
25
25
18
15

Fig.3.


14
25
25
39
47
48
20
20
47
46
48
38
24

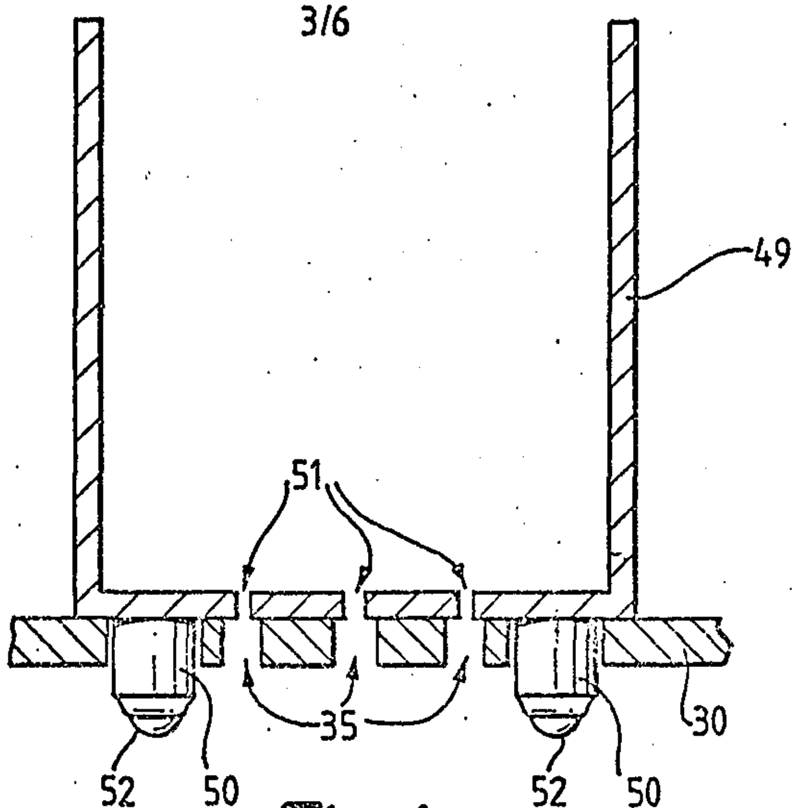


Fig.4.

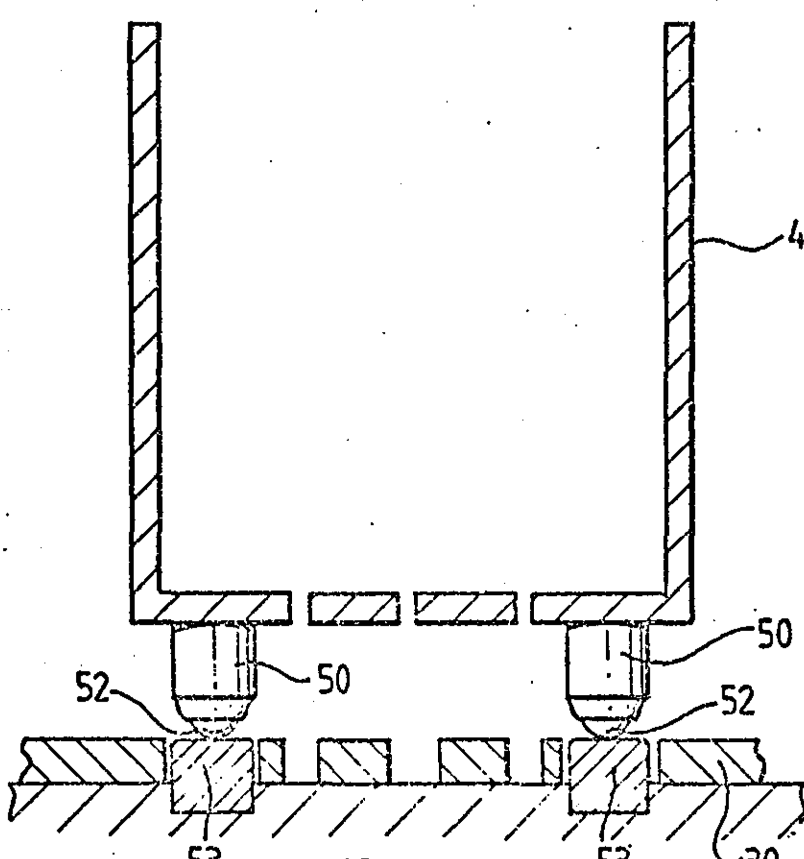


Fig.5.

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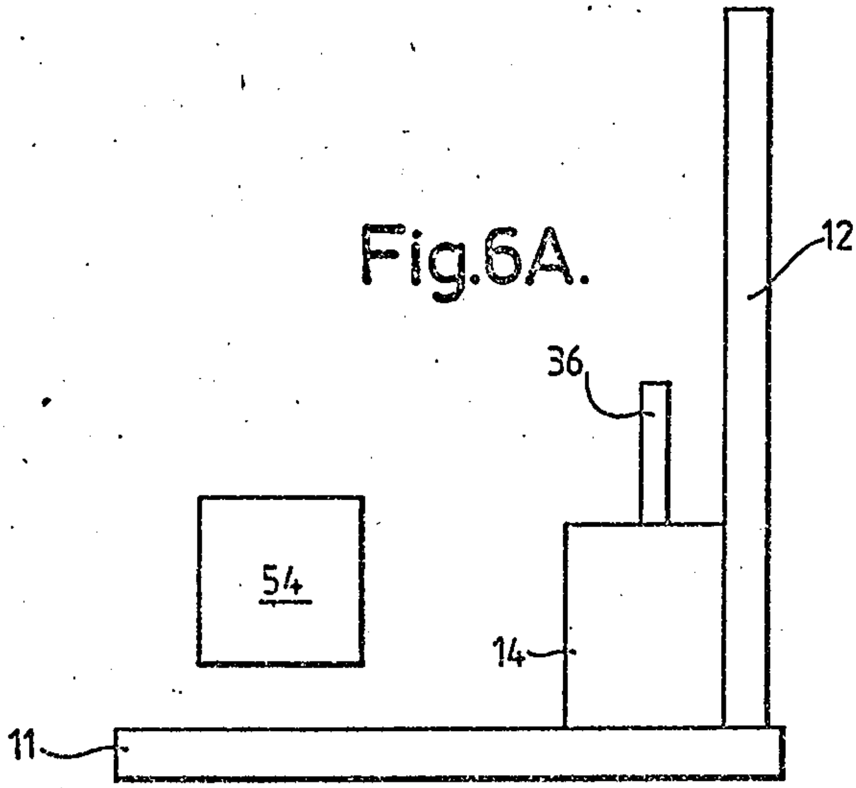
Fig.6A.



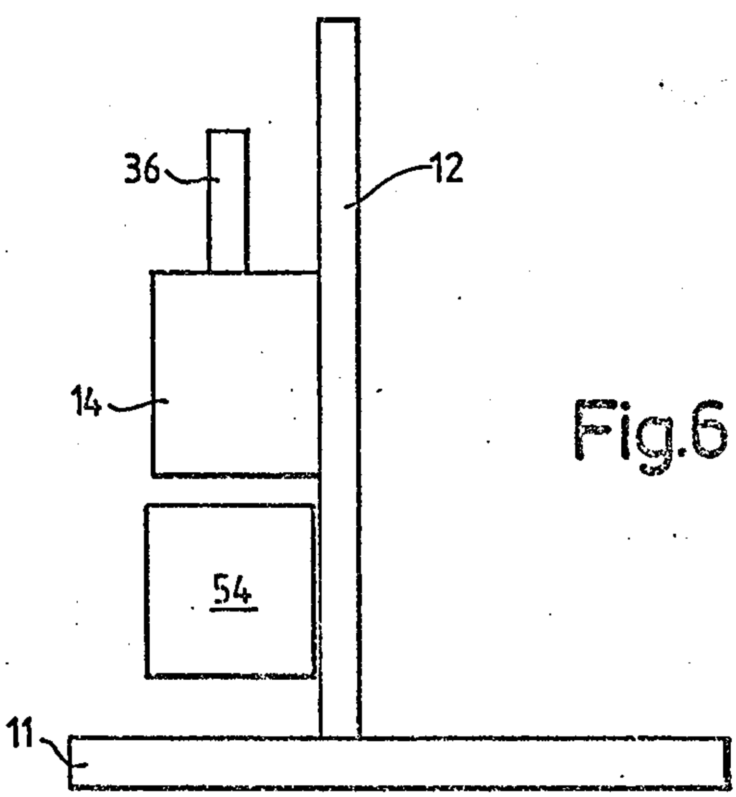


Fig.6B.

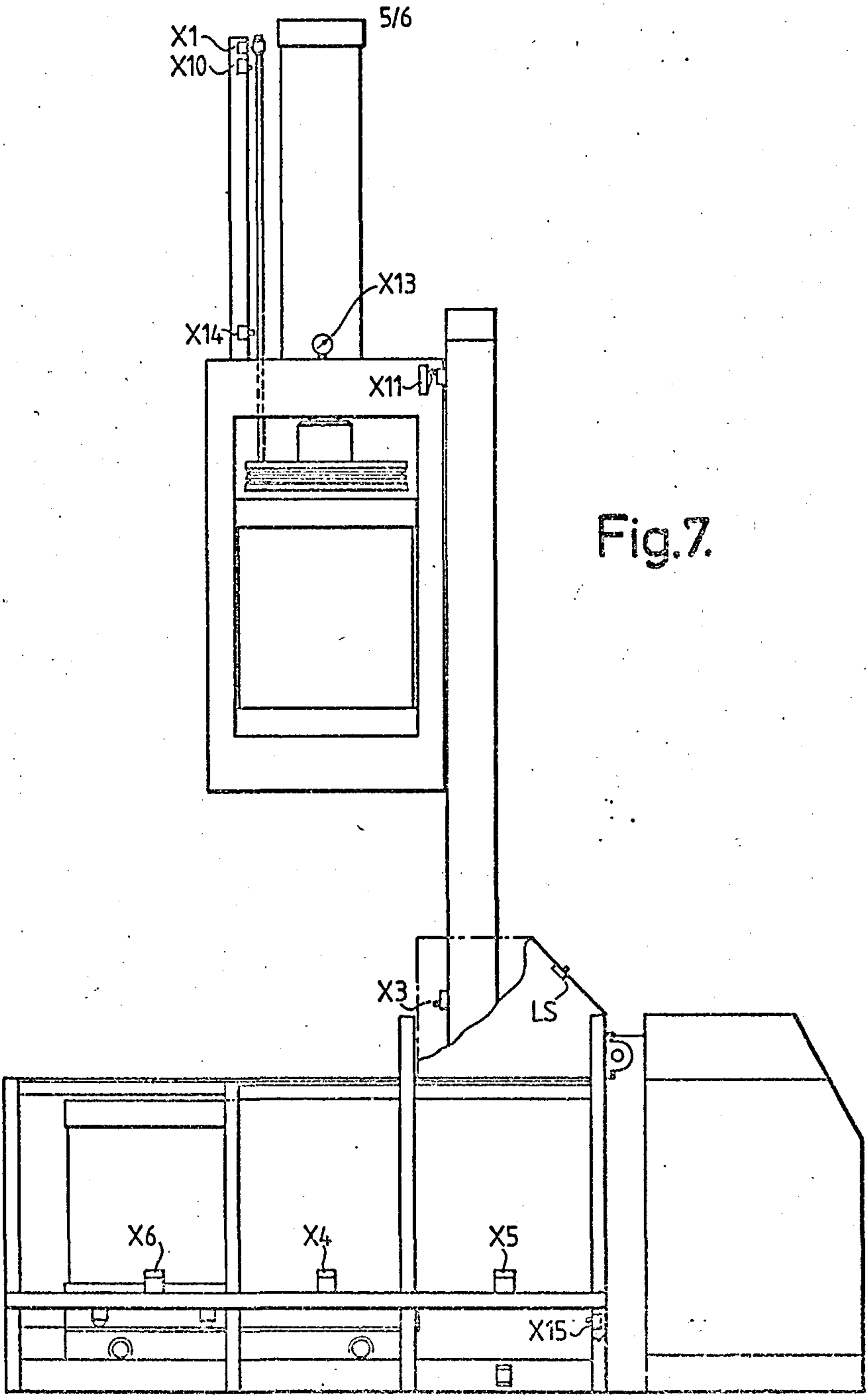


Fig.7.

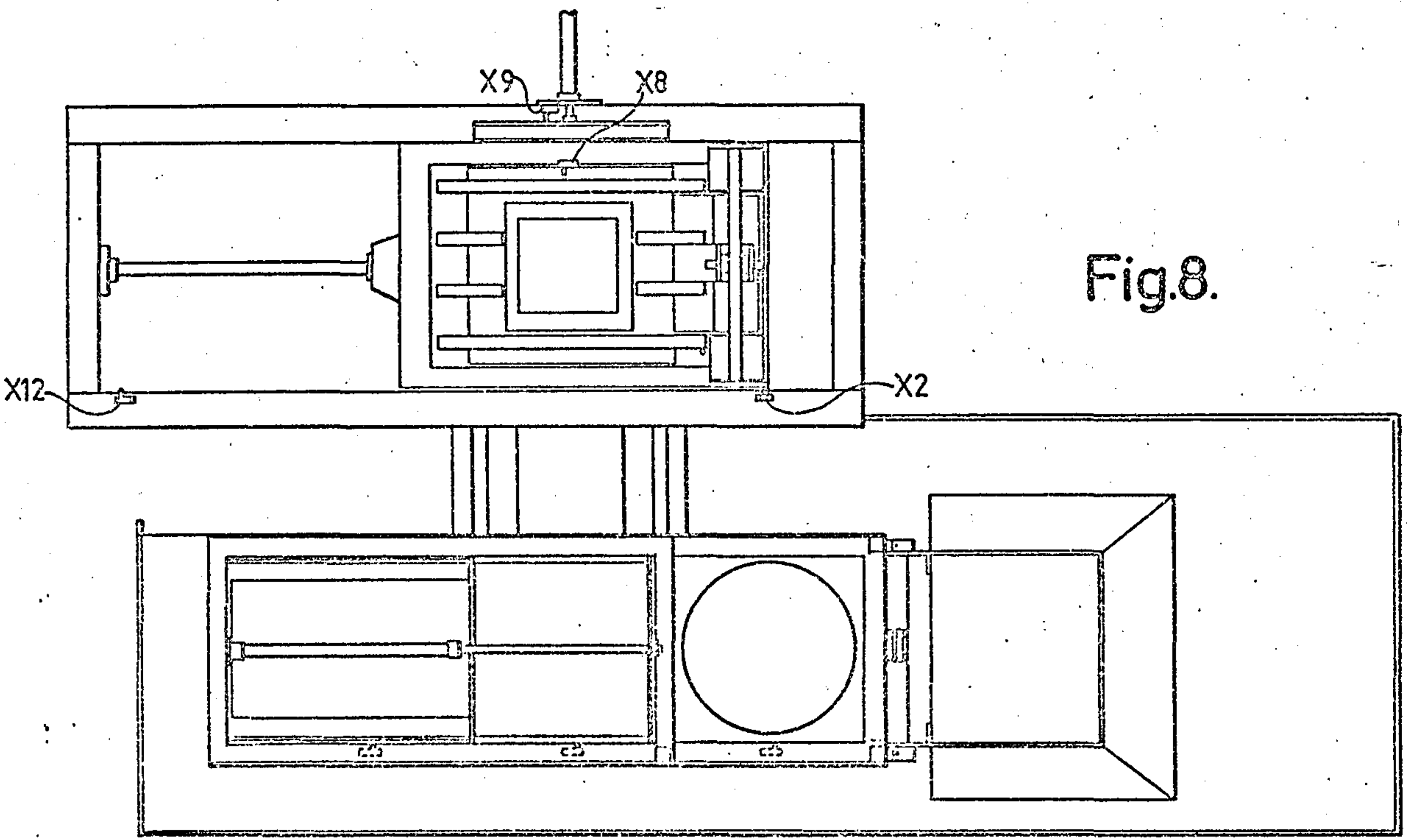


Fig.8.

Appendix 'G'

List of Working Drawings

DRAWING NO.	DESCRIPTION
79W/0001	Engineering Analysis Chart
79W/0002	Support for Experimental Extrusion Cylinder
79W/0003	Experimental Extrusion Cylinder
79W/0004	Experimental Piston Detail and Assembly
79W/0005	Experimental Extrusion Cylinder 205 MM dia.
79W/0006	Experimental Extrusion Piston Detail and Assembly
79W/0007	Layout of Extrusion Plant
79W/0008	Extrusion Machine Assembly
79W/0009	Base/Mast Subassembly
79W/0010	Base Fabrication
79W/0011	Details
79W/0012	Mast Fabrication
79/W0013	Positioning Ram Mounting Details
79W/0014	Extrusion Frame Lifting Arrangement
79W/0015	Shackle Details
79W/0016	Extrusion Frame/Mast Subassembly
79W/0017	Extrusion Frame Fabrication Detail
79W/0018	Extrusion Frame Fabrication Detail
79W/0019	Extrusion Frame Bottom Plate
79W/0020	Extrusion Frame Top Plate
79W/0021	Extrusion Frame Subfabrication
79W/0022	Extrusion Frame Yoke Fabrication
79W/0023	Extrusion Frame Fabrication
79W/0024	Cross Beam
79W/0025	Mast Fabrication Pieces
79W/0026	Chassis Left-hand Longitudinal Member
79W/0027	Chassis Right-hand Longitudinal Member
79W/0028	Mast/Chassis Pieces

DRAWING NO.	DESCRIPTION
79W/0029	Mast Track Fabrication
79W/0030	Mast Brace
79W/0031	Cylinder ejecting Pegs
79W/0032	Cylinder Transporting/locating Arrangement
79W/0033	Extrusion Cylinder Fabrication
79W/0034	Extrusion Cylinder Machining Detail
79W/0035	Extrusion Cylinder Fabrication Pieces
79W/0036	Piston Fabrication Pieces
79W/0037	Seal Backing Ring
79W/0038	Piston Fabrication Detail
79W/0039	Piston Machine Detail
79W/0040	Piston Assembly
79W/0041	Control Schematic
79W/0042	Extrusion Machine Perspective View
79W/0043	Part List for Extrusion Machine Ass.Drg.No.79W/0008
79W/0044	Part List for Base-Mast Subassembly Drg.No.79W/0009
79W/0045	Part List for Positioning-Ram Mounting Detail Drg. No. 79W/0013
79W/0046	Part List for Extrusion Frame Lifting Arrangement Drg. No. 79W/0014
79W/0047	Part List for Extrusion Frame-Mast Subassembly Drg. No. 79W/0016
79W/0048	Filter Cake Handling Equipment Frame Fabrication
79W/0049	Filter Cake Handling Equipment Frame Base Fabrication
79W/0050	Filter Cake Handling Equipment Frame Base Pieces
79W/0051	Filter Cake Handling Equipment Frame Top Rail
79W/0052	Filter Cake Handling Equipment Frame Top Rail Pieces
79W/0053	Filter Cake Handling Equipment Frame Inner Left-hand Skirting
79W/0054	Filter Cake Handling Equipment Frame Inner Right-Hand Skirting

DRAEING NO.	DESCRIPTION
79W/0055	Filter Cake Handling Equipment Frame Outer Skirting
79W/0056	Filter Cake Handling Equipment Frame Column
79W/0057	Filter Cake Handling Equipment Transfer Platform
79W/0058	Filter Cake Handling Equipment Transfer Platform Pieces
79W/0059	Filter Cake Handling Equipment Hopper Fabrication
79W/0060	Filter Cake Handling Equipment Table Fabrication
79W/0061	Filter Cake Handling Equipment Table Top
79W/0062	Filter Cake Handling Equipment Table Angles
79W/0063	Filter Cake Handling Equipment CLEVIS BRACKET
79W/0064	Filter Cake Handling Equipment Tilting Cradle Frame
79W/0065	Filter Cake Handling Equipment Cradle
79W/0066	Filter Cake Handling Equipment Cradle Fabrication
79W/0067	Filter Cake Handling Equipment Table Stub Axle
79W/0068	Filter Cake Handling Equipment Table Stub Axle Spacer
79W/0069	Filter Cake Handling Equipment Longitudinal Positioning Ram Bracket
79W/0070	Filter Cake Handling Equipment Assemble
79W/0071	Hopper Shutter (Filter Cake Handling Equipment)
79W/0072	Shutter Track (Filter Cake Handling Equipment)
79W/0073	Filter Cake Handling Equipment Part List
79W/0074	Filter Cake Handling Equipment End Mounted Cradle
79W/0075	Filter Cake Handling Equipment Side Mounted Cradl
79W/0076	Extrusion Plant Limit Switch Position
79W/0077	Extrusion Plant Hydraulic Piping
79W/0078	Extrusion Plant Drawing Chain Mounting Detail
79W/0079	Wiring Connection to Sequence Controller
79W/0080	Control Wiring Output Connection

DRAWING NO.	DESCRIPTION
79W/0081	Control Wiring Input Connection
79W/0082	Bottom Plate for Cowan Plant
79WOO/83	Flapper Guide
79W/0084	Extra Hole Detail on Extrusion Cylinder/ (Cowan Plant)
79W/0085	Die Plate Mouthpiece
79W/0086	Transverse Loading Ram Mounting Detail
79W/0087	Part List for Drawing No. 79W/0086

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