INTRODUCTION.

The University regulations state that a thesis for the Engineering D.Sc. "must be a record of original research undertaken by the candidate, or of important engineering work designed by himself, and actually carried out". My application is made under the second head.

During the last five years, as electrical engineer to a firm manufacturing electrical ignition, lighting and starting apparatus for motor cars, aeroplanes, stationary gas engines, etc., I have been solely responsible for the design of all classes of such apparatus.

To comply with the regulations in no case are designs referred to unless they have been actually carried out. In my work I have had the assistance of the firm's technical and drawing office staff; when this help has been of importance I have made an appropriate acknowledgement, but not in case of work carried out to my instructions.

PAGE DATE

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Appended are also copies of 4 Patent Specifications and 7 Applications for Patents.

COIL IGNITION.

Coil or Magneto Ignition.

There has been for many years past a keen rivalry between the two ignition systems. Coil ignition is much the more popular in America, and magnetos are just as much in the majority in this country. I have had the experience - unusual in this country, as almost all manufacturers have confined themselves to one system only - of developing both types of apparatus side by side, and much light has frequently been thrown by each system on the other. As to the rival merits, there is much to be said on both sides.

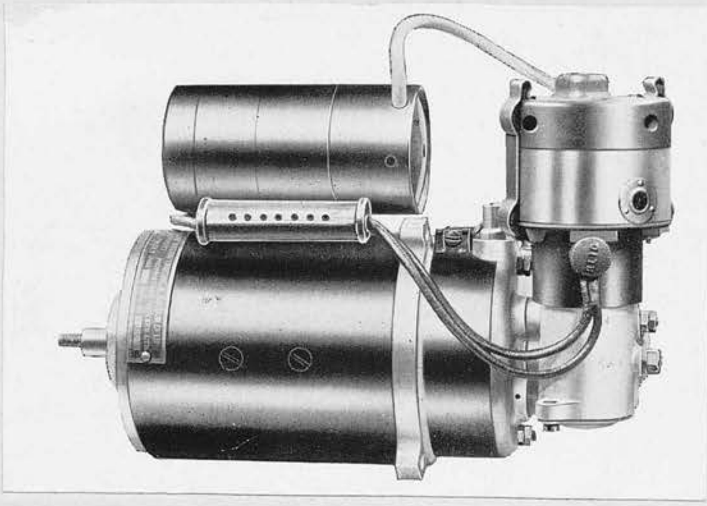
The greatest advantage of the magneto is that it works independently of any external source of energy, and consequently is a self-contained unit, not requiring any external (primary) wiring.

Coil ignition has many advantages, and quite a number of drawbacks. A coil is slightly cheaper than a magneto; the parts requiring occasional inspection are generally more accessible; if it is combined with a dynamo much valuable space is saved and an independent drive is eliminated; there is a definite spark however slowly the engine is turned; a greater flexibility of engine can be obtained in some cases by increasing the range of timing variation - strictly limited on the magneto, it may be as wide as you please on the coil. The spark at slow speed, however, may occasionally be embarrassing, as a backfire may take place where it would not have done had a magneto been fitted. A loose wire or loose battery terminal, meaning complete failure of the ignition, (very difficult to prevent with a car in use year in, year out)may take an unskilled driver hours to locate. A complicated automatic cut-off is required if the magneto is to be imitated; if a hand-operated cut-off switch is provided, failure of the driver to switch off will mean that the battery will be run down and quickly exhausted. Any failure of the battery charging arrangemant means that only a limited and uncertain mileage can be run before the matter must be attended to. Still further considerations, however, tend to mitigate thses drawbacks. If, for instance, the battery charging arrangements fail, they must in any case be quickly put in order or the car will be without lights. Further, should the battery be in such a condition that the starter will not operate, there should still be enough energy for a little light, and even then if the lamps glow only dimly there should be energy sufficient to obtain ignition for some hours; with such a series of warnings a driver has only himself to blame should he find himself stranded with a completely exhausted battery. I should sum up by saying that the coil was a little the cheaper, and at the same time a greater pleasure to drive with, but that the magneto was slightly the more reliable.

Alternative Forms.

A complete coil ignition unit has been made up in the following forms; the parts are the same, however the unit is constructed, only the drivè and fixing being varied, to suit the engine maker's requirements:-

Embòdied with the dynamo. A vertical spindle, housed on one of the dynamo end brackets, driven by skew gear from the dynamo spindle, carries a cam to interrupt the contact breaker and the distributor brush. Details of the arrangement are shewn in fig. 1. The coil is placed sometimes on the top of the dynamo, and sometimes on the dashboard, under the bonnet.



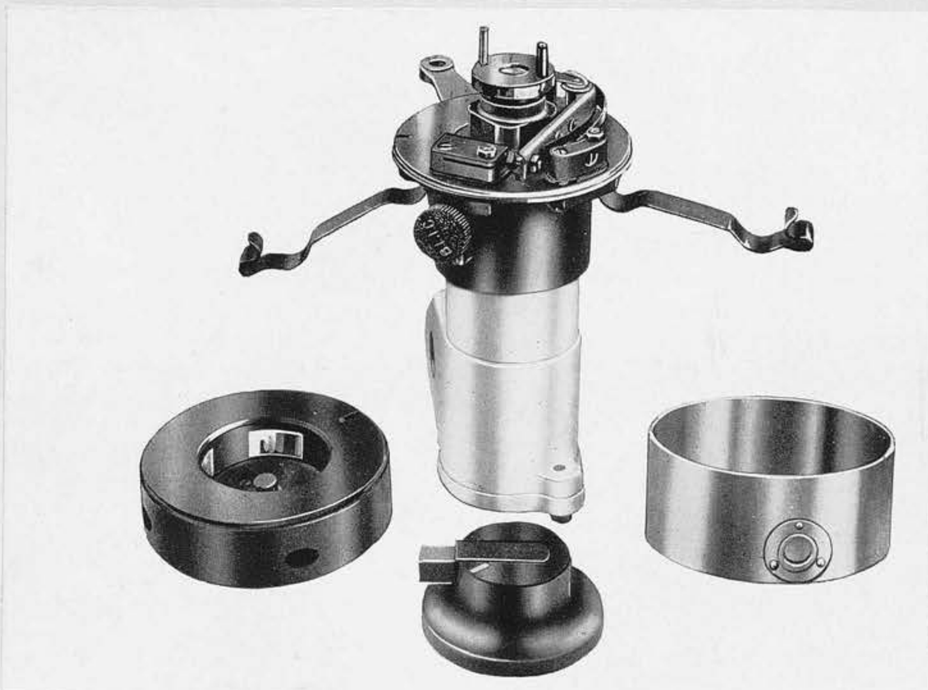


Fig. 1.

Magneto replacement unit. As shewn in fig. 2; this unit is interchangeable with a standard magneto as regards fixing dimensions, speed of drive, etc.

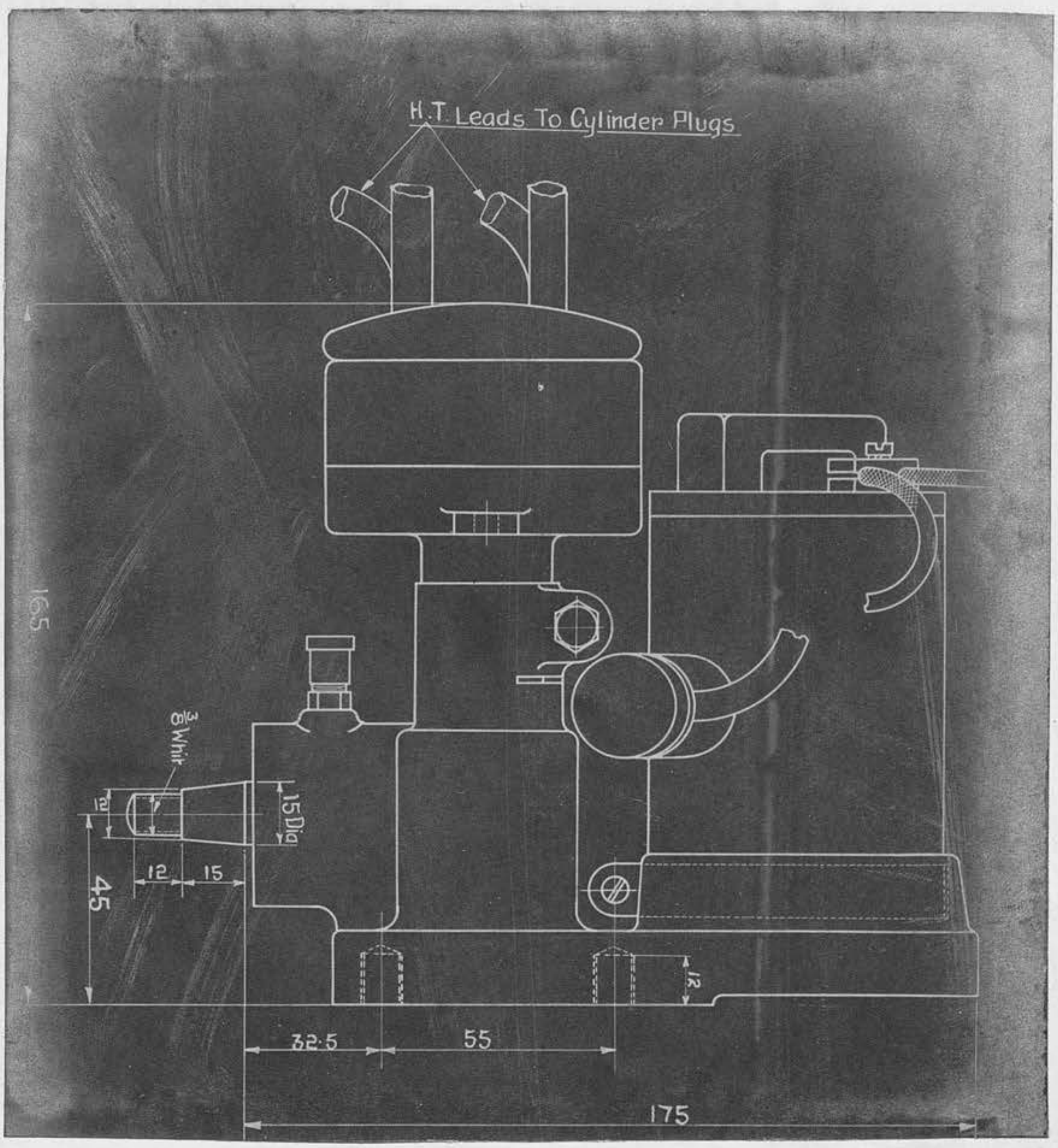


Fig. 2.

S.A.E.* standard mounting. Contact breaker and distributor are provided as a separate unit, a drive at cam shaft speed being provided. See fig. 3.

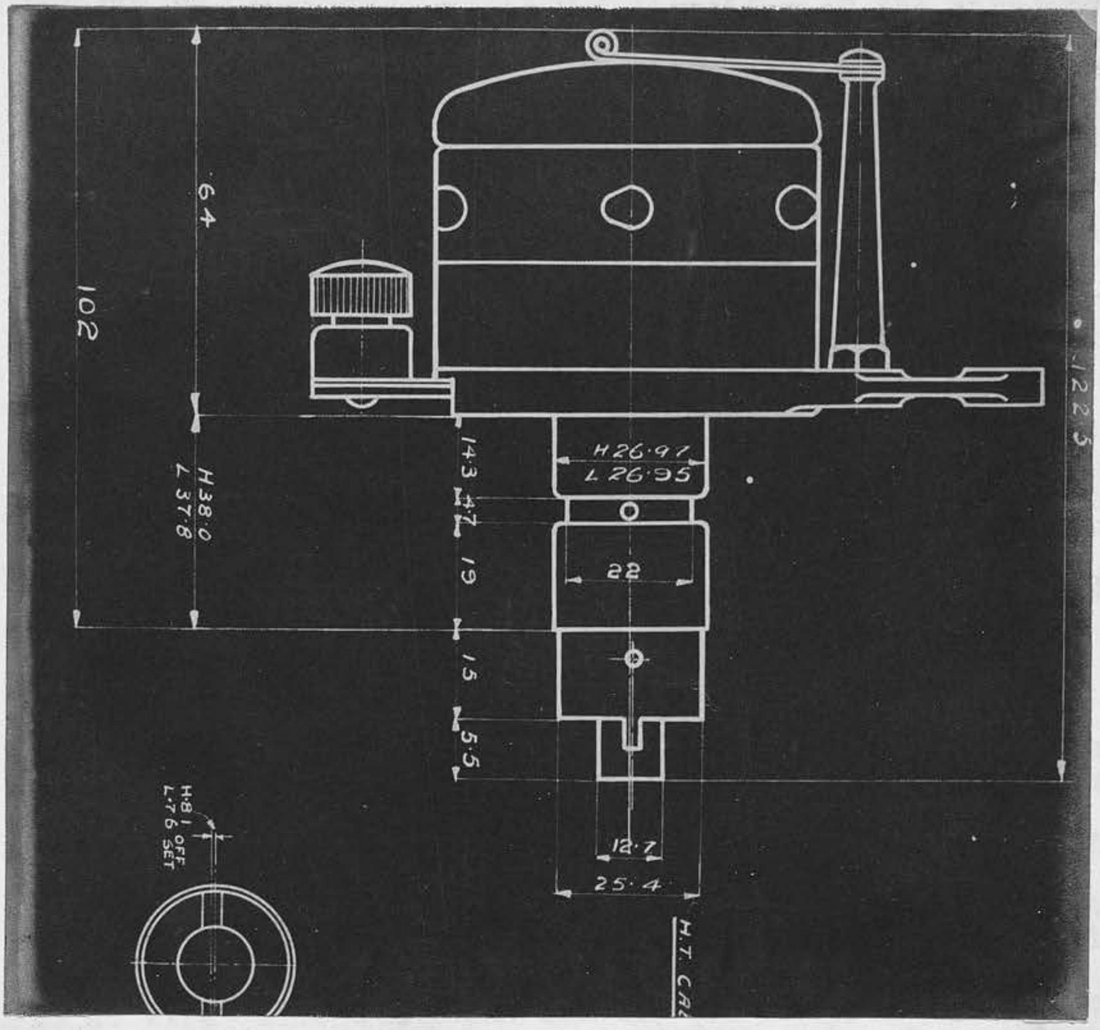


Fig. 3.

* Society of Automotive Engineers — An American standard.

Contact Breakers.

Magneto contact breakers will be referred to later. The same remarks apply, to a great extent, to coil ignition breakers. One or two fresh factors, however, have been of sufficient importance to require further study; these are dealt with below.

Contacts. In all magnetos, with the exception of a single cylinder machine with one cam, giving one spark per revolution of the armature, the direction of the current interrupted by the contacts is reversed each time they are opened. The result is that the contacts wear uniformly, at a rate dependent solely on the mechanical hammering they receive - that is assuming there is no loss of metal due to sparking taking place - and there is no piling up on, or loss of metal from either contact. With coil ignition the direction of the current is the same at each interruption. There is a choice of alternatives; either a reversing switch may be provided, or the effect of uni-directional interruption may be observed and suitable provision made.

The following table (fig. 4) shews the result of tests of contacts of Platinum and Tungsten operating under different conditions.

The contacts referred to in this table were all of 3.75 m/m. diameter, the pressure between the faces being adjusted to 1½ lbs. A cam breaking the circuit 4 times per revolution was employed; a uniform speed of 900 R.P.M. was maintained, that is an engine speed of 1800 R.P.M. The corresponding road speed may be assumed to be about 36 miles per hour. Thus the mileage corresponding to a 600 hours' test may be estimated at rather more than 20,000. This is more than the majority of cars cover in twelve months or even in two years; as the usual guarantee period is one year, a run of this duration is more than ample to discover any possible shortcoming in the provisions made for wear.

To overcome any inaccuracy in alignment, the tungsten contacts were slightly rounded on the working faces; it is thus difficult to state the exact amount of wear in each case, as at first almost a point contact was made, broadening out into a larger area as time went on, the rate of wear dropping off rapidly as the area of apparent contact increased. At any given interruption the current passes across the contact faces at practically a point; at all events, however carefully the faces are bedded together, the area across which the current flows is very small compared to the total area of the face. From time to time, as wear takes place, the current shifts to a fresh part of the contact;all this can be detected if the contacts are observed while working.

The coils were all operated on a 12-volt circuit; the current broken was about 2.0 amperes, the primary inductance 0·02 henries, and the capacity 0·17 microfarads; throughout the test the secondaries were set to spark across 5.5 m/m. 3-point gaps.

WEAR OF CONTACTS

CONTACT MATERIAL	LENGTH OF RUN (HOURS)	CONDITIONS OF TEST	AMOUNT OF WEAR IN M/MS. FIXED CONTACT	MOVING CONTACT	REMARKS
TUNGSTEN.	456.	NO CURRENT	0·02	0·09	
TUNGSTEN.	612.	MOVING CONTACT POSITIVE.	0·135	0·10	
TUNGSTEN.	580	CURRENT REPEATEDLY REVERSED.	0·135	0·06	
PLATINUM.	530	NO CURRENT.	0·006	0	
PLATINUM.	595	MOVING CONTACT POSITIVE	0·34	0·465	INCREASE OF METAL ON FIXED CONTACT
PLATINUM.	610.	CURRENT REPEATEDLY REVERSED	0	0·01	

FIG. 4

Fig. 4.

Making some allowance for the effect of the rounded faces, it is seen that with tungsten contacts the wear due to the hammering action alone is very small; with the current flowing the rate of wear is apparently increased, but there is no tendency for one contact to wear more rapidly than the other and there is no tendency for metal to pile up on the negative contact. The tungsten employed was pure tungsten; the platinum was platinum-iridium, with 25 per cent of the latter metal. In order to avoid the uncertainty introduced by rounding the faces the faces of the platinum contacts were left flat, and were set carefuly in line. The wear due to mechanical hemmering is evidently inappreciable. Reversals of current were made more or less at random throughout the test at intervals of 6 to 8 hours, or longer; under this condition the wear is also evidently negligible. With unidirectional flow of current a crater formed in the positive contact, and a mass of metal resembling an electrolytic deposit formed on the negative contact.

Contact Breaker Sparking - Causes & Effects.

It has been my experience that however carefully the primary capacity is chosen, sparking at the contacts is never entirely done away with. Under most favourable conditions a contact breaker may be watched, operating in the dark, and not a flicker be observed for minutes together. A particle of dust, however, of insulating material from the heel perhaps, will start sparking which may continue for some time; oil, petrol, or any foreign matter on the contacts is of course fatal. Abnormally high secondary voltage, as for instance when the plug points are opened rather too far, increases the tendency to spark; again, a condenser which appears to suppress sparking at high speed is generally less successful at low speed. Six-volt coils, breaking 3 to 4 amperes, of one particular type were never entirely sparkless; similar coils breaking half the current on a 12-volt circuit gave very much less trouble. The capacity required to reduce sparking to a minimum frequently has a definite value, either more or less than this amount causing the sparking to increase.

It appears, too, that there are critical values either of LI^2 or some other expression involving the current and the inductance; sparking which takes place where the constants are below the critical value is desultory, local heating is not excessive, and the contacts retain their polish and wear well. If the critical values are exceeded, the sparking tends to become continuous, the contacts become roughened and pitted, the action is cumulative, and the resultant life is enormously reduced.

The nearly closed circuit coils which I am now designing require a very much smaller capacity than the more usual open circuit type; the difference is so considerable as to call for further study and experiment, but this I have not yet had time to undertake.

It will be readily understood that tests such as those referred to in fig. 4 take a very considerable time to carry out. When, in 1918, I first designed a dynamo-battery ignition equipment very little information as to contact wear and sparking was available, and I was particularly anxious to have no trouble due to this cause. I accordingly decided at first to use platino-iridium contacts, to keep the inductance as low and the primary capacity as high as was consistent with the secondary performance required, and to use a reversing switch. An excellent reversing switch was obtained from the Remy Company of U.S.A. The connections of this switch are as shewn in fig. 5.

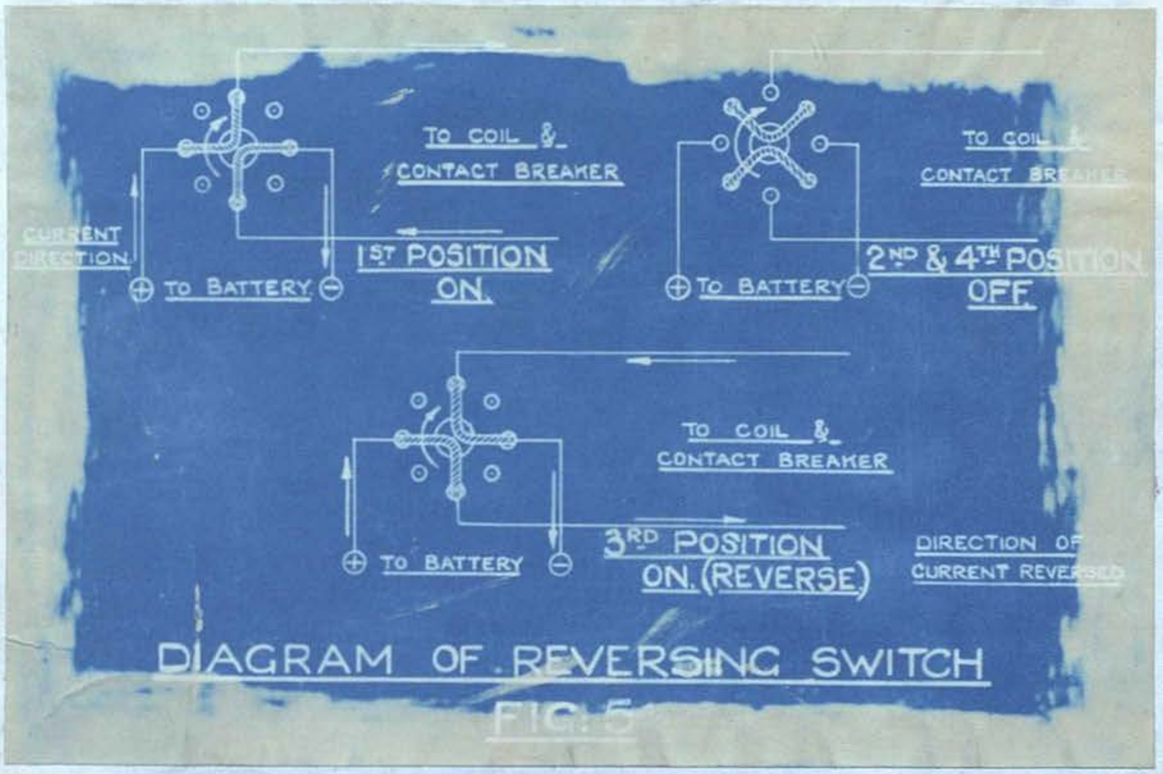


Fig. 5.

It will be seen that there are eight positions of the switch during a complete revolution of the contacts; a ratchet ensures movement in a clockwise direction only; On and Off positions follow alternately; in each On position the current through coil and contact breaker is in the opposite direction to the one before. This switch ensures a continued reversal; the driver operates it as if it were a simple cut-off switch.

My experience with this arrangement on the car endorses the results obtained on the test bench. If the contacts are properly in line, are kept clean, and oil and petrol are not allowed to creep near them, they will last for almost an indefinite period.

In due course I carried out the tests referred to in fig. 4, and in spite of the excellent results obtained, I decided to give up the use of the reversing switch, and to use instead a simple cut-off switch, for the reasons stated below:-

1. If a reversing switch is employed both contacts and their terminals must be insulated, and it is possible for a careless driver, adjusting his contacts without first opening his switch, to short circuit his battery. The present aim being, quite rightly I consider, to make the elctrical equipment ever more rigidly fool-proof in such details, this must be judged a drawback. Using an earth return, I now employ the scheme of connections shewn in fig. 6, which overcomes this drawback.

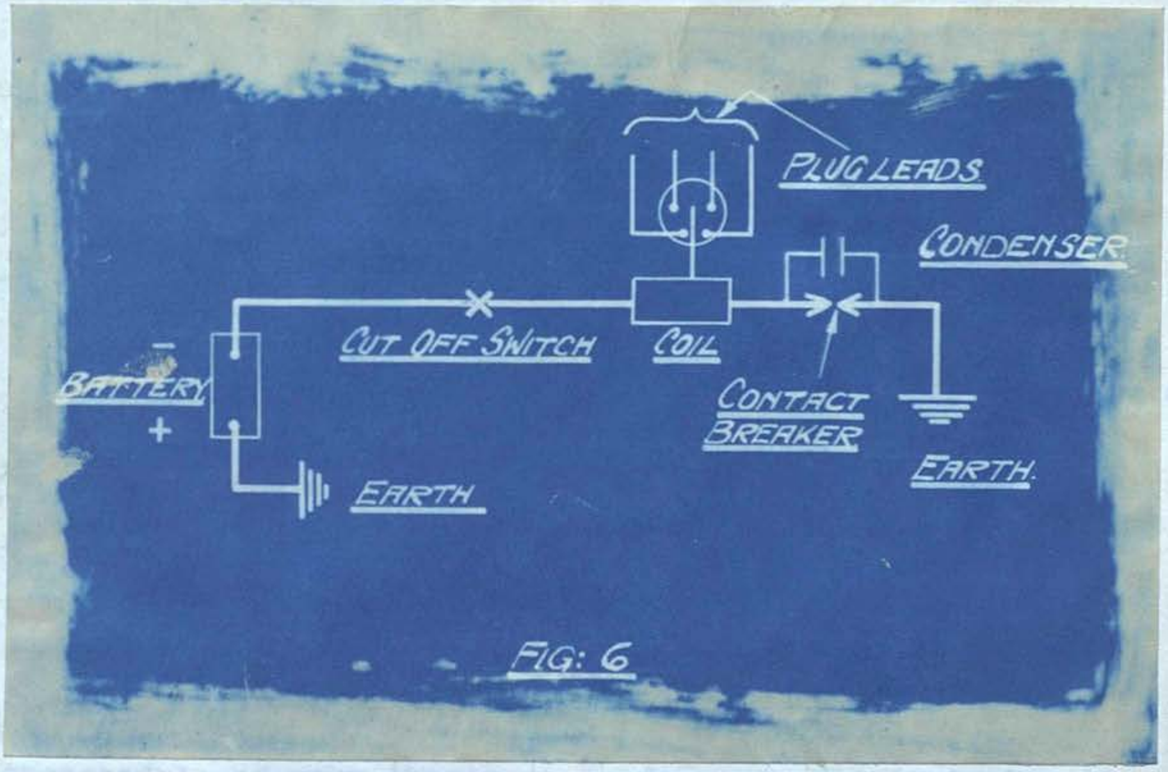


Fig. 6.

The driver, in earthing a contact, can only make the circuit; he cannot short the battery.

2. The extra cost of double pole wiring, insulated terminals, and special switch, is a disadvantage.

3. I find that with the provision of three switches in line, for head and tail lamps, side and tail, and

ignition, respectively, all of uniform appearance, the driver more readily acquires the habit of pushing them all off together, with the result that complaints of switches left on over week-ends and batteries exhausted are now much more rare. A reversing switch cannot readily be made uniform with the lighting switches.

4. From fig. 4 it appears that a platinum contact 0.75 m/m. thick, a familiar standard, would probably last for about 36,000 miles, or several years' life of an average car; this is all that can reasonably be demanded of the manufacturer, as even after this time the cost of renewal is trifling.

Current limiting arrangements and automatic cut-off switches.

The running current of an ignition coil is much less than it takes when standing; many coils burn out if left standing with current switched on for half an hour or so. To prevent this I choose a primary wire such that the standing current will raise the coil temperature to no greater than the limit usual for windings. From 8 to 12 watts, depending on the type of construction of the coil, may be dissipated with a temperature rise not exceeding 80° C. 20 watts or more may be the total consumption of the coil when standing. The difference I have made a practice of dissipating on a resistance unit of wire wound on mica, and covered with a silicate cement. The object of the cement is to endeavour to prevent the wire from getting brittle owing to unequal or extreme local heating which might occur were bare wire used. At the outset I was extremely nervous lest the fracture of this resistance wire should be a common occurrence, having had an unfortunate experience of this happening in the past on another class of work. It must be borne in mind that a failure of this kind is of so much greater importance than many other troubles, as a break in the primary circuit means a total paralysis of the car, with perhaps hours of work before the fault is located, let alone repaired. Actually the arrangement has proved quite successful; of many thousands so far made no single breakage has been brought to my knowledge.

One well-known American firm employs an air-cooled wire of high positive temperature coefficient, presumably pure nickel, wound on porcelain. My experience is that with a temperature rise that can be permitted - i.e. without fear of tarnishing the metal - the hot resistance of nickel is about 3 times the cold. This gives a convenient method of combining a moderate standstill current with an increased voltage on the winding at high speed, where it is most required. The device has been patented.

Automatic cut-off switches, in which the differential expansion of a brass-iron member heated by a coil wound round it is caused to trip the switch, have been on the market for some time. My experience is that with the cumulative effect of permissible shop variations in manufacture and the wide range of voltage over which the battery varies, and so on, switches of this kind have too narrow a margin between operating too quickly and not operating at all; either contingency is so embarrassing as to make the substituting of a hand-controlled switch preferable. They are apt to introduce complications of this kind unless very carefully made and calibrated, and are then apt to be expensive. Other methods, for instance a diaphragm in the induction pipe which closes a contact on the first suction stroke*, are being tried.

There is little doubt that when one turns from this problem to look at the magneto, one great drawback of coil ignitoon is at once displayed.

Cams and Contact Breaker Levers.

The usual arrangement for breaking the circuit is that the contacts are opened by the cam and closed by spring pressure. The maximum opening of the contacts is usually arranged to be about 0.4 m/m. If a smaller opening is provided there is very little margin for wear, while a larger opening is undesirable, as the forces acting at high speed are apt to be unpleasantly large and a greater gap increases them. The actual profile of the cam will of course depend on the ratios of length of make to break and on the ratios of distance from pivot to heel and pivot to contacts, whilst the acceleration during the beginning of the break period is also of much importance and must be taken into account. I find that cams made of case-hardening steel, hardened, carefully ground and finished to a high degree of polish give very satisfactory results and cause very little wear, provided that the cam is so shaped that the initial rate of opening (when it first strikes the lever heel) is not too great. The difference made if these precautions are omitted is surprising; the face of the heel will be worn down rapidly and after only a short run the contacts will hardly open, the timing be changed, and soon the coil will stop sparking. The ratio of time of make to time of break can be settled without much hesitation. The make period can be either quite short or comparatively long - both systems are in use. If a very short time of make is adopted there are two disadvantages to be faced; the current interrupted at low speed is necessarily higher than where a much longer make is provided, and sparking at

* Due to Mr. J. H. Barnett.

the contacts is more difficult to suppress; in addition, the arrangements for making and tripping the circuit, in order to ensure good wear, are necessarily more elaborate. On this account I have always employed a long make, of about two-thirds of the total period. With a very short make ~~the inductance must necessarily be~~ ~~and~~ the current interrupted will fall off rapidly with increasing speed. With a long make the coil time constant can be chosen so that only at the very highest speed is the current interrupted substantially less than the maximum (standstill) current. In order to employ as big a primary inductance as is permissible the time of make should be chosen as great as possible; there is the practical difficulty, however, that a very short break would necessitate a very narrow heel and a very quick lift, both making for undue wear; further, any increase beyond, say, a two thirds make period will mean only a relatively unimportant percentage increase in contact time. Two thirds make, one third break, or thereabouts, therefore, may be adopted as the most satisfactory compromise.

To reduce the shock due to the impact of cam on heel at high speed, to minimise the wear of the heel, and to avoid unduly stressing the lever, the rate of opening of the points should be as low as can be permitted. One writer[x] assumes that the cam is shaped so as to produce a sinusoidal movement of the contact lever during the first part of its opening, as in A, fig. 7.

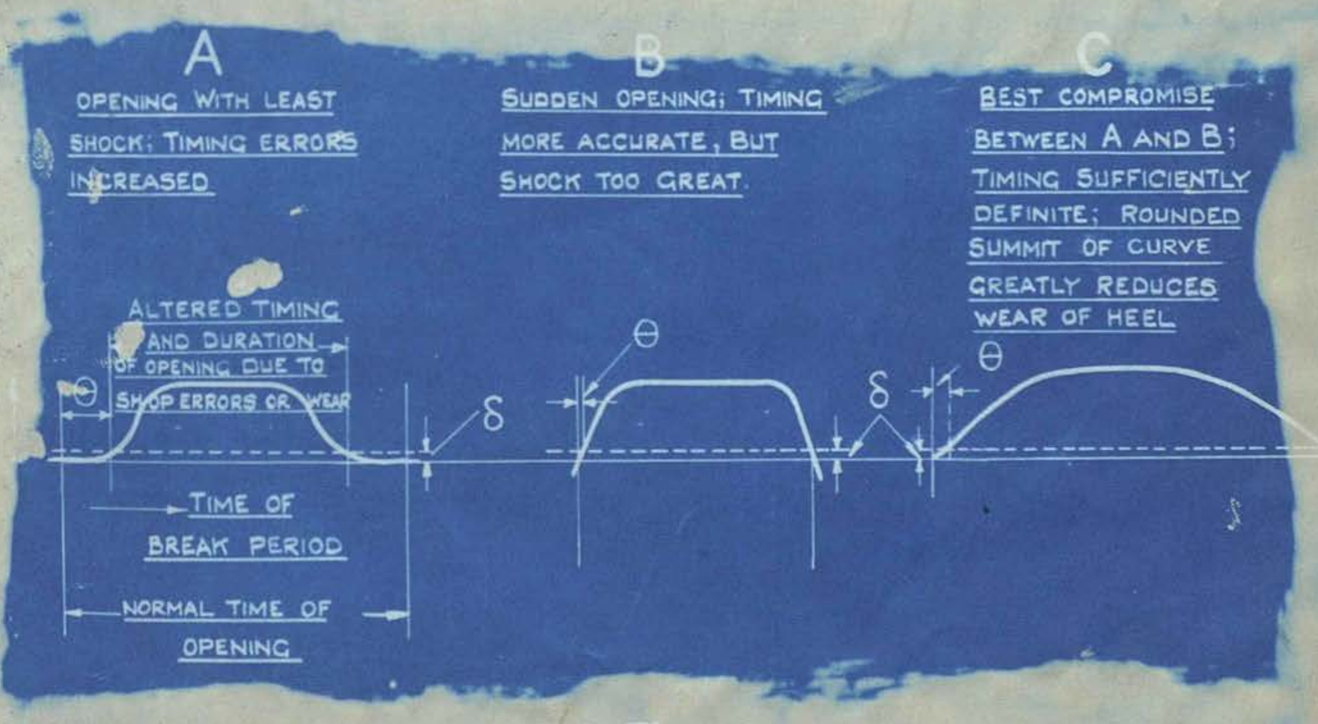


FIG: 7

x Mr A.P. Young.

As the total amplitude of the movement may be perhaps as little as 0.2 m/m. (this of course depends on the construction), and as the movement depends partly on the cam shape and partly on the exact bedding of the heel on the cam, an attempt to specify so accurately the displacement time curve of the lever is, in my opinion, impracticable. It has to be taken into account, too, that many engine makers demand that the firing intervals shall be extremely accurate. For instance, a maximum error of one degree (measured on the crank shaft) between successive firing angles is commonly asked for. This requirement calls for an abrupt opening, as shewn in B, fig. 7., which with accumulated variations due to manufacture or to wear for a given displacement of the lever, marked δ , representing the effect of these errors (or of the wear) produces only a small error of timing, θ . A displacement curve as shewn at A would not permit of the required accuracy of timing being maintained; for the same value of δ , θ will obviously be much greater; curve B would not only cause too rapid wear to the heel but, with the usual spring pressure, would cause the lever to fling badly at high speed, delaying the start of the next makeperiod, a very serious matter, as will be seen presently. A compromise such as is shewn diagrammatically at C produces, I find, good results and gives little trouble from any of the causes named.

Operation of the Contact Breaker at high speed.

It is of no great importance if a magneto contact breaker heel does not strictly follow the cam at high speed; a slight amount of flinging means that the break period is prolonged and the contact period correspondingly shortened; unless in an extreme case the instant of break, upon which the timing of the spark depends, will not be affected. There is always a large surplus energy at high speed, and a much shorter time of short circuit will generally be ample to provide a spark energy considerably in excess of what is sufficient at low speed.

With coil ignition, however, it is imperative that there shall be no flinging at all.

A coil designed to give with the least possible primary current not less than a certain definite spark utility at a stated maximum engine speed will at top speed break a primary current much less than the maximum. Thus any reduction of the time of make will mean, as illustrated in fig. 8., a further serious reduction of the primary current broken from i_1 to i_2 and of the spark utility.

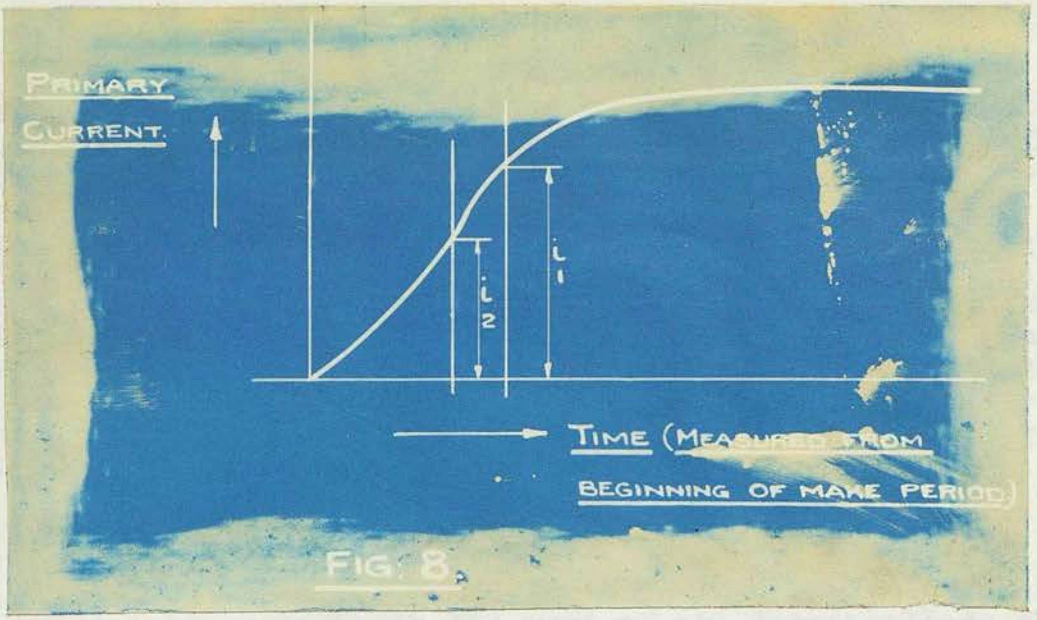
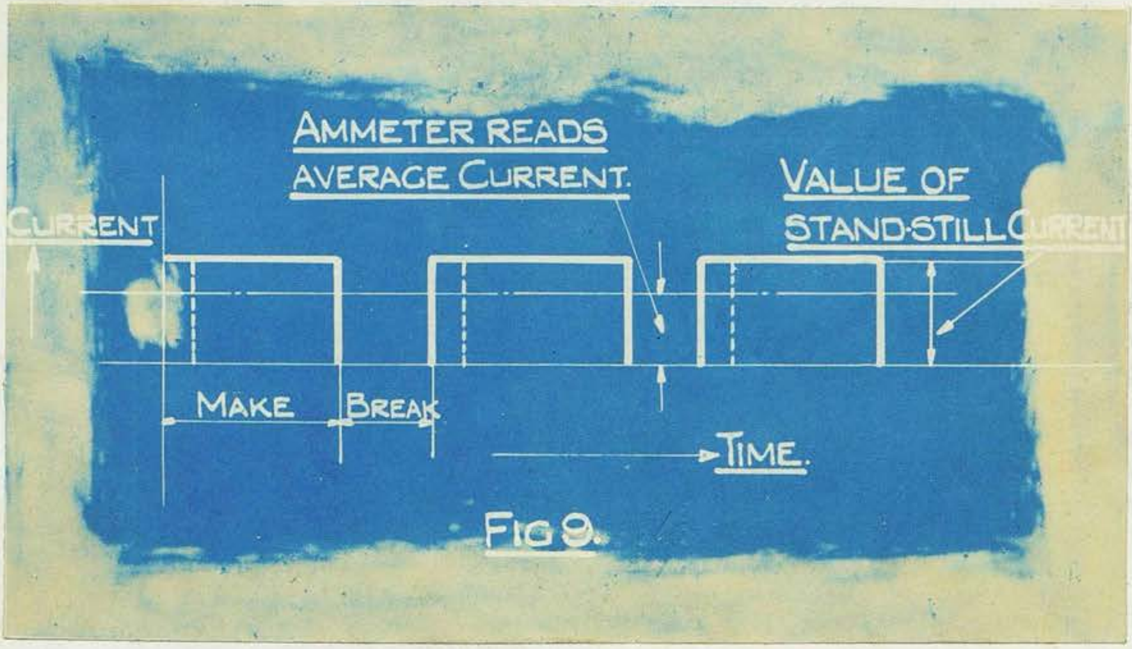


Fig. 8.×

I have found that a most useful method of testing the contact breaker for flinging is to measure with a moving coil ammeter the variation with speed of the apparent current in a strictly noninductive circuit interrupted by the contact breaker under examination. If there is no flinging the ratio of ammeter reading to standstill current should be independent of the speed, being determined solely by the proportions of the cam (see fig. 9).



× Shape of curve intended to indicate effect of saturation on rise of current.

If flinging takes place the instant of make will take place later, as shewn by the dotted line, and the ammeter reading will fall. When one is accustomed to watching the ammeter reading fall rapidly with increasing speed, as when the apparent coil current is measured, it seems remarkable to observe the performance of a carefully designed breaker; the ammeter reading will shew not the slightest sign of movement for a very large range of speed. The test is very helpful in clearing up all doubts on the score of cam shape, moment of inertia of lever, or spring pressure; it is obviously necessary to dispose of these matters before considering coil performance at high speed.

Spring Control.

If at the moment of opening the contacts the product of initial acceleration and the mass of the lever exceeds the spring pressure, the lever will bounce, the heel leaving the cam; if it returns before the cam is ready to let it drop the break period will not be affected; otherwise the break period will be lengthened. It is possible for the lever to lag behind the cam on the closing edge; it is also possible for the moving contact to bounce back after it has struck the fixed contact. Owing to any or all of these causes the break period is lengthened, and this must be avoided.

The lever must be made as light as is consistent with the strength required; the shape of the cam has already been discussed; only the spring pressure remains to be considered. This should not be excessive or the contacts will spread under the force of the blows and the heel will wear more rapidly. To provide nearly uniform pressure for large quantities of breakers with the inevitable small variations in dimensions of spring, fixing arrangements, and so on, that are bound to occur in manufacture, it is desirable that the spring should be under a large initial stress before the contacts open, and that it should not change much when they are open to the fullest extent. On the other hand, a spring exerting little pressure when the contacts are closed but increasing considerably with the normal opening will cause no additional hammering on the contacts and will be much more useful in preventing flinging. Should the heel fling clear of the cam this pressure would still further increase, the extent and time of the fling would be less and the heel being in the air no additional wear would be involved. A combination of both springs appears to me to answer best; in the contact breaker illustrated in fig. 10

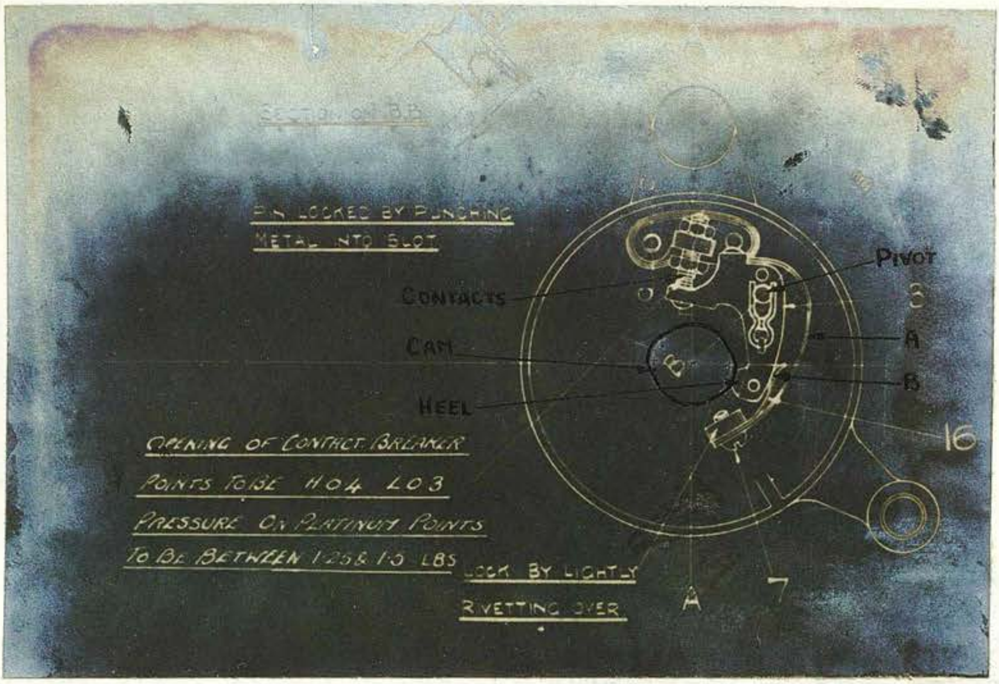


Fig. 10.

the uniform pressure is given by spring A, the spring B is much stiffer. The combined effect is shewn diagrammatically in fig. 11.

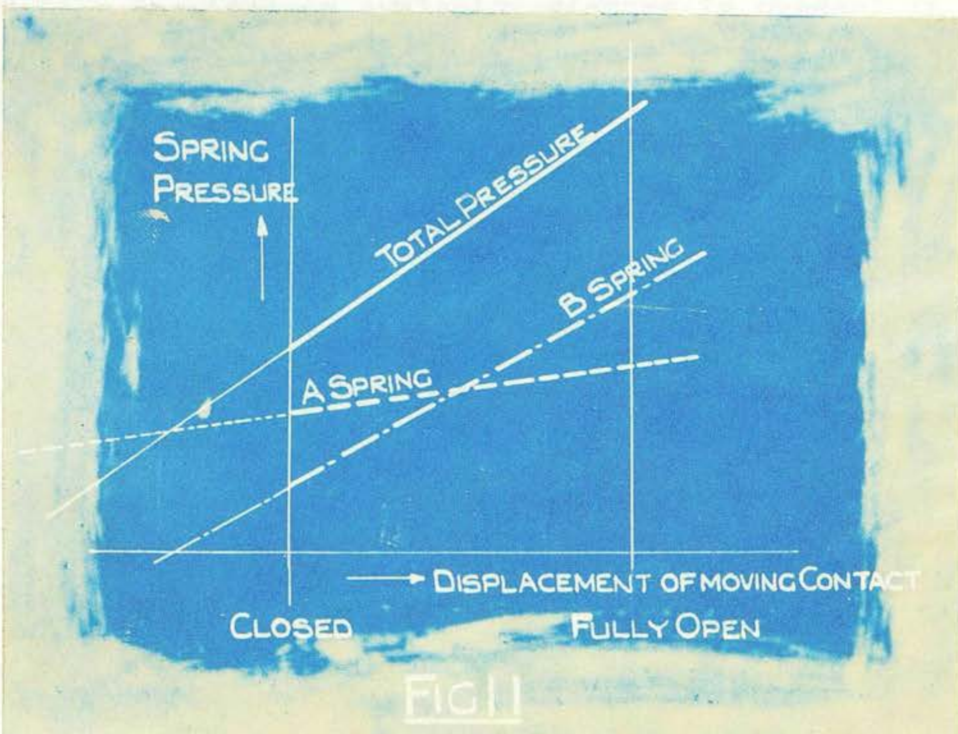


FIG 11

Pivots and Heels.

Trouble due to sticking magneto contact breaker pivots will be referred to later; I have never experienced more than a fraction of the trouble with coil ignition, large because a stationary lever can be employed with more room for the parts, and larger working forces. For convenience of manufacture I now use many common parts for both magnetos and for coil ignition, and all the remarks about magneto contact breakers apply here equally. It appears most satisfactory to make the heel of fibre or bakelite, choosing the direction of the grain so that wear takes place across the edges of the laminae, not across their faces.

IGNITION COILS.

Requirements to be fulfilled.

In one way there is much more scope for good design in coil ignition than in the magneto. Of the latter you may say "look after the slow speed performance and the rest will look after itself", but the former has no such single obvious limitation; the performance as a whole should be judged according to the degree with thich it fulfills several conditions which have a certain amount of independence of one another.

It is generally assumed by most writers on ignition that if a spark actually occurs at the plug ignition will follow provided an explosive mixture is present in the cylinder, that however much the spark energy be increased no increased power will result, and that if a spark takes place and no explosion follows, increasing the energy of the spark will not cause an explosion. Engine makers and designers will seldom accept these statements; the temptation to blame the spark for not being hot enough, when any trouble, the cause of which is unknown, occurs, is too great. Many times have I been told that when the spark energy has been increased, - e.g. by working a coil from a higher voltage - missing has been stopped; on investigation it always turns out that some other unsuspected trouble proves to be the cause, or that one or more plug circuits have so low an insulation resistance as to prevent a spark from occurring at all at the lower voltage. Of course, occasional missing of the spark is not uncommon under adverse circumstances, such as when the insulation resistance of the plug circuits approaches the limiting value below which the coil begins to miss, and as such occasional missing is very difficult to detect it is not unnatural to ascribe an increase of power with increase of coil energy to an increase of energy per explosion rather than to an increased number of explosions of the sameenergy.

Assuming then that it is necessary merely to cause a spark without regard to its character, the first requirement of a coil is to provide a spark which is quenched by the lowest possible insulation resistance; that is the utility * of the coil should be as high as possible.

So far as I know all writers on the subject of ignition ignore the fact that owing to more than one cause the spark takes place at high engine speed in a much lower compression than at low speed. There is a very good reason why they ignore it; they consider the subject exclusively from the point of view of the magneto, in which no use can be made of this fact; the energy of the magneto spark normally cannot but increase automatically with increase of speed. In fig. 12 particulars of a number of engines of different characteristics have been collected, from which it is seen that the compression at the moment of explosion may be less than half as much at high speed as it is at low speed.

CYLINDER COMPRESSION AT HIGH SPEED.

NUMBER OF CYLINDERS	MAXIMUM POSSIBLE COMPRESSION LBS/IN²	MAXIMUM ANGLE OF ADVANCE MEASURED FROM TOP DEAD CENTRE	APPROX ACTUAL COMPRESSION ALLOWING FOR THROTTLING AT HIGH SPEEDS AT STATED ANGLE OF ADVANCE. LBS/IN²	CORRESPONDING SPEED R.P.M.	RATIO OF REDUCED COMPRESSION. MAXIMUM COMPRESSION.
2	100	45	53	3000	0·45
4	100	45	56	3000	0·45
4	130	50	63	3700	0·38
4	100	45	45	3000	0·45
4	100	45	58	2800	0·45
4	130	50	45	3300	0·35
6	100	45	45	2500	0·45

FIG: 12.

Fig. 12.

* If R is a resistance in parallel with the spark gap and is such that it causes the spark to miss occasionally, $10^6/R$ is termed the coil utility at that voltage or for that spark length.

Assuming, as appears reasonable, that a uniform factor of safety is desirable at all speeds and that the value of the utility is a measure of this factor, the coil should be designed to give approximately equal utilities at low and at high speeds, the latter being measured at reduced pressure, or if measured in air, at a reduced gap langth corresponding to the lower pressure chosen. This statement needs a little qualification. Owing to condensation taking place on plugs and terminals when the engine is cold, starting (that is,- slow speed) conditions are rather worse than subsequently when the engine has warmed up and the moisture has been evaporated. Thus the slow speed utility may well be a little more× than the high speed value, even when the difference of pressure is allowed for. This may be considered the second requirement.

Another requirement is that the coil should spark at as low a voltage below that of the normal battery as possible. When a starter is operating from a nearly exhausted battery, especially when the engine is cold, the battery terminal voltage may be very low. It is in such circumstances that the highest utility may be required. Apart from starting it is an advantage if the coil will operate from an almost exhausted battery. Another great advantage is gained if in the absence of a battery altogether a driver can in an emergency get sufficient energy from a refill for a pocket electric torch; a standard 3-cell refill will give about 2 volts 0.5 amperes; the latest standard coil I have designed will operate at 1.5 volts (normal voltage 6) taking a running current of .3 amperes or less. Thus this requirement can easily be fulfilled.

Lastly, the current consumption should be low, the lower the better. The designer's problem is to meet all these requirements as completely as possible.

The Design of the Magnetic and Electric Circuits of an Ignition Coil.

In 1918 it became necessary to prepare for the manufacture, in large quantities, of ignition coils for high speed 4-cylinder engines. So far as I am aware, the design of ignition or induction coils has been considered by few of the authorities on the design of electric apparatus, and by none of them in any detail. Professor Taylor-Jones' papers* shewed how complex the subject was, but did not readily permit any conclusions being drawn which would be of much assistance to the designer, at all events not without prolonged experiment, for which there wqs then no time. Recent experiences incline me to believe that even from a commerical point of wiew there is a

*. Republished in book form under title "The Theory of the Induction Coil" 1921

× I now work to a ratio of 3 to 1, both values being measured, for convenience, with the same gap length.

great deal more to be considered than appears at first sight, and the subject seems to grow the more closely it is studied. Wiewed with later knowledge, my earlier designs appear sadly out of date; however, in order that this may be an accurate record of work done, in the following pages I have first described the methods I employed in 1918 in order to obtain satisfactory results; later improvements are then described, and finally the nearly closed circuit coils which I am at present designing.

I first made an analysis of the chief features of the best known ignition coils then on the market; two or three were made by American firms and one by Bosch. None of these afforded very much useful information. I was told that the former did not prove very reliable, that insulation breakdowns were too frequent, and that contact wear was excessive, perhaps owing to too great primary current. The latter were used chiefly in conjunction with magnetos, the coils being apparently designed only for starting and were evidently not suitable for running at high speed.

An engineer, unused to the problem and with scanty information to guide him, who wishes to design a transformer, may conveniently proceed by assuming a definite magnetic circuit, and calculating suitable windings to link with it; the performance may then be worked out in detail, the initial assumptions modified in whatever direction is indicated by the results, and the calculations repeated to obtain a newresult, the procedure being repeated until the most satisfactory solution is arrived at. As an induction coil somewhat resembles a transformer I adopted this procedure.

Alternative Forms of Magnetic Circuits.

Most induction coils have only a core of magnetic material, the circuit being completed through an air path; unless the outer diameter of the coil is small in comparison with the core length the linkage of flux with the outer layers of the windings will be far from complete. Presumably to overcome this difficulty Bosch used a core with circular laminated cheeks, of the diameter of the top of the coil, fitted at either end. No one so far as I know has employed a magnetic circuit more nearly closed than this. Apart from the effect on functioning I considered that there was an objection to covering the coil in with iron over the top of the windings, as with the H.T. end of the secondary winding outside - the usual procedure - very thorough insulation would have to be provided between the winding and the iron (the latter being at earth potential) so that both the overall dimensions and the cost would be increased; the secondary capacity would also be increased, and this I found was apt to lower the spark utility.

Both theory and experiment shewed that the flux linkage with the secondary turns in a circuit of this shape was quite good. The magnetic circuit, shewn full size in fig. 13,

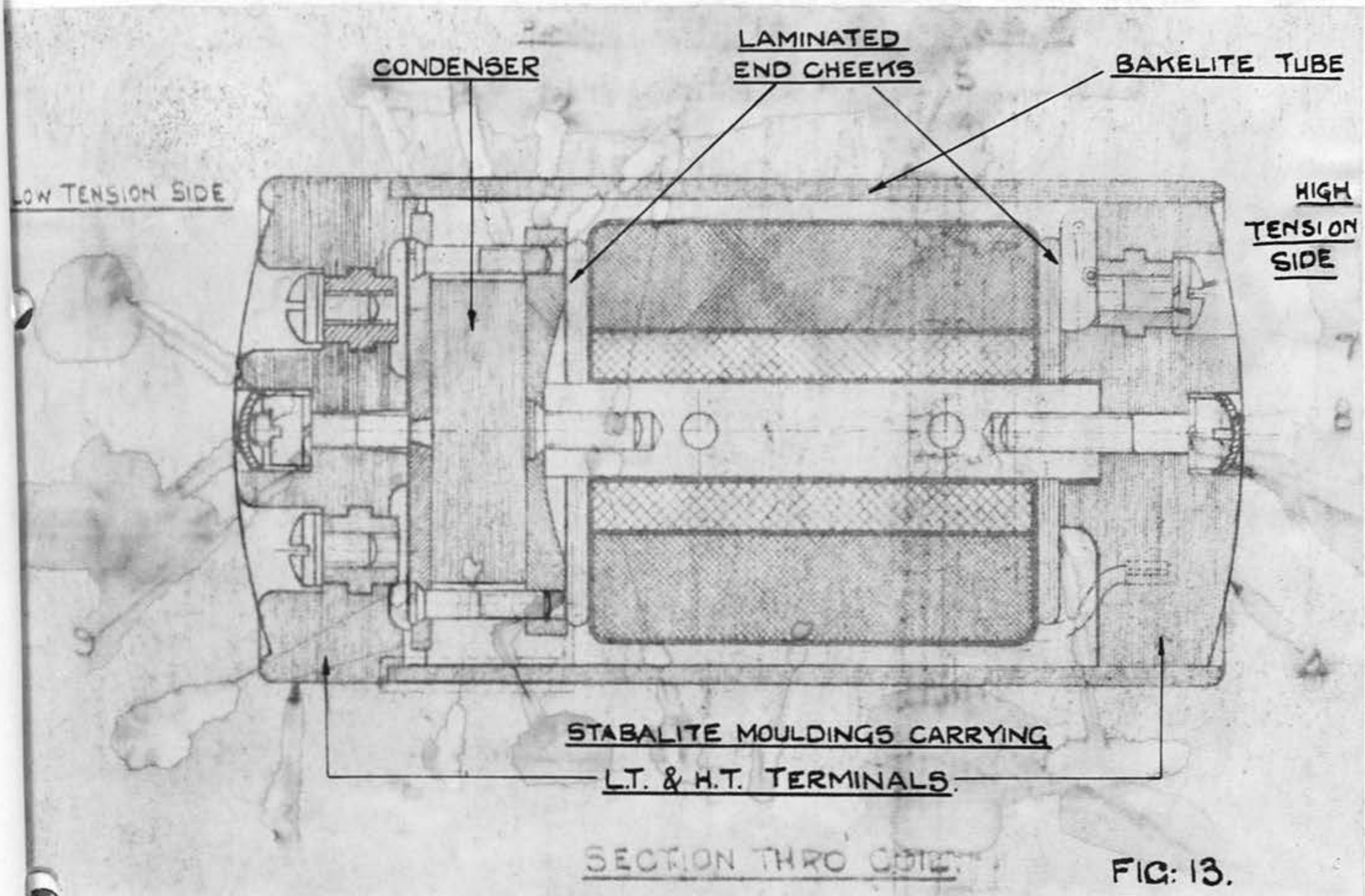


Fig. 13.

was accordingly adopted, and for this it wasfound that (with equal primary and secondary turns)

$$M = 0.85 L_1$$
$$\Phi = 17.5 I_1 T_1$$

both relationships being approximately true for low densities in the core; with the dimensions and number of turns adopted this linear relationship was never substantially departed from. With a construction employing iron core only it was found difficult to increase the value of M much above 0.70 L_1. It may be noted that with the use of the end cheeks the field due to the primary does not ~~with this form of construction~~ stray over so large a space; a circle of twice the diameter of the end cheeks would embrace probably more than ninety per cent of the total flux. If a magnetic core only is used the same percentage of the total flux would be enclosed in a much larger volume, of much greater length than the coil as well as of increased diameter. As the coil may in practice be mounted close to a large mass of solid metal, either magnetic or nonmagnetic and with low resistivity, such as aluminium, the partial screening provided by the iron end cheeks is a second advantage possessed by this form of circuit.

The Primary Winding.

Assuming in the first instance that the steady current consumptionof the coil when the contacts are closed is already fixed by conditions imposed on the designer, such as the size of battery to be employed, the charging current of the dynamo, and so on, there will be a definite number of primary turns which will give the best high speed performance.

The equations governing the optimum number of turns are

$$\Phi = 17.5\, i_1 T_1 \quad \text{---- (i)}$$

and. $$i_1 = I_1\left(1 - \varepsilon^{-\frac{tR_1}{L_1}}\right) \quad \text{---- (ii)}$$

L_1 is given by the expression $$\frac{T_1 \Phi}{10^8\, i_1} = \frac{17.5}{10^8} T_1^2 \quad \text{-- (iii)}$$

The coil to be designed had the following constants

E_1	12 volts	R_1	6.67 ohms
I_1	1.8 amps	t	6.67×10^{-3} secs.

These values were inserted in the above equations and values of i_1 for different values of T_1 were worked out; the product of i_1 and T_1 were then plotted against T_1, as shewn in fig. 14; the maximum value of $i_1 T_1$ was found to be 550 occurring at a value of T_1 of 420

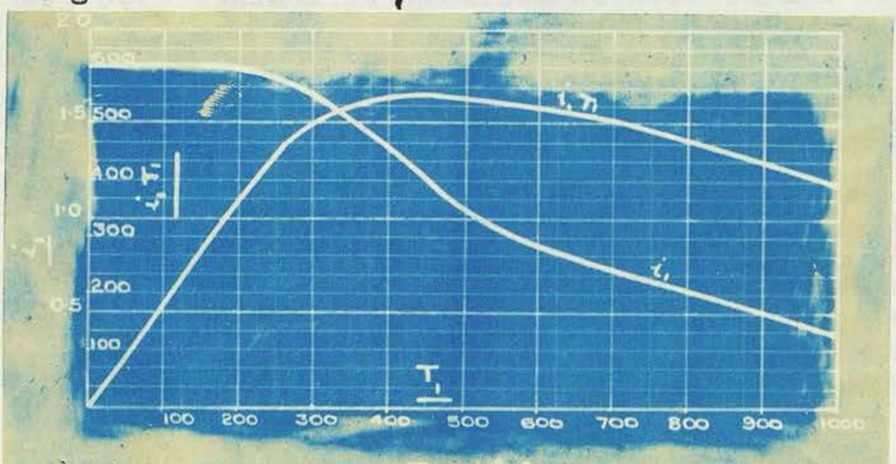


FIG 14.

The same solution could of course be arrived at analytically, but with higher flux densities equation (1) can be represented only by a magnetisation curve, while L is no longer a constant and must be represented by further reference to the magnetisation curve, so that in general a graphical solution is the only possible one.

The number of turns actually decided upon was 350 instead of 400, the optimum value already found. The smaller number was chosen, as a lower inductance meant less tendency to spark at the contacts and the peak was not very pronounced.

The number of turns decided, the size of wire was settled by assuming that if the driver omitted to switch off, and the engine stopped in such a position that the contacts were closed, the standstill current would raise the coil to about 80° C. About 10 watts could be dissipated in the coil with this temperature limit; the rest of the power, 11 to 12 watts, was absorbed in an air-cooled series resistance, outside the coil.

Secondary Winding and Insulation.

Secondary voltage is determined by the number of secondary turns and the rate of decay of the flux. Over the latter factor the designer has no control, it being taken for granted that all active iron is laminated as much as possible; as for the former, sufficient turns must be provided to permit of a reasonable low voltage performance. With 24,000 turns, the number chosen, the secondary would spark across a 5.5 m/m. 3-point gap (9,000 volts, say) with slightly less than half the normal voltage; this was then considered good enough. S.W.G. 42 enamel insulated copper wire was employed for the secondary conductor, there being about 60 layers, and 400 turns per layer. If the voltage at which the safety gap operates is assumed to be, say, 15,000, the maximum voltage between layers will be 500. The peak of the pressure wave may well be considerably higher than the value assumed, however, so I decided to insulate between layers with varnished paper, doubling the thickness over the half layer at the end at which the voltage was the maximum. The insulation between the outer layers of the coil and the cheeks had to be very thorough; I used washers of varnished silk, empire cloth, and leatheroid, the last adjoining the cheeks; I found that with a reasonable amount of insulation properly disposed, no brush discharge could be observed from the coil in the dark.

Several thousands of these coils were made, and have proved successful, insulation breakdowns from one cause or another having occurred in only five coils (so far as I can tell) up to the present, the failures from all causes including such mechanical failures as broken or severed connections not being many more.

Coils with Improved Performance.

No great improvement in the design of any particular apparatus can be expected until a reliable and accurate method of testing and comparing performances had been developed. I attempted to estimate the ignition value of the spark by the following means:-

(a) By finding the greatest gap the spark would jump without occasional missing.

(b) By direct measurement of the spark voltage.

(c) By measuring the spark current.

(d) By measuring the spark energy (in a calorimeter).

As other investigators have shewn, many interesting and curious results may be obtained from such tests, but their interpretation is a difficult matter, and their value now seems small. The test of 'utility', as defined on page 19, which seems by far the best yet devised, was introduced, so far as I am aware, by a committee of the British Ignition Apparatus Association. One authority on magnetos, Mr. E.A. Watson, employs as resistance a step-down transformer and varies a resistance connected across the low tension circuit. I have avoided such an arrangement thinking that probably spark generators of different characteristics - e.g. in wave form or frequency - would with an equivalent resistance of this nature give misleading results. I first used a high resistance consisting of rods formed of a mixture of carbon and non-conducting material; the resistances were high enough but had an unpleasantly high temperature coefficient. Mr. J.D. Morgan pointed out to me that in addition, owing to the nature of the discharge, there might well be an effect similar to what takes place in a coherer and that the rods might therefore be unreliable. He suggested a water-column. This I tried, found to be very convenient, and have used ever since. All that is necessary is a number of water columns in glass tubes of varying diameters; the resistance of each may be varied by means of a movable electrode; the amount of the resistance can be measured by a megger.

The coils referred to above were built before I had made much progress in utility testing. A comparison of the utility of this coil with that of a standard magneto at high speed (see fig. 16, No. 1) suggests that the performance of the former might with advantage be improved. It is difficult to say exactly how large the utility ought to be made, as the question obviously depends on plug insulation and other quantities which may vary very largely. Many of these early coils have been use for winter and summer without ever causing misfiring. Missing at one or more plugs on starting has sometimes been reported in very cold weather owing to petrol condensing on the plugs, which do not thereafter spark until they have been dried. It is difficult to say whether this was not a fault of carburation rather than of ignition, but the coil might have functioned better with an increased utility. There is no necessity very greatly to increase the utility; apart from the expense, the additional current consumption, and so on, the plug electrodes would burn away too quickly; further, experience shews that if the resistance of the plug circuits is very low it is due to abnormal and unsuitable conditions; either they will quickly improve - as by the evaporation of moisture - or grow worse, causing a short circuit - as with overheated or cracked plugs, etc.

A utility of, say, 10 means that there would be a H.T. leakage current at 10,000 volts of 0.1 amperes, in addition to the spark current. Unless the skin effect is great the resistance drop in the coil with this current would not be large, but the reactance voltage may well be considerable, as the effective frequency at which the discharge takes place must be high. Thus if, as in the coil described above, the secondary turns are many more than are necessary, at normal primary voltage, to give the necessary secondary voltage, reducing the number of secondary turns will lower the internal drop and increase the utility.

Experiment proves this to be the case. In fig. 15

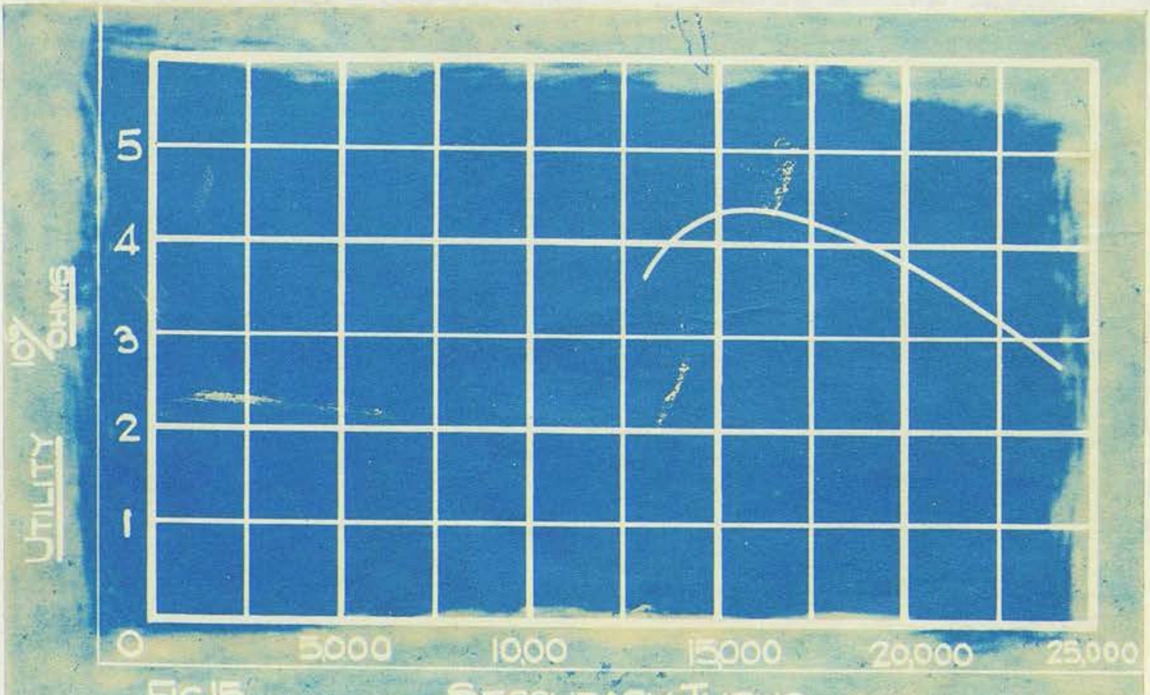


FIG 15

are plotted the results of a test made on a coil, the utility of which was measured with a fixed primary winding, primary current, condenser, and magnetic circuit, but the number of secondary turns of which were varied. This suggested a way of increasing the utility of coils of earlier design. A reduction of secondary turns however meant a worse performance at low voltage; this I found could be remedied by carefully increasing the primary ampere turns as much as possible, without causing contact sparking or increasing the time constant so as unduly to prejudice the high speed performance. Further tests on contact sparking shewed that the inductance of the early coils might be increased by a substantial amount without danger, and considerations such as those shewn in fig. 11, page 19, indicated that the high speed utility might with safety be allowed to drop. The necessity for high primary and low secondary ampere turns to develop the greatest possible utility in the magneto has been pointed out by Mr. E.A.Watson;* the same is evidently true of the ignition coil, for which the low voltage test corresponds to the low speed test in a magnet.

A further series of coils was made embodying the modifications just considered; the performance of these coils shewed a considerable improvement over the earlier types. The variation of utility with speed and spark length with voltage are shewn in figs. 16 and 17. The figures of merit of a number of coils of different design are tabulated in fig. 18.

The numbers shewn on the curves in the first two of these figures refer to the coils tabulated in fig. 18. In fig. 16 the early type of coil described above, and numbered 1, has a rather worse performance than number 6; the latter however has almost twice as many secondary turns and a different type of magnetic circuit. Coils 4 and 8 had the same magnetic circuit as coil 1; coil 4 was designed for specially high speed engines for racing; all the foregoing were for 4-cylinder engines. In coil 8 for a 2-cylinder engine advantage was taken of the increased time of make, to increase the primary inductance. The two-cylinder engine runs twice as fast as shewn on the speed axis. Coil 12 is built with a nearly closed magnetic circuit and described below. In figure 17 the danger of a large number of secondary turns (coil 6) is shewn; the performance with a variable voltage shews that although this coil gives an excellent spark with low voltage it is entirely dependent at normal voltage on the safety gap for keeping down secondary voltage in the event of a break in a plug lead. If the safety gap is disconnected or accidentally widened the H.T. voltage at normal battery voltage will rise

*I.E.E. Journal, Vol. 59, No. 301.

dangerously, thus risking an insulation breakdown.
In working out the figures of merit tabulated in fig. 18, column 14 , the slow speed utility has been chosen, unless the high speed uitilty is less than one third of that at low speed, in which case three times the high speed values has been employed. This is done on the assumption that the best conditions are when the windings are so proportioned as to give the three to one ratio.

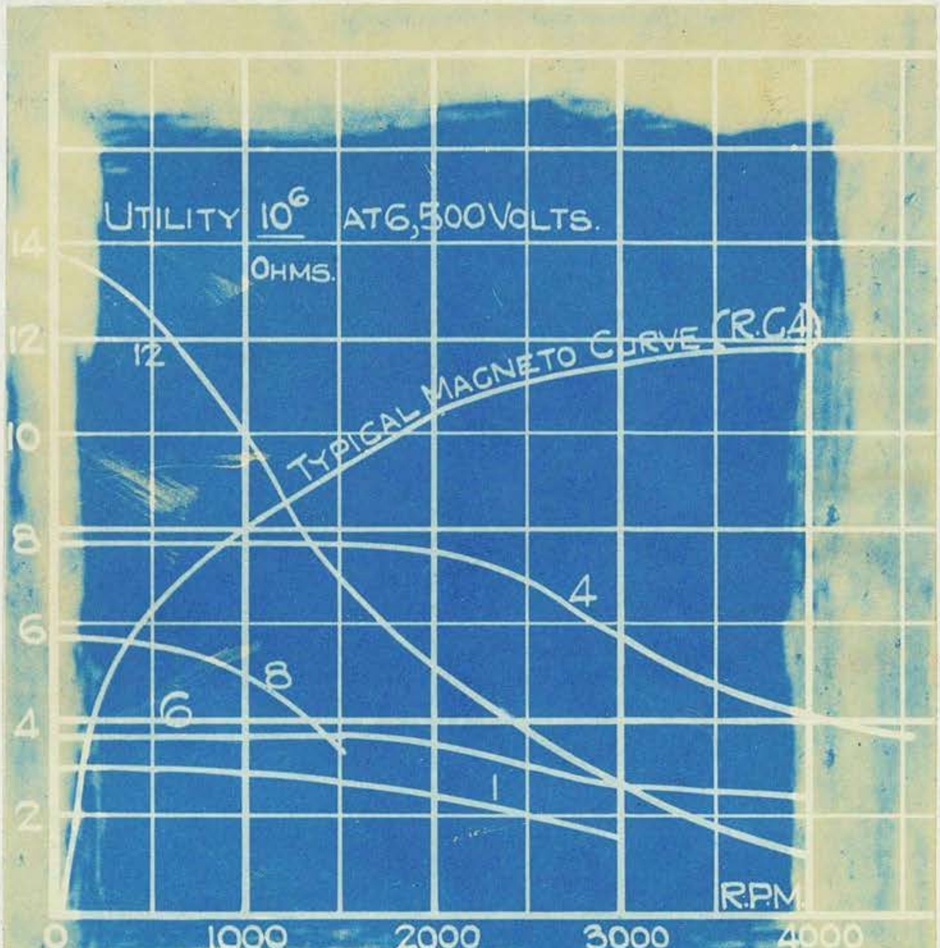


FIG. 16

Coils with nearly closed magnetic circuit.

Believing that the limit of improvement obtainable by varying the windings had been reached, I next made some experiments with the object of obtaining a still better performance by modifying the magnetic circuit. I first attempted to see to what extent the air gap path could be reduced, and thus the primary M.M.F., for a given flux, without interfering with the performance. As a preliminary I made a test to determine the coercive force of Lohys steel, and found that this varied between 1 and 2 H. I then made up a magnetic circuit with a very short gap, and calculated its magnetisation curve, and also the residual flux left in the circuit on opening the contact breaker. So far the test results shewed close agreement with this. Although the length of gap was chosen so that the flux drop on switching off was a maximum, the performance proved to be not so good as when a larger gap and smaller flux was employed. I attributed this apparent discrepancy to the form of the magnetic circuit adopted. I had made the coil as shewn in fig. 13, adding a laminated yoke registered into the end flanges; presumably the lamination was not sufficiently good at those parts in the circuit where the mechanical construction introduced joints. I accordingly

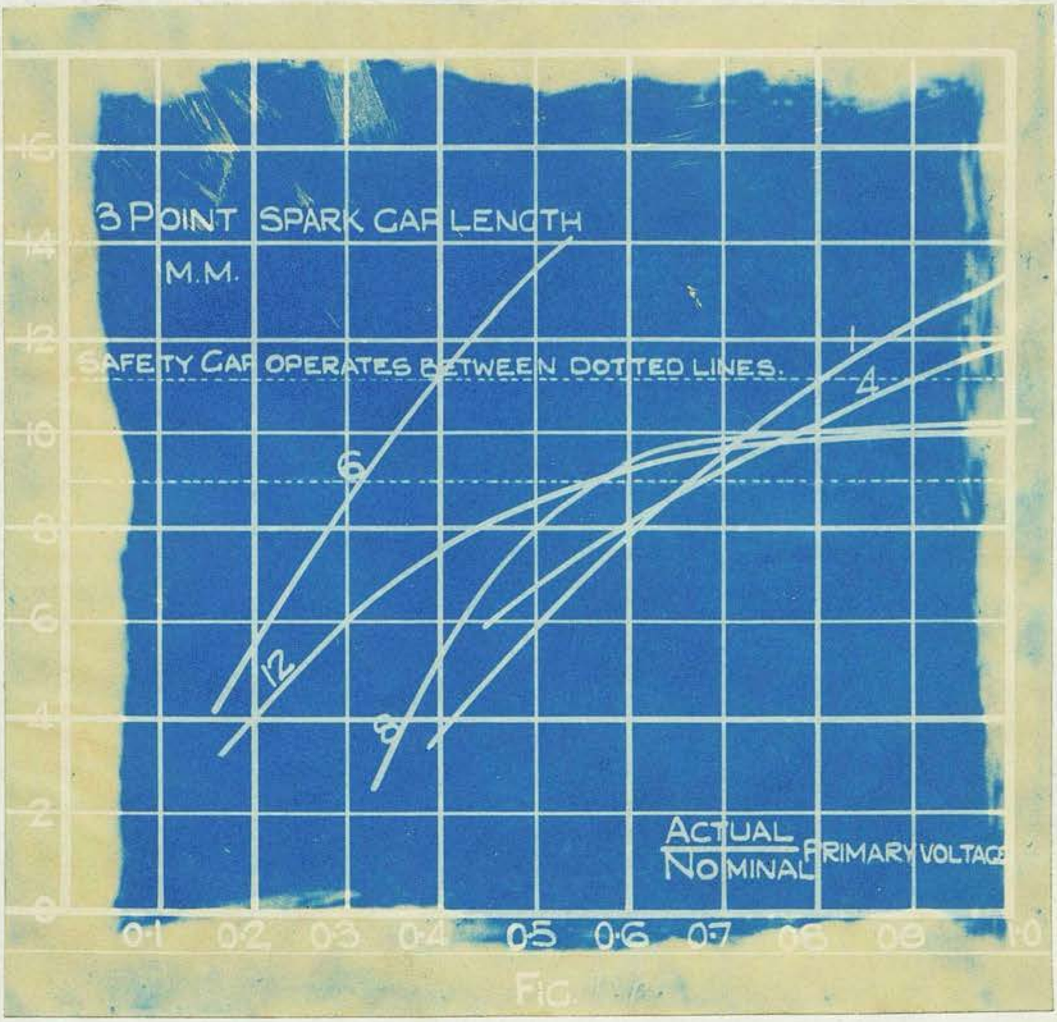


FIG.

made up coils having joints interleaved and the whole circuit arranged as in a shell type transformer. This form gave better results than before, but I still found that the maximum active flux (that is to say the difference of flux which takes place on switching off) did not give so good a performance as when a larger gap was chosen. On further consideration it appeared that at least two improvements might be made. If the gaps were split up into several places in series in the magnetic circuit the length of gap at each joint and consequently the eddy currents produced by whatever proportion of such flux as strays across the plane of the lamination, would be reduced. In the second place there appeared to be an advantage in locating one or more gaps in the core on which the primary winding is wound, particularly if one of the gaps is made in the middle of the core, as obviously the flux fringing across the gap, and consequently any eddy currents, should be less here than anywhere else in the circuit. Further experiments proved this to be the case. I made up coils with three very short air gaps, one in the middle of the core and one at each end. The results obtained from coils of this type were not only much better than any previously obtained but the best performance occurred with a much shorter gap and at much higher flux densities than before. It would seem to appear from these results that with more careful lamination ot the circuit the length of air gaps which gives the maximum active flux also gives the best sparking performance. The results of tests carried out on nearly closed circuit coils are shewn in figs. 16 and 17.(№ 12) It will be seen that the all-round improvement, taking into account the cost of production, in which the number of secondary turns and the capacity of the condenser form a high proportion, the reduced current consumption, and the other quantities involved in the figure of merit, is very considerable. An incidental discovery was made that sparking can be suppressed by means of a much smaller condenser than was necessary with the open circuit coils. In the latter a condenser of capacity from .10 to .15 microfarads was required, the cost of manufacture of which alone amounted to several shillings. With the nearly closed circuit coil a condenser of only about 0.04 to 0.06 microfarads proves to be sufficient; I presume that the matter is connected closely with the nature of the voltage wave producing the initial discharge which goes to form the spark. Further advantages of the nearly closed circuit type coil are described in Patent Application No. 11727/22., a copy of which is sent herewith.

Ref Nº	Description of Coil	Values measured at standstill of: Volts E_1	Amps I_1	Watts E_1I_1	I^{ary} Amp Turns I_1T_1	Flux Φ	Number of Secondary Turns T_2	$\frac{\Phi \times T_2}{10^6}$	Capacity C_1 in Microfarads	Utility at Low Speed	Utility at 3500 R.P.M. (4 Cyl. Engine)	Ratio of Lowest/Normal Volts to Spark 5·5 M/M Gap	Figure of Merit $\frac{11}{5 \times 13}$	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Magnetic Circuit	12	1·8	21·6	630	11,000	24,000	264	·17	3·0	1·0	0·48	0·29	
2	of all coils	6	3·6	21·6	720	12,600	24,000	302	·13	2·5	0·8	0·36	0·32	Similar to Nº 1.
3	constructed as	12	2·0	24	680	14,000	14,000	196	·17	6·25	3·9	0·575	0·46	For high speed engines
4	shown in Fig: 13	6	4	24	730	12,800	15,000.	192	·13	7·7	4·9	0·42	0·77	For racing engines –
5	Windings as Tabulated	8	5	40	850	14,800	24,000	355	·17	4·4	3·7	–	–	Extra high speed.
6	Iron Core only – No cheeks	12	2	24	1460	10,000	45,000	450	–	2·9	0·7	0·19	0·625	By another firm.
7	Similar to 1–5	6	2	12	1240	22,000	19,000	420	·17	7·7	–	0·35	—	Unsuitable owing to Contact Sparking
8	For 2 Cylinder Engines	6	1·7	10·2	800	16,000	19,000	304	·17	5·7	–	0·41	1·36	Replacing Nº 7
9	Nearly closed circuit coils: Cylindrical Yoke.	7	2·6	18·2	520	15,800	9,000	142	0·03	5·9	3·5	0·4	0·81	
10	Nearly closed circuit coils, shell type circuit: 1 M/M Gap at Core Ends	6	2·8	17	840	15,100	10,000	151	0·036	8·0	2·5	0·525	0·84	
11	Nearly closed circuit coils, shell type circuit: 0·2 M/M Gap at Core Ends. 2·0 M/M Gap in Yoke	6	2·8	17	840	22,000	10,000	220	0·036	11·0	1·6	0·433	1·49	
12	Nearly closed circuit coils, shell type circuit: 0·2 M/M Gap in Middle of Core 0·2 M/M Gap at Core Ends	6	2·8	17	840	28,800	10,000	288	0·045	12·5	4·3	0·25	2·94.	Best Performance
13	Nearly closed circuit coils: As in Coil 12 but with Cylindrical Yoke.	6	2·8	17	840	27,600	10,000	276	0·045	10·5	2·2	0·325	2·1	

Fig: 18

MAGNETO IGNITION.

Preliminary.

Practically all the literature that has been written on the subject of magnetos is the work of the last four or five years. When first I had to design a magneto there was very little information to fall back on; perhaps the greatest difficulty of all was the absence of any definite and accepted standard or unit by which the performance of a machine might be judged, and much time was fruitlessly spent in attempting to measure quantities which afterwards proved to have little or no relation to the essential requirements. Bosch had been at work for many years on the subject, but had kept his conclusions to himself. The Bosch patents, over a 100 in number, are of considerable interest, but refer chiefly to small mechanical features, and principles are hardly referred to at all. However, there were magnetos of many types and sizes in existence, and in the absence of a theory it was necessary to construct one, checking it by continual reference to test results. In designing I began by following closely on the lines of the Bosch machines, but very soon found that it was desirable to deviate from these in one way or another; in the latest types I have designed there is very little resemblance to a Bosch or any other machine except in the principle of operation. Reviewing my early experiences and in the light of later knowledge I consider that the Bosch magneto owed its reputation to its superlative workmanship, that its electrical performance was only fairly good, and that its mechanical design was unnecesarily intricate. The last feature was the cause of many of my early difficulties and some failures. I now think that the root of much trouble lay in the unsuitability of German design for reproduction by English labour; later designs have shewn that such troubles need never have occurred.

It will be understood that a chronological account of work designed and carried out would be a somewhat confused account of theoretical considerations, imperfect designs, test results, and fresh beginnings. For the sake of clearness I have grouped together all similar matters without referenceto the order in which they were considered; certain matters to which I refer have already been dealt with by others working in the same field, but I have not thoughtit necessary on that account to exclude my own results; where I have been indebted to anyone for information I have stated it.

Output and Input - Figure of Merit.

One of the greatest difficulties with which, in common with other investigators, I was faced at the outset was to decide what was to be considered as the output of the magneto; much valuable time was at first wasted (so I now think) in attempting to measure spark energy, and so on. The only quantities which appear to be of real service as measures of the output are the reciprocal of the least speed at which the magneto will spark across a standard gap, and the 'utility' developed at a standard high speed. The latter denotes the greatest conductance which can be paralleled with the standard gap before missing commences; if it is assumed that conductance at a fixed voltage measures the current, then utility may be treated more or less as an output. In order to make a just comparison between magnetos of different design, however, it is not sufficient to compare only their utilities; the slow speed performance should also be brought into account, since by varying the secondary turns the one may be improved at the expense of the other, both the utility and the minimum sparking speed varying approximately inversely with the secondary turns. Input, if the magneto were viewed as an alternator, would be the mechanical power required to drive the machine, the excitation of which is provided from a separate source - the magnet. Actually neither input nor efficiency are of much interest to the designer; the magnet, however, which is the chief factor in determining both the output and the main dimensions of the machine, should be introduced into any expression to be used as a figure of merit. In fig. 19 (a) a portion of a magnetisation curve is shewn; to establish an armature flux ON a magnet flux $OQ = \phi_t$ is required, and, allowing for armature reaction, ampere turns of value $OR = \bar{A}$. In fig. 19 (b) STU is part of the magnet hysteresis loop; if a magnetof cross-sectional area A and length L are chosen, while OV = x and TV = y, them the relationships exist

$$\left.\begin{array}{l} yA = \phi_t \quad \text{or} \quad A = \phi_t / y \\ \text{and } xL = \bar{A} \quad \text{or} \quad L = \bar{A}/x \end{array}\right\}$$

thus the magnet volume

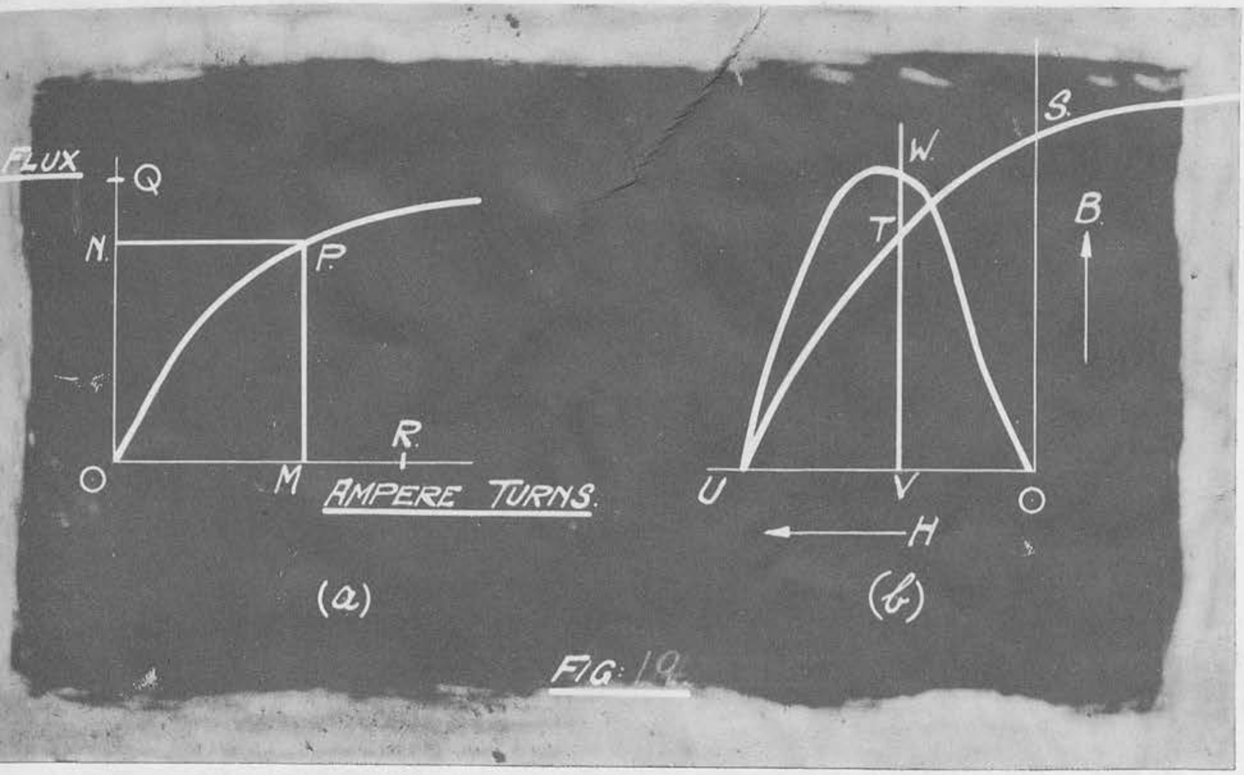
$$V_m = AL = \phi_t \bar{A} / xy$$

and will be a ~~maximum~~ minimum for given values of ϕ_t and $\bar{A}$ when xy is a maximum. OWU represents the product zy plotted against values of H. If it is assumed that a magneto is designed so that it operates in the region of the(BH) max. product, ot in other words that the magnet is used to the best advantage, the product $V_m (BH)_m$ will serve in place of input and will enable comparisons to be made between machines of different sizes, as well as with magnets of different materials. A figure of merit may be made with the quantities referred to above in the form

$$\frac{\text{Utility}}{\text{Least sparking speed} \times \text{magnet volume} \times (BH)_m}$$

or in symbols

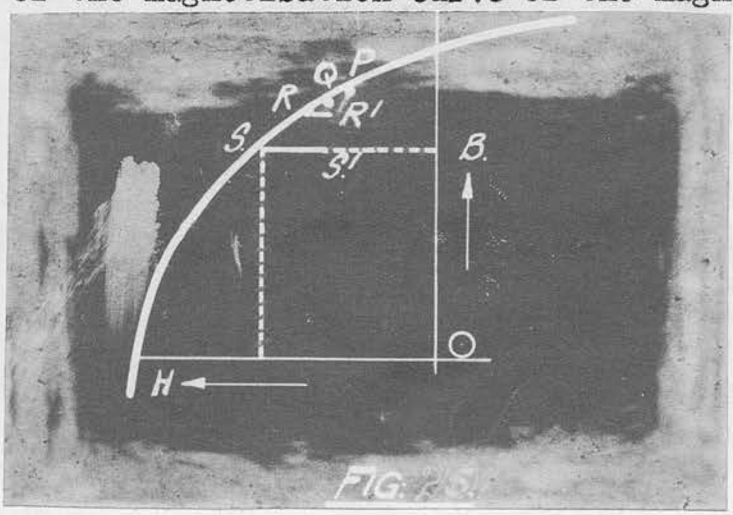
$$M = \frac{U}{N.V.(BH)_m}$$



It may be considered as the utility generated per unit of magnet available energy, reduced to a common standard slow speed performance; to a certain extent this corresponds to the output coefficient used for other classes of electrical machinery.

Equivalent Magnetic Circuit of a Magneto.

If a magneto, assembled before magnetising, is magnetised by means of an electromagnet, on switching off the exciting current the magnet flux will fall to a value slightly below that corresponding to the remanence of the steel. In fig. 20 a portion of the magnetisation curve of the magnet is shewn;



P may be considered as the point referred to. If the magneto is removed from the electromagnet the reluctance of the machine being greater than the joint reluctance of machine and electromagnet, the flux will fall to some lower point on the curve Q. If the rotor is now rotated, it being assumed that the machine was magnetised in the position of minimum reluctance, there will be a further drop to R, the magnet describing at each revolution a small subsidiary loop RR′ , at practically constant flux. There will be a final flux drop if the primary and secondary windings are short circuited and the machine is run at high speed; the machine thereafter will operate on the loop SS′. The best value for S will be where the corresponding BH product has its maximum. I consider it good practice to make a point of short circuiting the armature before beginning to test the normal performance; although much higher flux and a batter performance (10 to 20 per cent) are obtained if this is not done, an instant's short circuit, or a run at high speed, retarded, both of which may happen in practice, at once reduces the working flux to the lower value. Once this drop has taken place the magnet is to all practical purposes permanent. I have newer come across a case where there has been a subsequent drop of flux which could be attributed to ageing ; magnetos commonly spark worse after prolonged running, but this can be accounted for entirely by alteration of the contact breaker timing through wear, by surface leakage across the high tension insulation, or by some other cause. It can be assumed then that the magneto operates with substantially constant magnet flux, independent of the position of the armature or of its M.M.F., and whether the latter consists of forward or back ampere turns. In most magnetos the leakage flux, produced by the magnet, and not linked with the armature in the position of maximum flux, is considerable, varying from 25 to 35 per cent of the total active flux, according to the type and degree of saturation of the circuit. Obviously if the leakage flux is appreciable when the armature reluctance is a minimum it will be greater at all other times, and must be brought into account in any attempt to determine the variation of flux in the armature.

In fig. 21 are indicated diagrammatically the principal flux paths in the magneto; a rotating magnet machine is shewn, but the following analysis will apply equally well to a rotating armature machine. The reluctances of the air gaps at diagonal tips may be assumed as being practically equal to each other; the reluctance of each trailing tip is marked A, of each leading tip B; in addition there are the magnet leakage flux path, the reluctance of which may be called D, and the reluctance of the iron path of the armature shoe extensions and the armature core, which may be called C. The distribution of flux as the rotor revolves, and these reluctances vary, can best be studied by applying Ohm's Law in a magnetic circuit.

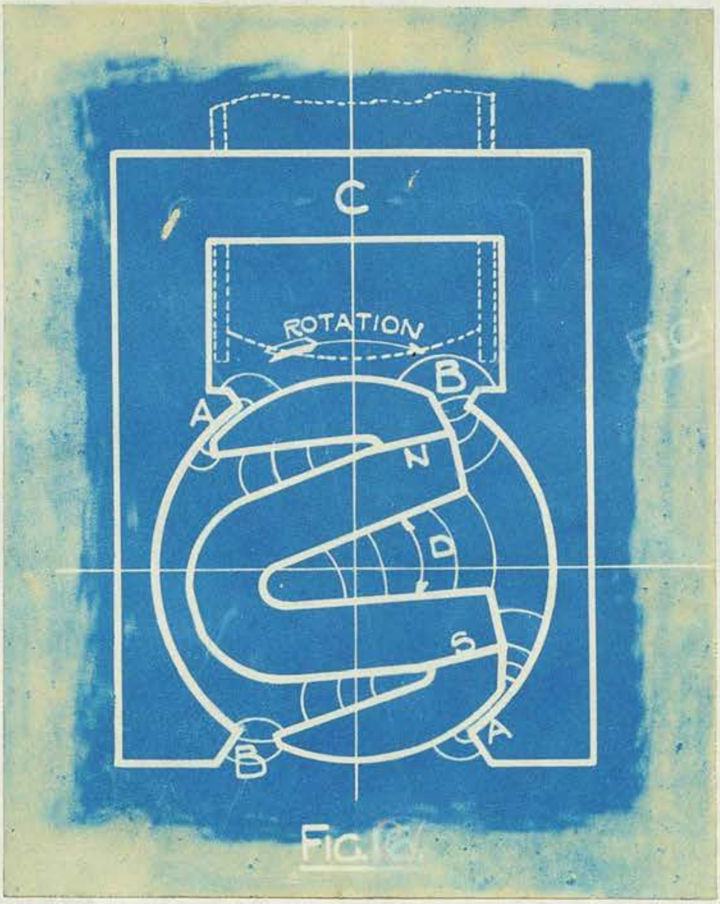
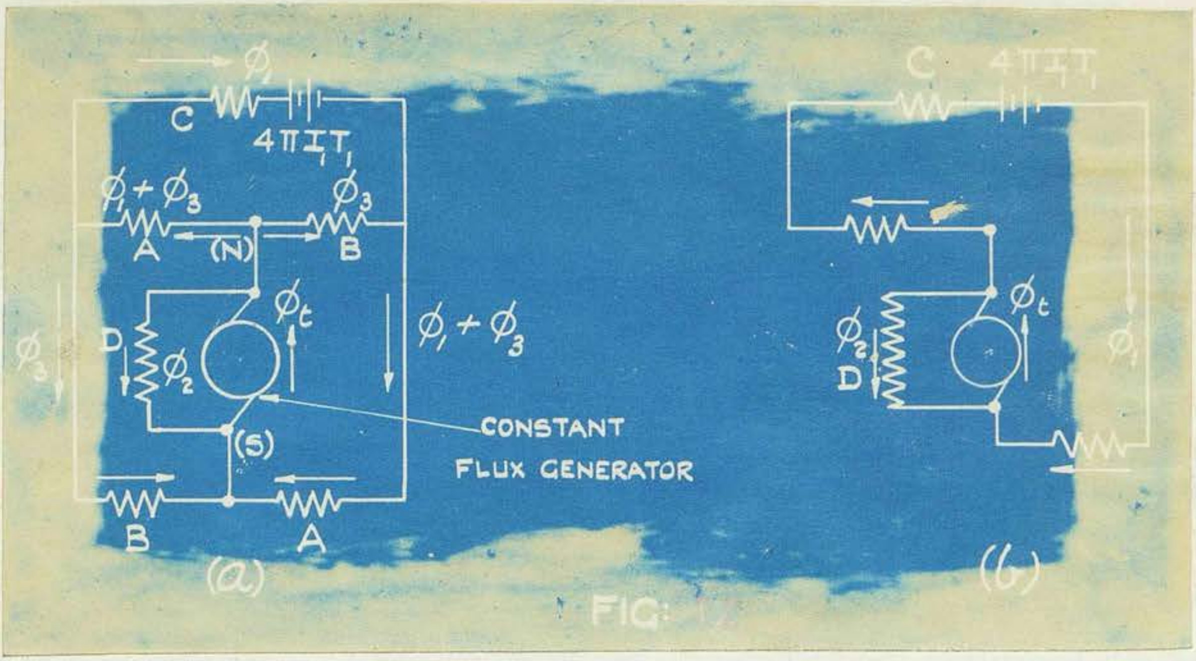


FIG. 21.

Fig. 22 is intended to represent the same magnetic circuit as shewn in fig. 21, the reluctances being connected so that the circuits correspond to the actual flux circuits of the machine. Thus starting from the N pole of the magnet the main flux circuit (ϕ) is through the reluctance A, the armature reluctance C, returning through the right hand pole shoe and reluctance A. There is a leakage flux, ϕ_2, independent of the reluctances A and B, part of the path of which is indicated in fig. 21, and part of which is in a plane rising out of the paper. Two other equal leakage paths, each carrying flux ϕ_3, are on the left through A and B, and on the right through B and A. The reluctances of rotor and stator pole shoes and of joints have been neglected. When the armature is short-circuited the primary M.M.F. has to be taken into account. It is assumed that angles and time are measured from the maximum (armature) flux position; that is, when the armature and magnet pole shoes face each other.



<u>No Load.</u>

The flux paths across B become of importance only when the rotor angle is in the neighbourhood of 90°; the flux can therefore be disregarded for small angles or angles near 180°, and the simplified diagram shewn in fig. 22, (b), adopted. With constant total flux ϕ_t the M.M.F. of branch paths may be equated.

Thus

$$\phi_t = \phi_1 + \phi_2$$

$$\text{and } D\phi_2 = 2A\phi_1 + C\phi_1$$

or

$$\phi_{10} = \phi_t \frac{D}{2A+C+D} \quad - - - - - (i)$$

For larger angles B must be introduced, but as both reluctances A and B will be comparatively large, and the armature flux will be comparatively small, vanishing (at no load) at 90°, the reluctance C may be neglected

Thus

$$\phi_t = \phi_1 + \phi_2 + 2\phi_3$$

$$D\phi_2 = A(\phi_1 + \phi_3) + B\phi_3$$

$$B\phi_3 = A(\phi_1 + \phi_3)$$

Substituting for ϕ_2 and ϕ_3

$$\phi_{10} = \phi_1 = \pm \phi_t \frac{D(B-A)}{2AB + D(A+B)} \qquad (ii)$$

The plus sign holds for 0 to 90° and the minus for 90° to 180°.

Short Circuit.

The armature M.M.F. $4\pi I_1 T_1$ must be added to the reluctance-flux products, due attention being paid to the sign. For small angles as before,

$$\left.\begin{aligned} \phi_t &= \phi_1 + \phi_2 \\ D\phi_2 &= 4\pi I_1 T_1 \pm \phi_1 (2A + C) \end{aligned}\right\}$$

$$\text{Thus } \phi_{1S} = \phi_1 = \frac{4\pi I_1 T_1}{2A + C + D} \pm \phi_t \frac{D}{2A + C + D} \qquad (iii)$$

For larger angles

$$\phi_{1S} = 4\pi I_1 T_1 \frac{Q}{P} \pm \frac{1}{P} \phi_t \qquad (iv)$$

$$\text{where } P = 1 + \frac{A}{D} + \left(\frac{A}{B-A}\right)\left(\frac{A+B+2D}{D}\right)$$

$$\text{and } Q = \frac{A+B+2D}{D(B-A)}$$

At 90° $A = B$, $\frac{1}{P}\phi_t = 0$, and the expression reduces to

$$\phi_{1S} = 4\pi I_1 T_1 \times \frac{1}{A}$$

The meaning of this is that at 90° the position of the magnet being such that it supplies no M.M.F. to the **armature** circuit the flux is determined solely by the armature ampere turns and the reluctance of the fringes of the shoes at four corners, each reluctance being the same, and of value A, the four reluctances being connected two in series, two in parallel; the joint reluctance is thus also A.

The reluctances A, B, C, and D, intorduced into the foregoing equations can be worked out for a given machine and plotted for different positions of the rotor with a fair degree of accuracy. A and B depend on the overlap of the pole shoes and the (radial) air-gap, due allowance being made for fringeing; C can be reasonably closely estimated from the magnetisation curve of 'Lohys' steel; D can be found by comparing (with a search coil) the values of ϕ_L and ϕ_1 in the position of maximum armature flux at open circuit. The measurement of the short circuit current will be referred to later.

The Spark Flux.

When the contact breaker opens, assuming that the primary current falls immediately to zero, the flux will immediately change from the short circuit to the open circuit value. If the small interval of time during which the change takes place is constant and the secondary voltage is a simple oscillation of constant frequency, the product of flux change and secondary turns is a direct measure of the sparking voltage. For convenience, the term spark flux will be used to denote this difference between short circuit and open circuit flux at whatever angle it is measured. At the very lowest speed the generation of the maximum possible voltage is required in order that the spark shall break down the gap; at higher speeds the requirement is different, the maximum utility at constant voltage beingrequired. Actually, as Professor Jones has shewn, there are two oscillations that take place, the frequencies of which may vary, affecting boththe secondary voltage and the utility; the damping due to eddy currents and the rate of decay of the flux may also vary, and there is no means of bringing these into account. In most magnetos, however, the coupling of the windings being very close, the widest variation of the inductance of the primary windings (owing to altering the shape of the magnetic circuit, or the number of turns, the only factors considered above,) that is likely to be made will probably not cause more than slight variations in the resultant secondary voltage, and it thus seems reasonable to assume that the spark flux is the chief factor in determining the secondary performance.

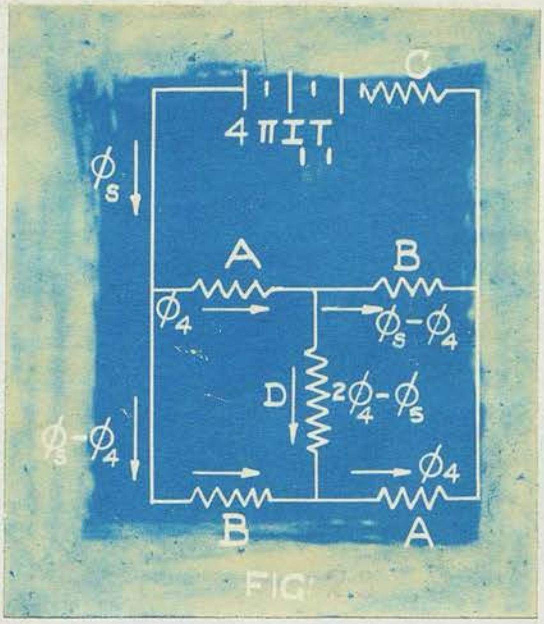
From equations (i) and (ii) maybe obtained a value for the spark flux for small rotor angles

$$\phi_s = \phi_{1s} - \phi_{10} = 4\pi I_1 T_1 \times \frac{1}{2A+C+D} \quad \text{---(v)}$$

From (ii) + (iv), for larger angles

$$\phi_s = 4\pi I_1 T_1 \times \frac{A + B + 2D}{2AB + D(A+B)} \quad \text{---(vi)}$$

The same expression for ϕ_s as in (vi) can be obtained by considering the problem in a slightly different way. In the first part of the cycle current is being generated in the armature, and, at the instant that the contact breaker is about to open, has reached a certsin value, depending on the speed at which the rotor is driven and the angle of the rotor at the moment under consideration. The instantaneous armature M.M.F. $4\pi I_1 T_1$ may be considered as establishing a core flux ϕ_s which is dispersed in the network of branch circuits, as shewn diagrammatically in fig. 23; each flux may be regarded as superimposed on the fluxes already exiating and due to the magnet M/M/F. As soon as the contacts open ϕ_s collapses and open circuit conditions are reestablished.



No path is indicated through the magnet, which is assumed to be a constant flux generator, and thus carries no part of the flux which collapses. To make the expression more general C may be introduced

$$\left.\begin{aligned} 4\pi I_1 T_1 &= C\phi_s + A\phi_4 + B(\phi_s - \phi_4) \\ \text{and } \phi_4(A+2D+B) &= \phi_s(B+D) \end{aligned}\right\}$$

Hence

$$\phi_s = 4\pi I_1 T_1 \left\{ \frac{A+B+2D}{2AB+D(A+B)+C(A+B+2D)} \right\} \text{--(1}$$

I find the expression of some service in studying the spark characteristic under the very varied conditions which practical requirements demand. I have not attempted to deduce an expression for the amplitude or wave-shape of the primary current; this has been done already by one writer, starting from an assumed triangular shape of E.M.F. wave, but I consider that such assumptions limit the usefulness of the results very greatly. I measure the wave shape of the primary short circuit current, experimentally by means of a Joubert contact maker, and the amplitude at various speeds with a hot wire ammeter; the equivalent reluctance I calculate and check by clamping the rotor in a number of positions, supplying a suitable direct current to the armature, and measuring the flux change on switching off or reversing the curremt. In figure 24 are shewn the

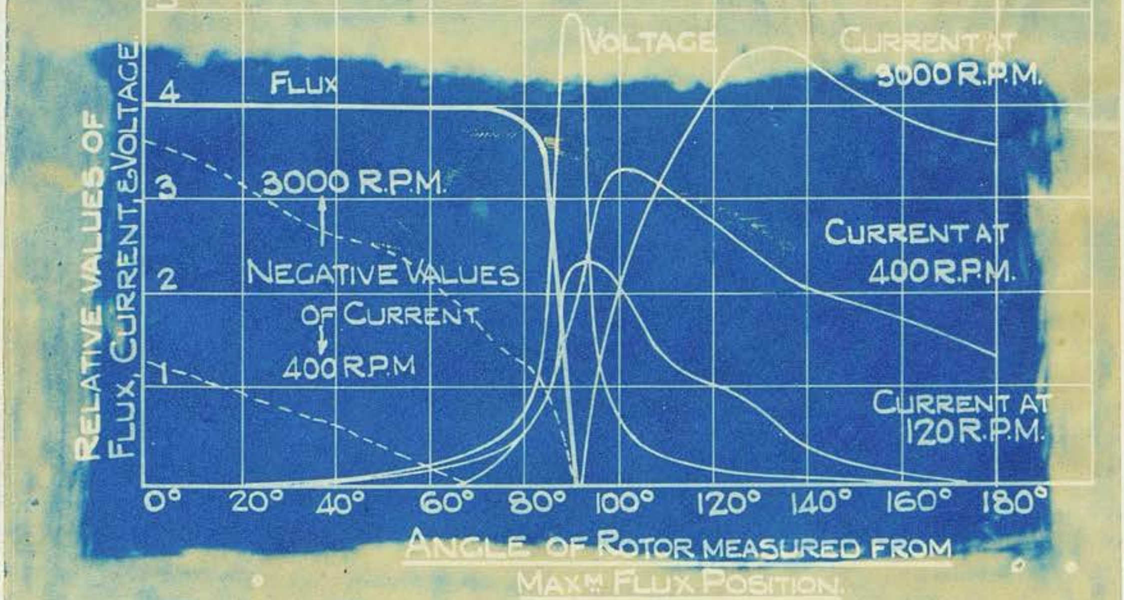
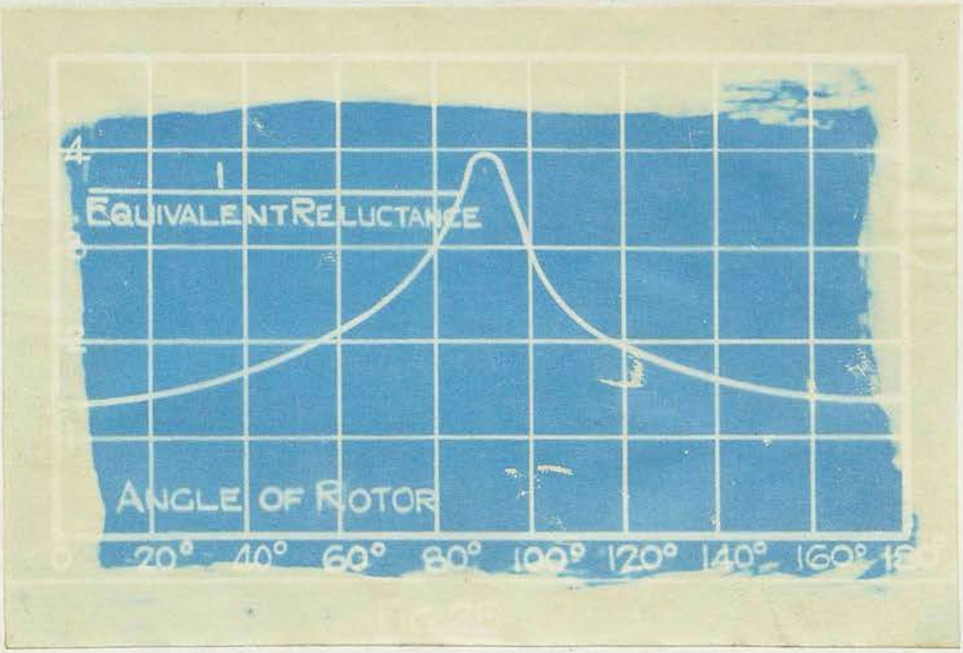


Fig 24.

the armature flux, open circuit voltage and short circuit current wave shapes for a rotating magnet machine; the equivalent armature permeance of the same machine is plotted in fig. 25.



At low speed the current is determined almost entirely by the resistance of the armature, the reactance not being great enough to exert much influence. Thus as the speed rises the peak not only rises but moves more and more to the right, the current lagging behind the voltage by a greater angle as the reactance with higher speed predominates over the resistance. Since according to (vii) the spark flux is obtained by multiplying the current by the equivalent permeance, the information obtained from these tests is of service in shewing the effect and relative importance of the various variables which enter in; the curves are also of service in determining the best conditions for any required range of timing. The same analysis can of course be made if, as will be discussed below, it is desired to fit specially shaped pole tips to control the slow speed performance. To shew the connection between short circuit current and utility the test shewn in fig. 26 was made. It is not necessary in practice that a machine should spark except over a very limited range; this figure shews how extended the range may be at high speeds. On comparing fig. 26 with the high speed current curve shewn in fig. 24 the relationship between the two is at once suggested.

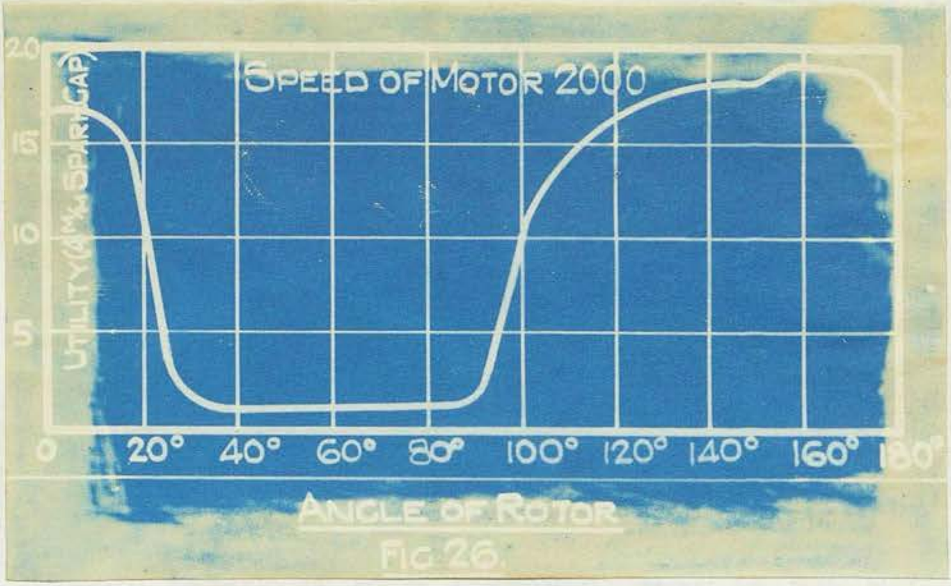


FIG 26.

Relation of Gap Diameter to Length.

In the design of D.C. machinery the relation of gap diameter to length is a matter of some importance. For good commutation and good cooling the core length should be relatively short, for cheapness it should be long. Is the ratio of any importance in a magneto? The question can be most simply answered by considering the effect on the performance of varying the gap length, maintaining the gap diameter and the mean length of the magnet constant.

Imagine two machines, the former of length L, the latter of length aL. If both work at the maximum energy of the magnet their fluxes will be ϕ and $a\phi$, provided flux densities are the same throughout the circuit. Armature core areas will be A and aA, while lengths of least turns will be (with square core) ℓ and $\ell\sqrt{a}$; voltages and short circuit currents (at low speed) will be E, E/R, and aE, $aE/R\sqrt{a}$. The current in the latter machine is $\sqrt{a}$ times that in the former, the number of turns and size of wire being assumed as constant. There is thus an advantage in slow speed performance for the longer machine; the short circuit ampere turns are higher, and consequently the spark flux will be greater than in proportion to the increase in length. A long machine will have the same leakage flux per unit length measured axially and relatively less end leakage; this is a second slight advantage for the long machine. Will a long machine be demagnetised more readily at high speed? The high speed current is determined solely by the primary reactance, that is by its inductance, which per unit turn is 4π times the permeance of the circuit.

The permeance of the two magnetic circuits will be P and aP; but the two fluxes are ϕ and $a\phi$ so that the E.M.Fs. are proportional to the fluxes and the reactances to the permeances, as the currents at high speed will be the same, and both machines will be demagnetised equally.

There is thus, including the consideration of cost, an advantage in making (for a fixed gap volume) the length great; mechanical design will generally decide the limit.

Open Circuit Test.

The open circuit voltage wave of a magneto does not change its shape with varying speed as the current wave does; the amplitude is therefore directly proportional to the speed. This gives a useful comparative test for the effectiveness of the lamination of the magnetic circuit. When tested in this manner rotating armature machines shew at high speed an appreciable falling off from the straight line owing to the increasing effect of eddy currents; this is not noticeable in the rotating magnet machine, in which the lamination is much more thorough. This test frequently proves of service to detect faults which are not easy to detect in any other way.

Short Circuit Test.

The short circuit test is a very valuable one; as has already been explained, the amplitude at any point on the wave gives a measure of the spark flux at that instant, and gives thus some indication of the available timing range of the machine at that speed. As the speed rises the inductance increases, and, the resistance being of course constant, the current lags more and more, increasing in amplitude, and at the same time changing very considerably in wave shape (see fig. 24). Over a considerable range at high speed, say from 1,000 R.P.M. upwards, the current, as would be expected, remains substantially constant. The change in wave shape is in one way unfortunate, as on that account each measurement of the current by an A.C. instrument requires correction.

Slow Speed Performance.

The size of magneto which has to be supplied for any given engine is determined chiefly by the slow speed performance which is required. A large engine cannot be turned by hand so fast as a smaller one; consequently the magneto for the larger engine must be capable of a sparking at a slower speed than is necessary for the smaller engine. When running at high speed the smallest magneto is generally large enough for the largest engine. In the table shewn in fig. 27

the speeds given in the ~~third~~ fourth column are, roughly, the highest speeds at which engines of the cylinder capacity stated in the ~~second~~ third column can be turned by hand. As these speeds are also the least speeds at which the magnetos types in column 1 will spark under 100 lbs. compression, the cylinder volumes represent approximately the largest size of engine for which each type of magneto can be employed. The minimum sparking speed with ignition advanced is, as shewn, generally about half that required to spark when retarded. Were it

STARTING OF 4 CYLINDER ENGINES.

MAGNETO TYPE	ROTOR. DIAM. × ACTIVE LENGTH	CAPACITY OF ENGINE LITRES.	LEAST SPARKING SPEED		RANGE OF TIMING CRANKSHAFT DEGREES.
			RETARDED	ADVANCED	
R.M	40 × 40	1·2	200	100	25
R.G.	51 × 52	3·0	130	60	30
R.E.	60 × 60	6·0	75	30	35

FIG

Fig. 27.

not for the slow speed requirement the smallest magneto would be satisfactory to use with the largest engine. The impulse starter, which has been made by a number of firms, is an attempt to overcome this trouble by interposing between the magneto and its drive a special coupling which produces a quick break however low the cranking speed may be. Another arrangement which has been used provides movable pole shoes which give the advantage of the advanced sparking performance at all timing angles. After carefully testing both methods I decided to use neither. The drawback of the impulse starter is that it is difficult to make so as to run for, say, 12 months without attention. To do this successfully moving parts must be very simple indeed and able either to contain their initial lubrication for a year or more or do without it altogether. Movable pole shoes take up additional space where it is most valuable and are difficult to laminate thoroughly. I have found it best to provide a rather larger machine without either attachment; there is little if any extra cost in so doing, and the simple machine is more reliable. There is still another method of improving the slow speed retarded performance - by the use of extended pole shoe tips. If the trailing tips of the stator shoes are extended into the interpolar arc, for an angle somewhat less than the timing range required, and the reluctance of the extended portion is made very much greater than that of the main portion of the shoe, the result will be that the best performance occurs at a much later angle than before. The effect may be considered as follows: In the normal machine the change of flux between 90 and 95 degrees is very rapid; with the help of the extended shoes the same change of flux is spread over perhaps 20 degrees. The drawback of this arrangement is what might be expected; the high speed advanced performance has in reality been converted into to superadvanced performance and the utility is considerably lowered owing to the lower short circuit current interrupted when the contact breaker is too fully advanced, as already referred to. This arrangement has, however, the advantage of being simple and cheap, and it is of service for special requirements. The increased reluctance for the extended tips may be obtained in many ways; for instance the tips of the laminations may be combed, the length of the tips may be made much less than the axial length of the main part of the shoes, they may be stepped so as to overhang the rotor, and so on. The effect appears to be much the same whatever plan is adopted.

High Speed Performance.

In the early days some trouble was experienced owing to machines missing at high speed at every alternate opening of the contact breaker. Frequently, by connecting through a distributor, and short circuiting first one gap and then the next in order, the missing could be observed to change over from occurring at one break to the other. It was found that this trouble was invariably associated with the use of cams providing a comparatively short break and consequently a long make. I first met this trouble in connection with a number of American magnetos which had to be adapted for the use of the Air Board to run at a higher speed than they were in all probability designed for. I had an oscillographic test made of one of these machines; the result of this test is shewn in fig. 28. Apparently the break period was so short that after a spark had taken place the circuit was closed again long before the secondary current had died down; hence the flux change was delayed, and initial current was induced in the wrong direction during the make period immediately succeeding a spark and by the time the next break occurred the current had not risen to a value high enough to cause a spark. After a miss, however, the current rises in the normal manner to a higher value, and a spark occurs again; thus sparking and missing

Fig.28.

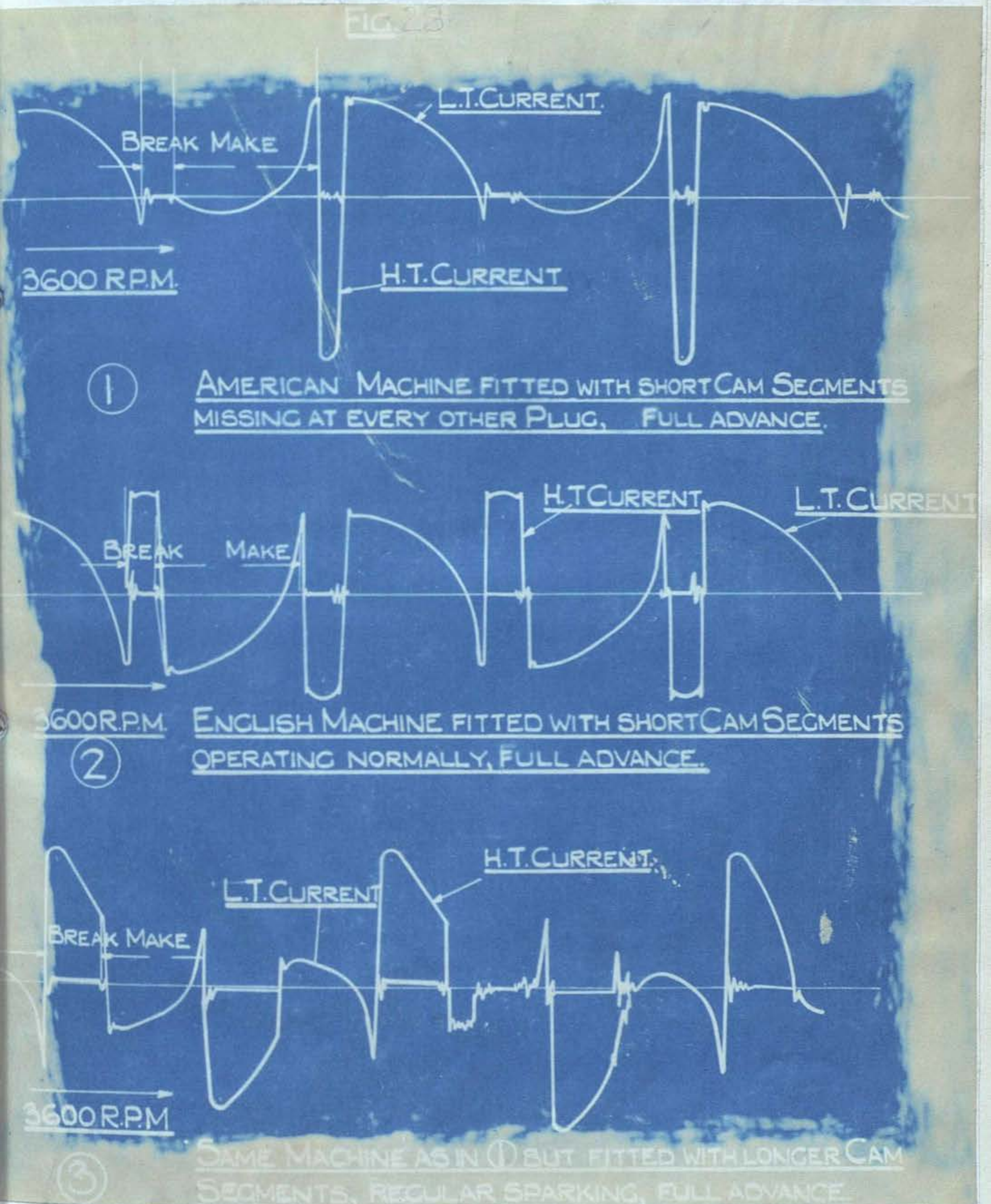


FIG. 28
L.T. CURRENT.
BREAK MAKE
3600 R.P.M.
H.T. CURRENT
(1) AMERICAN MACHINE FITTED WITH SHORT CAM SEGMENTS MISSING AT EVERY OTHER PLUG, FULL ADVANCE.
H.T CURRENT
L.T. CURRENT
BREAK
MAKE
3600 R.P.M.
(2) ENGLISH MACHINE FITTED WITH SHORT CAM SEGMENTS OPERATING NORMALLY, FULL ADVANCE.
H.T. CURRENT.
L.T. CURRENT
BREAK MAKE
3600 R.P.M
(3) SAME MACHINE AS IN (1) BUT FITTED WITH LONGER CAM SEGMENTS, REGULAR SPARKING, FULL ADVANCE.

take place alternately. The obvious remedy was to increase the length of break period by fitting a differently shaped cam; when this was done no further trouble occurred. At a later date when I had adopted the test already referred to for spark utility, I found that providing the longer break period was certainly the right step; where short breaks were provided even if a machine did not miss the high speed utility was frequently dangerously low, and the provision of a longer break in all cases effected a great improvement, without any other alteration at all being made. Apart from this trouble I have experienced very little difficulty in ensuring a satisfactory high speed performance. Magnetos run at high speed are invariably timed fully advanced; it is thus necessary to make sure, as already explained, that in this position the opening does not take place too far down the wave front; this is almost the only precaution necessary. Unlike coil ignition, with a magneto it is a matter of small importance if the contact breaker flings slightly at high speed; the energy is so much in excess of what is required that a small reduction is of no moment. Utility curves of a number of magnetos of different types are shewn in fig 29.

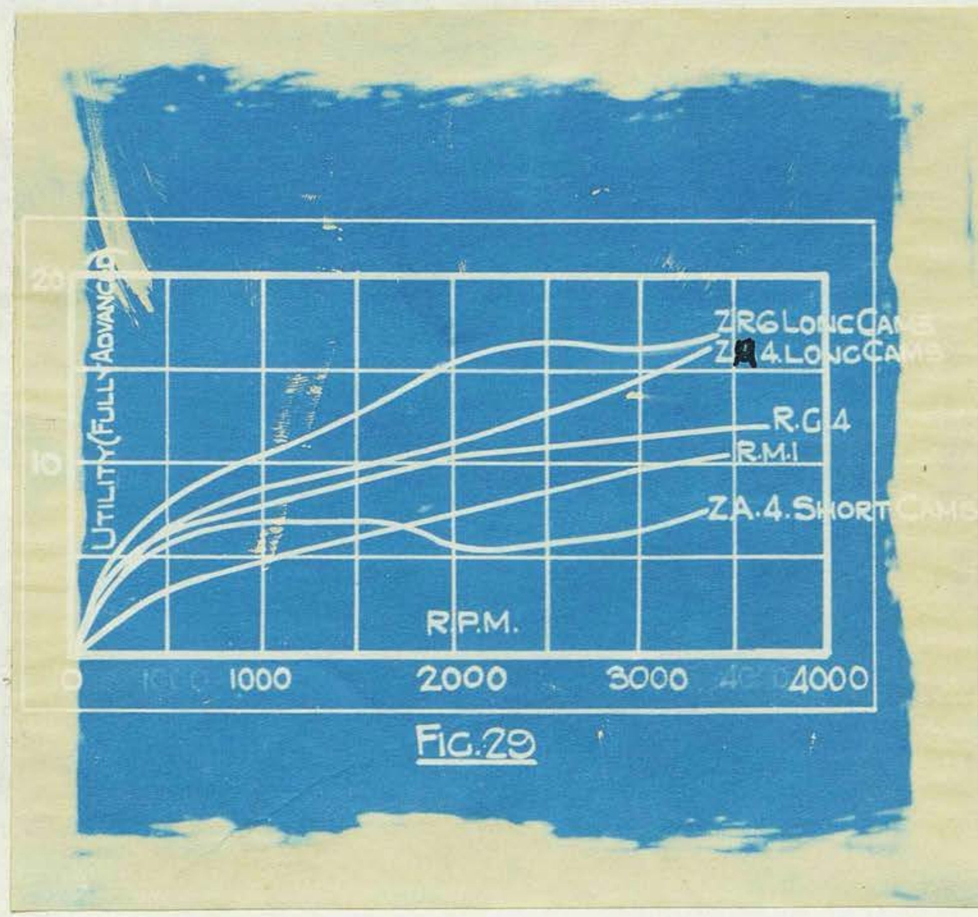


FIG. 29

/A

Earlier Types - Rotating Armature Magnetos.

At first, during the war, there was little time for developing improved models, a large output of magnetos being the chief requirement. The firm with which I was connected decided to manufacture magnetos on the lines of the Bosch machines, and during the first few years four sizes of rotating armature machines were developed as well as a sleeve inductor machine and also a very large low tension magneto with step-up transformer for use with large multi-cylinder stationary gas engines. Each of these types was manufactured in a number of different forms - the smaller sizes for 1, 2, V-twin and 4-cylinder machines, and the larger for 4 and 6-cylinder types. The sleeve inductor machines were made for 6, 8, and 9-cylinder engines; the gas engine magneto was made for any number of cylinders from 3 to 9. The successful manufacture in large quantities of these machines necessitated a considerable amount of investigation into the properties of a number of materials not usually employed in engineering work; in the following I have referred to the problems raised by these special materials, to certain constructional difficulties, and to the system of testing I have adopted to ensure the thorough reliability of the firms output.

Notes on Special Materials.

Magnets. During the war the Air Board drew up a specification for permanent magnets for magnetos, to which all manufacturers worked; the remanence was not to be less than 8,500; the coercive force was not to be lessthan 55, nor the product of the two less than 530,000. As soon as the war was over, more attention could be concentrated on improving performance, and it soon became evident that this specification ewas not really what was wanted. I frequently came across two magnets with equal remanence and coercivity, one of which had a much fatter loop than the other and consequently gave better results on the magneto. At present, by arrangement with the steelmaker, I order magnets which he guarantees shall have a minimum product of (BH) of so much, nothing being stated aboutnthe value of remanence or coercive force. At present the best quality of cobalt steel obtainable has a remanence of 10 to 11 thousand and a coercive force of 220-260, the minimum product guaranteed being 900,000. Actually I have already tested a number of magnetes where the product exceeds 1,100,000; with imcreasing skill and experience in the composition of the steel and its heat treatment no doubt still better results will be obtained.

Laminated Sheet Steel. For all parts carrying alternating or pulsating flux I employ 'Lohys Extra' 0.5 m/m. sheet; 'Stalloy' might be more suitable on account of its high resistance and low eddy current loss, but its brittleness is a great drawback, and on that account for many purposes it cannot be conveniently used.

Inductor sleeves. Low carbon steel tube (see specification for dynamo yokes) proved quite suitable.

Malleable cast iron. was employed with rotating armatures to form the cheeks clamping the laminations together, no trouble was experienced with this material except occasionally when it was too hard owing to insufficient annealing.

Forged nickel steel driving spindles. (with 25% nickel) were employed on magnetos for aeroplanes with the object of obtaining a stronger drive than if aluminium or other bronze were employed. The flange extension of the spindle lies between the magnet pole shoes, and it is thus necessary that the material should have a very low permeability. ~~of 2, which was~~ substantially uniform up to the limit required (about 50 H) was quite common; spindles were rejected if the permeability exceeded 5. A simple tractive test proved a very convenient way of testing these spindles in large quantities; tested on an electromagnet the pull-off force proved a sufficiently accurate proportional to the permeability.

Aluminium bronze spindles. forged from rod now prove to be quitesuitable for all types of magnetos. The material proved strong enough, and is much cheaper as well as much easier to machine than the nickel steel mentioned above.

Enamel Insulated copper wire. is employed almost universally for magnetos, in order to obtain a high space factor. I experienced at first much difficulty in obtaining suitable wire for the high tension winding - 40 to 44 S.W.G. The chief essential requirement is flexibility of the enamel; in winding so small a wire, though every precaution, such as employing very small bobbins to wind from (to reduce as far as possible the force of acceleration transmitted through the wire under tension at winding), and mounting the bobbins on ball bearings, is taken, the wire is bound to be stretched; with inferior wire this causes the enamel to flake off, thus risking a short circuit between turns, the probable cause of many apparently mysteriously "weak" armatures. A good enamel is so flexible that the wire may be stretched until it breaks without the enamel showing any sign of scaling.

Impregnated paper and silk. have been used very largely, and have caused very little trouble. If the manufacturers are requested, they will readily supply these materials after being stoved forshorter time than normal; the material is then in a tacky condition which is most suitable for the winder. A convenient reference* for puncture voltage, is to employ as a standard metal weight with flat base and rounded edges; the material to be tested is placed on a flat metal surface and the standard weight on top. This ensures a uniform pressure on the material.

Moulded and Vulcanised rubber compounds.- stabilite, and ebonite, occasioned much trouble in the early days of manufacture. In a rotating armature machine with distributor the H.T. current path from armature to slip ring through two brush holders and an insulated spindle, to the opposite end of the machine, to the distributor brush holder and thence to the distributor, is a transmission line which has to be insulated to operate at 15,000 volts above earth potential. The space is confined and most of the parts rotate. It is a little to be wondered at that in spite of all precautions breakdowns occasionally occur. I am thankful that in my latest designs it has been possible to sweep nearly all these parts away. A common fault was the displacement of the metal inserts from their proper position owing to unequal pressure while the mould was being packed; this was generally overcome by stiffening the insert or anchoring it more securely in its position in the mould. Another fault was the occurrence of blow holes , either owing to the material not being perfectly uniform at a joint in the mould or owing to the presence of traces of moisture before vulcanisation, which being converted into steam formed blow holes in the finished moulding. Steel tools are unsuitable for machining mouldings; the sulphur appears to attack the tool and they do not give a good finish; a diamond is the most suitable type of cutter, and gives an excellent finish to the work. One great drawback to its use is that it is generally wrecked if even a small steel filing, accidently lodged in the moulding, appears in the path of the tool. At one time, as it appeared impossible entirely to prevent the presence of an occasional fragment of steel in the mould, which in many cases would otherwise be quite harmless, and the number of diamonds destroyed was becoming very expensive, I attempted to make a magnetometer to detect the presence of steel near the surface of a moulding - i.e., at the depth to which machining was to be carried. A miniature electromagnet, balanced on a lever, hung as a galvanometer and used as a reflecting instrument, proved sufficiently sensitive, detecting readily steel the size of a pin's head an inch below the surface; it was then found, however, that the stabilite itself, although not apparently containing any steel, was faintly magnetic, that brass inserts were frequently decidedly magnetic, and so on; these so obscured matters that the attempt to determine the presence of steel in this way, had to be abandoned. With a new supplier the trouble did not occur to anything like the same extent, and it is now an extremely rare occurrence.

* Agreed with between my firm and suppliers.

Fibre and bakelite contact breaker bushes. In a rotating armature machine the contact breaker will most conveniently rotate also; thus, if a lever type breaker is employed a bearing and a bush must be provided, which it is almost impossible to arrange to lubricate. Bosch employed a fibre bush, which had the great disadvantage that in damp weather it swelled, causing the lever to stick and thus putting the magneto out of action until the contact breaker lever was removed and the bush slightly eased. There appeared to be no way of getting over the difficulty; the lever pin could not be left too slack a fitin the bush or the contacts would meet badly out of line. Although this seems in itself a small thing, it has probably been the cause of more trouble to the motorist than any other failure connected with his electrical equipment. It was no uncommon thing to hear of a motorist having had his car towed a fabulous distance on account of a failure he was unable to diagnose successfully, which turned out to be nothing more than a swollen contact lever bush. For years I employed fibre, for want of a better material; after being unsuccessful with a number of materials I tried bakelite-dilecto, which the makers (the Continental Fibre Co.) described as layers of very thin paper varnished in bakelite, dried, pressed, and subjected to heat treatment. This material seemed a suitable substitute for fibre, as it absorbs very little moisture:- 1.5 to 2 per cent I found, compared to 6 to 8 per cent for fibre; it also resists abrasive wear rather better, provided the rubbing action takes place across the edges of the layers of which the total thickness is made up, and not so that successive layers are scaled off. After prolonged road tests for many months, including trials on a number of buses running a mileage of 800 or more per week, this material proved itself, as might be expected, a great improvement; I have adopted it up till quite recently. The circumstances are now however rather different; on the latest machines the cam revolves and the contact breaker lever is stationary; I have accordingly provided a lubricated metal bush. On the whole this is probably the most satisfactory.

Contact material. Platinum-iridium alloy, with 25 per cent of the latter material, gives the very best results. Unfortunately it is very expensive. Messrs. Johnson, Matthey & Co. offer another cheaper alloy which I understand contains about 6 per cent of iridium; I have not had much success with this alloy, finding that it wears away somewhat too rapidly. A carefully designed pivot and a light lever which can be operated at high speed with the least possible spring pressure will probably help matters; further work remains to be done along these lines. Tungsten has been employed to a certain extent and is very much cheaper to fit than platinum; as it has a higher contact resistance than platinum; I have been very reluctant to fit it for magnetos without a rather longer experience of its behaviour. Fitted as a standard to automatic dynamo cut-outs, it has given no trouble at all; this may be because the voltage is rather higher than that obtained at hand cranking speed from a magneto. Here also is matter for futher investigation.

DIFFICULTIES OF CONSTRUCTION.

The Timing Mechanism.

In common with other firms we experienced at first very great difficulty in ensuring sufficient accuracy in the timing arrangements. It is necessary not only that the opening of the contacts in the two positions, 180 degrees apart, should be within one or two thousandths of an inch of each other, but at the same time at each opening the trailing edges of the rotor shoes must be in the correct position, that is - the fully advanced timing position being understood,- each edge must lie within 2 to 3 degrees of the edge of the nearest stator shoe. The latter requirement is met without much difficulty, but the former, which depends on the contact breaker being truly concentric with the two cams by which it is opened, has proved extremely difficult. In fig. 30 is

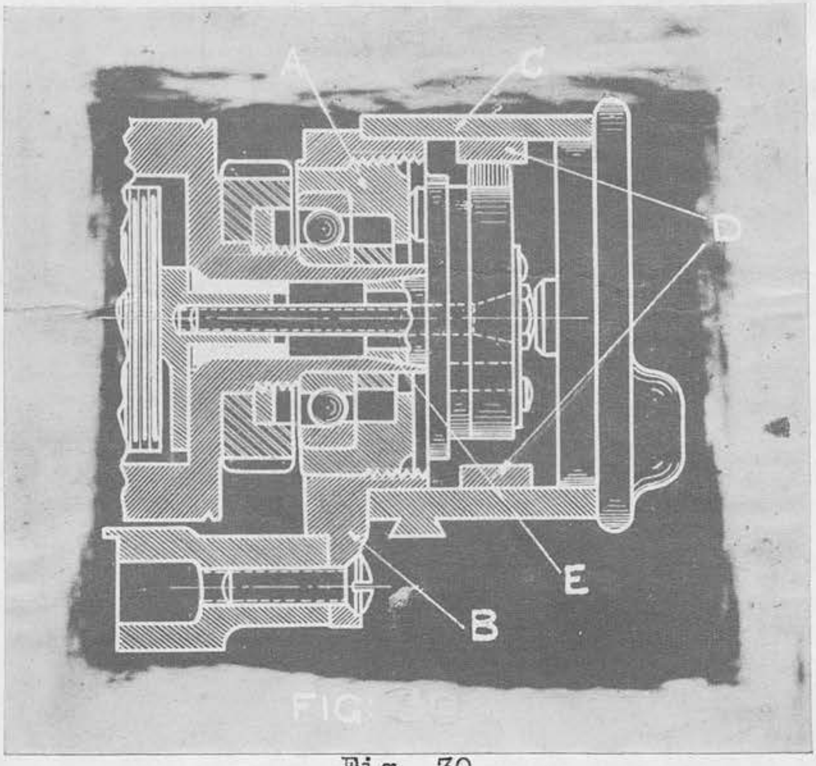


Fig. 30.

shewn the construction of the contact breaker end of a magneto built on the lines of the Bosch machine; it will be seen that the outer ball race is carried in an adjustable sleeve A which registers in a bracket B, which in turn carries the adjustable timing ring C, to which the steel cams, D, are attached. Any errors in machining the sleeve, the bracket, the timing ring, and the cams, twice for each part, conical as well as the surface of the contact breaker E, are liable to add up, producing a considerable eccentricity between the cylindrical surface on which the cam faces lie and that of the armature, and hence the contact breaker. Should the line joining the centres of these cylinders lie more or less in the direction of the line joining the diametrical positions of opening of the contacts - which have to be varied through wide angles - the difference in the amount of the opening will be doubled. The total opening of the contacts ought not to exceed 12 thousandths of an inch, for successful functioning, and the difference between the two openings ought certainly not to exceed 2 thousandths; that is the difference between the two centres referred to should not exceed one thousandth, and this permissible error has to be divided between some eight to ten machining operations. This is one example of what I have referred to as German design that is unsuitable for production by English labour. As soon as the situation was fully appreciated most English firms took various steps to deal with the difficulty, by eliminating the adjustable sleeve and taking up end play instead by introducing washers of suitable thickness, by forming the cams ina continuous ring instead of in separate segments, and so on. In the latest type of machine described below, with a stationary contact breaker and rotating cam, this trouble is practically non-existent, as, provided the cam itself is true the two successive openings must be equal to each other.

Noiseless Gears.

Owing to the impulsive nature of the magneto drive, a geared machine with metal gear wheels is apt to make an appreciable sound even at lowspeeds, and at high speed this becomes very decided. The contact breaker also cannot but made an appreciable addition to the volume of sound, and so to a certain extent do the ball bearings. Engine makers are now making cars run so quietly that they have complained that the magneto is the noisiest thing on the engine. I must confess that I certainly have heard engines in which the unmistakeable tinkle of the magneto gear was more noticeable than any other sound. After very considerable experiment I came to the conclusion that it was commercially impossible to make solid gear wheels as quiet as was required. The laminated gear wheel described in Patent Application No. 29290/1921 (a copy of which is submitted herewith) appears to get over this difficulty; it is very cheaply made, and after prolonged testing I find that it wears very well.

TESTING.

Tests prior to main assembly.

In order to keep down the cost of manufacture it is desirable that all elaborate parts shall be tested prior to final assembly, as any failure thereafter involves

(a) location of the fault,
(b) dismantling, reassembly, and re-test.
(c) delay, disorganisation, and incidental troubles, such as scrapping of spoiled parts, rivetted parts which have to be taken apart, and so on.

Armature Tests.

(a) Resistance tests are made on L.T. and H.T. windings, eliminating possibility of bad soldering in the former and of breaks in the latter.

(b) High voltage tests (at 15,000 peak voltage) are made with direct current, mechanically interrupted in the L.T. circuit. The voltage (length of 3-point spark gap) generated for a given L.T. current in a known type of armature provides a fairly reliable test for leakage and insulation resistance of the H.T. winding.

(c) Test (b) above gives no means of discriminating between two common classes of failures

(i) a secondary winding of which a few turns or layers were short circuited, the result being the formation of an independent short-circuited secondary, reducing the energy available in the external circuit,
(ii) surface leakage across the insulation to earth.

The former necessitates a complete rewind; the latter may be cured by recovering and varnishing the finished winding. I thought that if the armature was tested in a closed magnetic circuit, strictly as an A.C. transformer, the increased current taken by the primary in the former case would enable discrimination to be made, and that such a test would be a more searching one than (b).

To be of use an open circuit voltage of 15,000 peak 11,000 R.M.S. secondary volts is required; with 10,000 secondary and 170 primary turns - these values are representative for a number of armature types - this means that an A.C. voltage of 185 must be applied to the primary winding.

Unfortunately this voltage is not readily impressed on an armature as a transformer; at 50 cycles an E.M.F. of about 9 volts, only, is sufficient to establish normal flux. The density in the armature core is generally as high as can be permitted, 15,000 to 18,000 lines per cm^2, thus the only way to raise the impressed primary voltage is to increase the frequency. To obtain 185 primary volts with the above assumptions the frequency must be increased to 1,000 cycles.

A high frequency alternator.

At the time that the want of this was first felt (1917) the only quick way of obtaining such a thing as a high frequency alternator was to make it oneself. A year or more previously when an alternator was wanted for some special tests one of my assistants had pointed out that a certain two phase induction motor might be wound and used as a single phase generator in spite of an apparently unsuitable number of slots; I noted that this gave a means of securing the advantage of a distributed winding with only a single slot per pole. I made no use of this at the time, but when faced with the problem of magneto testing I went into the matter more thoroughly, and decided to make up a machine. I obtained the frame of a squirrel cage induction motor having 36 stator slots and a prime number of rotor slots. The former I wound as a 36 pole magnet, and the latter as a single phase armature having one slot per pole and a pitch slightly less than diametrical; appropriate gaps and reversals were made in the armature winding to permit the voltages of all the sections to add up correctly.

To see the wave shape oscillographic records were made of this alternator; these shewed that in spite of the pole consisting of simply one stator tooth, the winding employed gave a good sine wave shape under all conditions except with a pure capacity load, when a third harmonic was strongly shewn up. I considered the result sufficiently encouraging to apply for a patent to protect the winding; this was granted in due course, and a copy of the specification (No. 136,215) is submitted herewith; the theory of the winding is dealt with therein. The limit of frequency for which this method of generation is suitable is determined chiefly by driving speed. For example, a 15" diameter magnet rotor having a 4-m/m. slot pitch and running at 4,000 R.P.M. would generate at 3,200 cycles. Iron losses at so high a frequency would no doubt be very great; I have not yet made any attempt to measure them at 1,000 cycles, as the alternator used for testing does not get unduly hot, and a large amount of power is not required. The machine appears to me to be a very useful one for testing all coils where the over voltage required can be impressed only by increasing the frequency.

Magneto armatures tested with this alternator give greatly increased energy at the spark gap. To test for short-circuited secondary turns the secondary winding is left open circuited and the magnetising current noted, the armature being clamped into a split yoke which provides a complete magnetic circuit with practically no air gap. Even a turn or two short circuited generally shews a substantial increase in magnetising current, whilst a more thorough short circuit generates enough heat to set fire to the winding in about half a minute. This sounds rather an expensive display, but it must be remembered that before high voltage tests are made the armature must be impregnated and the varnish baked dry and hard. After this, owing to the frailty of the H.T. wire, it is impossible to effect any repair other than recovering the outside of the winding, and a winding with an internal short circuit has to be scrapped, the core stripped and rewound from the beginning.

<u>Condensers</u> are tested for capacity and a flash test is also made at high voltage. For capacity testing I employ the arrangement shewn diagrammatically in fig. 31.

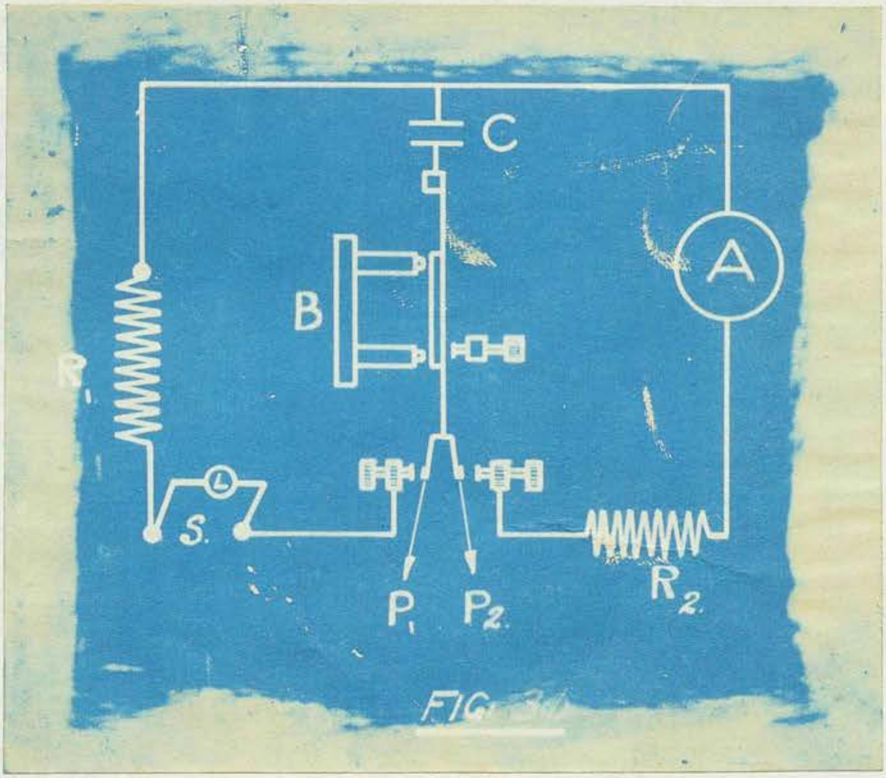


Fig.31.

B is a buzzer operated by a dry cell the armature of which carries two spring blades P1 and P2. When the armature is attracted the left-hand blade makes contact, charging the condenser under test, C, from the supply mains, S. When the buzzer contact is broken and the armature flies back, the right blade makes contact with P2, and discharges the condenser through the moving coil instrument A. A short-circuited condenser makes the lamp L glow; resistances R1 and R2 prevent any short circuits from occurring if the contacts are badly adjusted. I do not know to whom the two way trembler is due; I heard of it accidently without being able to trace who originated it. The D.C. instrument is calibrated by observing the deflections with a number of condensers of known capacity. The instrument gives a direct reading, the tremblers require very little adjustment, and the accuracy is more than is necessary for commercial work. I have found it a much better arrangement for shop use than by using a bridge, with telephone receiver, or any other arrangement.

Assuming that the maximum secondary voltage is 15,000 and that primary and secondary turns are 170 and 10,000 respectively, the peak voltage in the primary circuit would be about 260 volts. To avoid any doubt and to ensure an adequate factor of safety I flash test condensers at 500 volts A.C. Practically no cases have arisen of condensers that have passed this test and broken down at a later date.

<u>High Tension Moulded Parts.</u> These are tested at an A.C. peak voltage of 20,000; the parts in all cases are fitted up for test so that a metal member is disposed in the same manner as the corresponding earthed portion of the magneto when the part is assembled on it.

<u>Tests of Complete Magnetos.</u> A very thorough test specification was drawn up many years ago by the Air Board. I have used this as a basis, and, with the exception of one or two minor alterations and additions, work to it at present. The tests are carried out in the order shewn below.

1. Machines are to be run at high speed for 5 minutes with both windings earthed.

2. Machines connected up to spark through their distributors to 5.5 m/m. three-point gaps are to be run at a stated high speed (depending on the type) for 4 hours with timing fully advanced.

3. During this test the operation of the safety gap and the earthing device are to be tested to make sure they are operating correctly.

4. At the conclusion of the endurance run (2) and before allowing the machine to cool, the low speed sparking performance, both advanced and retarded, is to be noted.

5. Machines are then to be taken down - i.e. distributors, dust-covers, timing rings are to be removed and examined for wear.

Definite specifications for each type of magneto are laid down for minimum sparking speeds, speed of endurance run, and so on, the machines are rejected which do not fulfil the prescribed conditions.

The Development of a New Type of Magneto.

The introduction of permanent magnets made of cobalt steel has made it necessary entirely to redesign the magneto from first principles if the full advantage of the properties of the new steel is to be gained. During the last two years, due, no doubt, to their increasing knowledge of the most desirable proportions of alloys and the most suitable heat treatment, the steel makers have been supplying cobalt steel magnets with continuously improved constants. Fig. 32 shews a portion of the hysteresis loop of magnet steel of various kinds and also the product of B and reverse H plotted as a function of H. From this it will be noted that the maximum BH product obtainable from a good tungsten steel magnet, curve A, is about 260,000. The maximum product obtainable from cobalt steel has been steadily increasing, the curve B having its maximum at 700,000 represents the best results of about 12 months ago, whilst to-day the steelmakers are prepared to guarantee a maximum product of 900,000, curve C. I have already received and tested magnets which shewn even better results; the curve (D) plotted with a maximumof 1,160,000 is by no means an isolated example. Thus a magneto can be built with a cobalt steel magnet of about a quarter to a third of the magnet volume required to give the same performance as when a tungsten magnet is employed.

In the table shewn in fig. 33 the dimensions of magnets of a number of types of magnetos are shewn. The tungsten steel magnets were used on rotating armature machines, the cobalt steel magnets on the rotating magnet type described below. If the figures of merit of all the machines were the same the figures in the last column would be a measure of the output of each type. Types ZA and ZE had cast iron magnet pole shoes; type G had laminated magnet pole shoes and gave consequently an improved performance, rather better than type ZE, in spite of the larger magnet energy of the latter. Type G is a machine the leading dimensions of which have been

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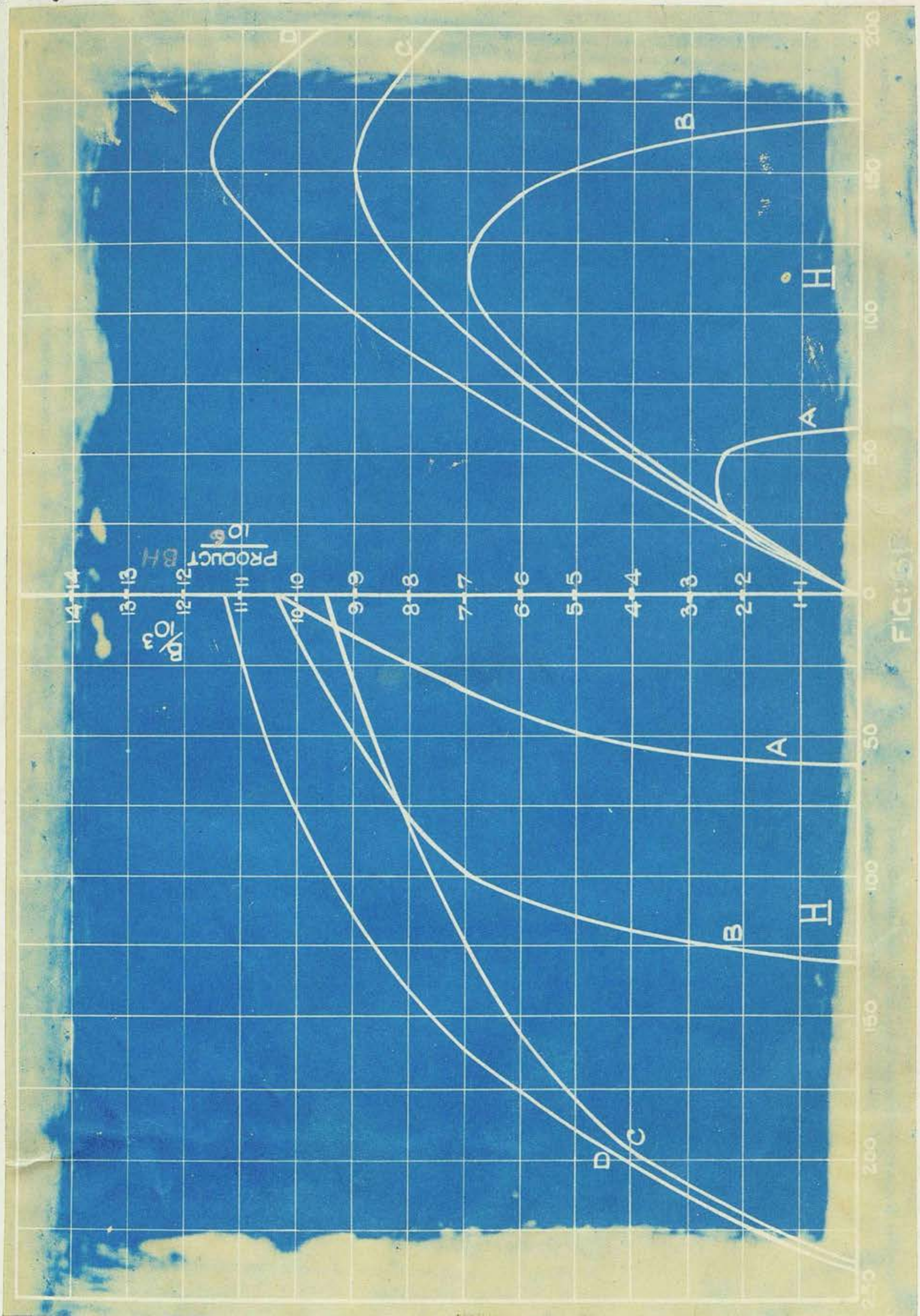


standardised by the British Engineering Standards Committee,*
and as this is a most useful 4-cylinder model suitable for cars of from 10 to 25-H.P., it was decided to consider first of all the design of a new type to replace this machine. Type R.G.

TYPE.	MAGNET		MATERIAL.	$(BH)_M \times VOLUME/10^6$
	AREA CM^2	VOLUME. CM^3		
Z.A.	5·7	130	TUNGSTEN STEEL	34
Z.E.	6·9	180	" "	47
G	4·6	120	" "	31
Z.U.	9·2	260	" "	68
Z.R.	9·2	300	" "	78
R.M.	3·0	17	COBALT STEEL	15·3
R.G.	5·0	38	" "	34
R.E	6·5	57	" "	51

FIG. 33

Fig.33.

(see table) is the type finally decided on, and described below.
As the remanence, and the flux density at which the $(BH)_m$ product occurs are very much the same whether tungsten or cobalt steel magnets are employed, no great change in the cross-sectional area of the magnet need be made, the chief difference is that the cobalt steel magnet needs be only about one quarter to one third the length of the tungsten steel magnet it replaces. Having settled approximately the magnet dimensions, the question arises as to what construction should be adopted to take the utmost advantage of the shorter magnet. There are many drawbacks inherent in the rotating armature machine. To anyone familiar with the extent to which the lamination of the flux alternating parts is carried in, say, an induction motor, the imperfections of the magneto armature will appear very striking. On either side of the laminations heavy solid cheeks have to be employed of area at the gap diameter about twice as great as the laminated portion between them. In addition, the laminated area is still further reduced by rivets through the whole structure. Other drawbacks have already been referred to - the rotating contact breaker, with

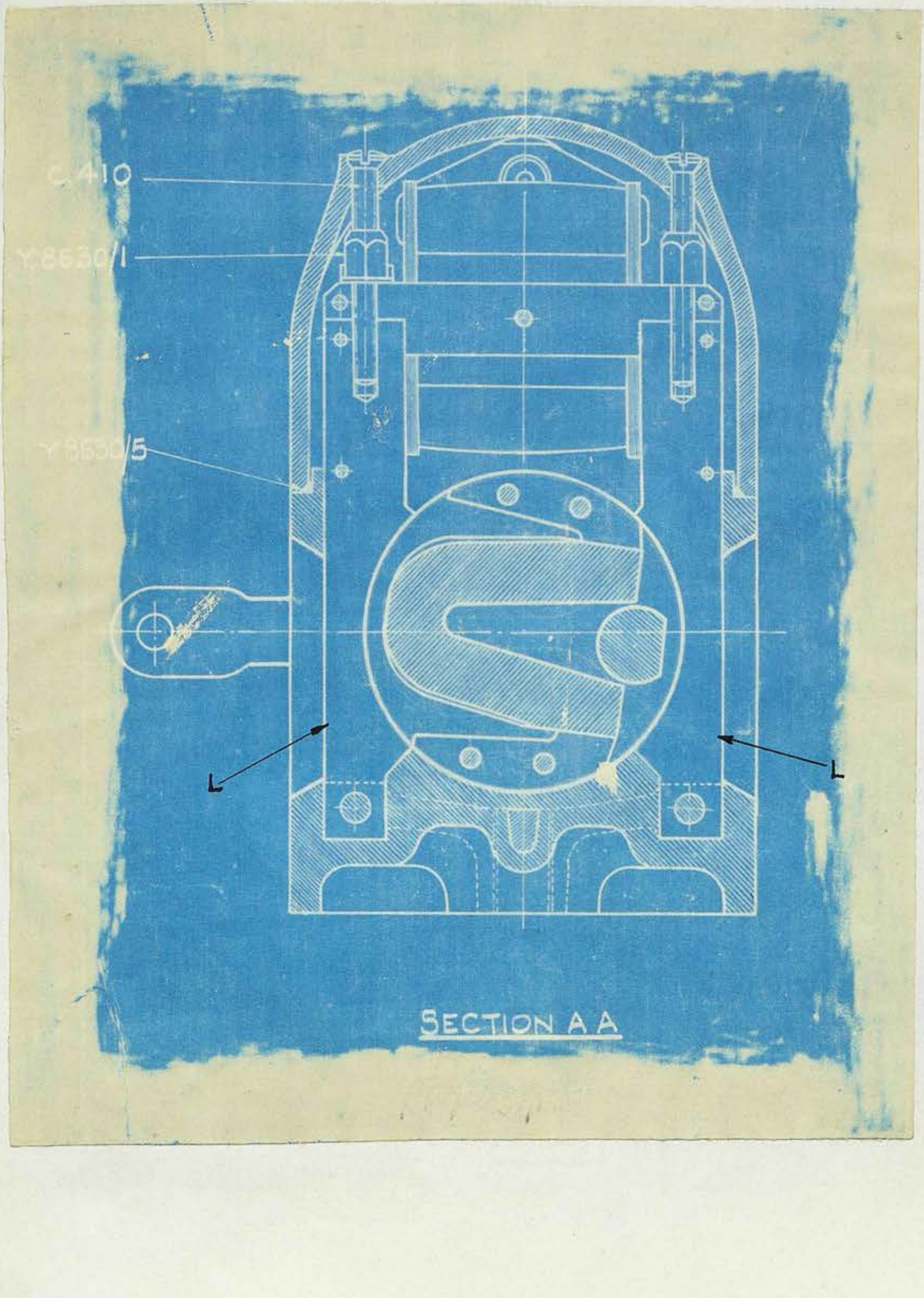
* Report No. 80 - 1917.

put forward as

the consequent moving parts which cannot be lubricated, and the multiplicity of high tension moulded parts. A rotating winding generating 15,000 volts would hardly be a practicable proposition by any other than a magneto designer. Shortening the magnet suggests no means of overcoming these disadvantages; although a more compact machine can be made with a consequent reduction in cost the leading faatures of the machine will remain the same. If the machine were made with fixed armature and magnet and revolving inductors, most of the foregoing objections would be overcome, but the inductor magneto has the disadvantages that four air gaps are introduced into the circuit instead of two, the inductors are not easily laminated (though this may be overcome), and extra material being interposed between armature and magnets results in increased weight, expense, leakage flux, as well as increased magnetic reluctance owing to the lengthened flux path.

The chief difficulty of the next alternative - a rotating magnet machine - is the construction of the magnet. The Swiss firm, Scintilla, manufacture a rotating magnet machine in which proctically the whole rotor, including the driving spindle, appears to be formed from a bar of magnet steel which has been machined into the shape of a horse-shoe, a portion at each end, of greatly reduced cross-section, carrying a laminated shoe, the gap diameter being less than the diameter of magnet, and the greater part of the magnet being outside the cylindrical space enclosed by the armature shoes. The cost of a machine of this type made in this country under the present labour conditions would not be competitive, however. This is the more unfortunate, as a rotating magnet machine has many advantages not possessed by other types; the windings are stationary, and insulation can be made more reliable; it should be possible to make the rotor more robust, and to laminate the stator more thoroughly. As already referred to, many of the H.T. moulded parts may be omitted, and the contact breaker made less intricate. These advantages are shared with the inductor type of machine; a further advantage, which a rotating magnet machine alone has, is the simplification of the magnetic circuit and the reduction of its reluctance.

I came to the conclusion that the rotating magnet type was the best, provided a convenient and cheap form of rotor could be devised; what appears to be a very satisfactory solution to the problem is described in Patent Applications Nos. 14777/1921 and 34662/1921, copies of which are submitted herewith. The form of rotor I am at present employing is shewn in fig. 34. A solid bar magnet is used and laminated shoes; in another view (fig. 35) the intermediate nonmagnetic members which serve to hold the structure together and limit the movement of the magnet are shewn, as also the bronze flanged spindles carrying the bearings at each end. This form of rotor has the advantage possessed by no other machine


C.410
Y.8630/1
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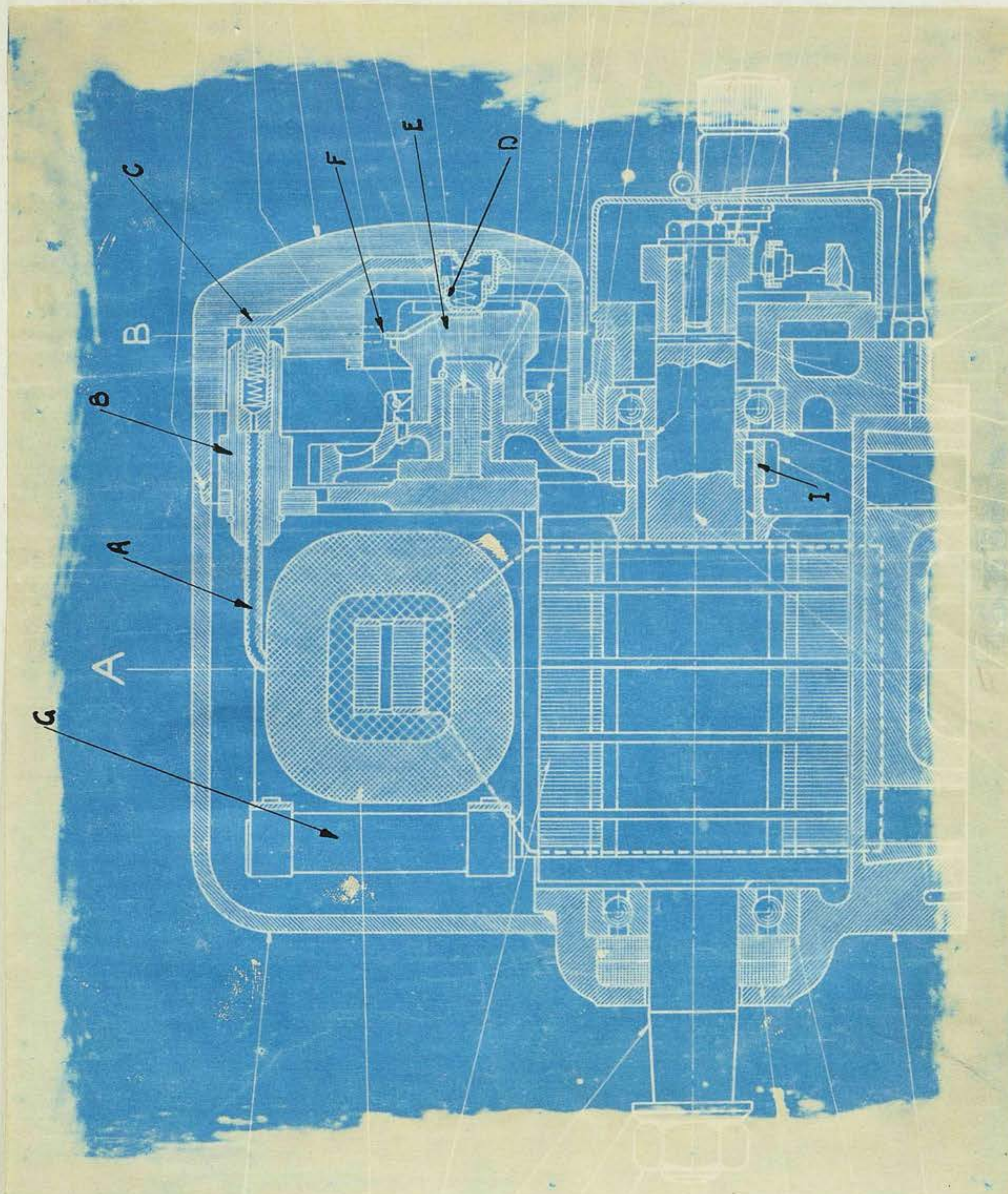
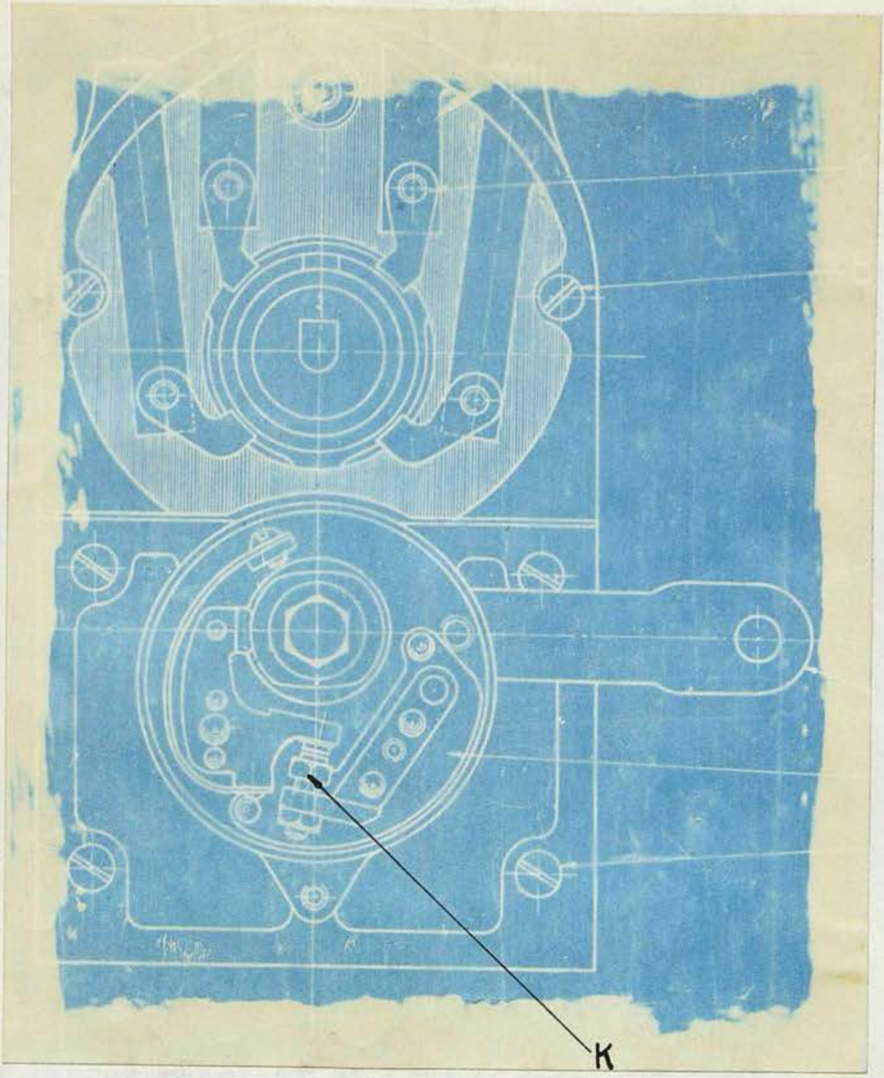
SECTION A A


C
F
E
D
B
B
A
A
G
I

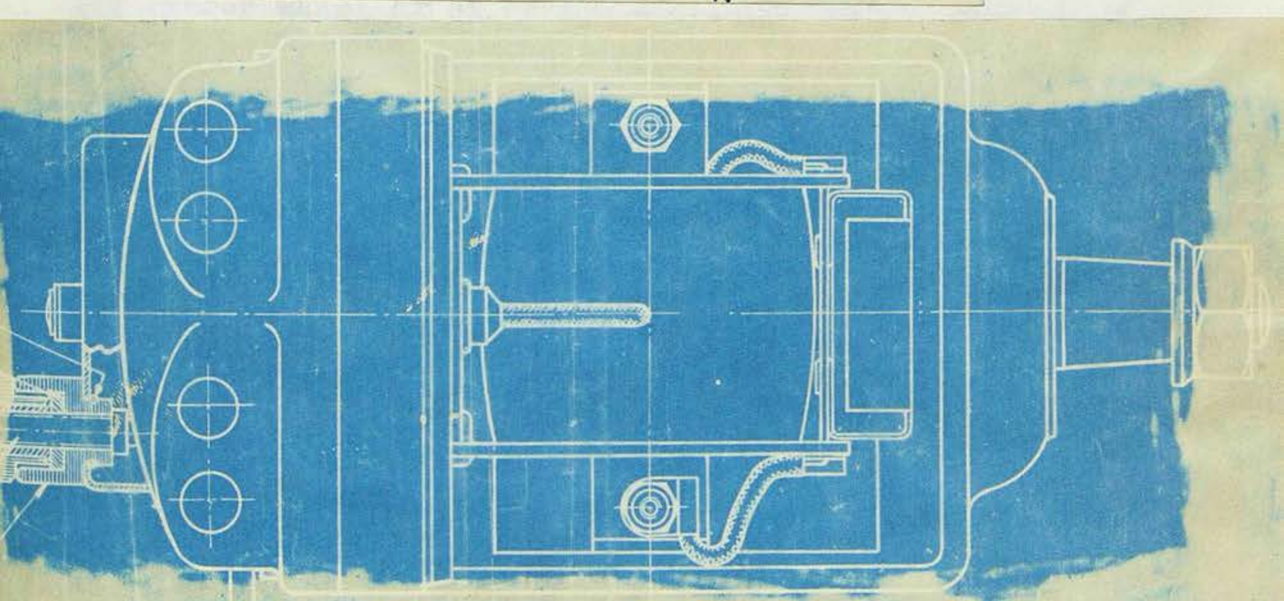
that I know of, namely, that the whole of the gap faces are practically equally active in transmitting flux to the armature, while the reluctance of the air gap is necessarily the minimum possible for the size of magnet adopted, as the pole face area encloses the whole of the magnet, and not merely a portion of it. The collection of flux from the relatively large area of the rotor face and the transmission of it without undue reluctance or eddy current loss to the armature presents a fresh problem which I have dealt with, as indicated in Patent Application No 14778/1921. The fan-shaped construction there described meets both requirements and is very easy to make up commercially. I find in designing a magnetic circuit in a machine such as a magneto, where an alternating flux has sometimes to pursue a tortuous path involving sudden changes of direction, one is apt to provide sufficient area, and laminate the structure, forgetting that any flux passing at right angles to the plane of the lamination will set up eddy currents exactly as in solid material, and that it is therefore necessary to make such arrangements that flux is not induced to cross the planes of lamination more often than is absolutely necessary. Judged from this standpoint the rotating armature machine is gravely defective. If the flux is spread out over the whole magnet shoe and ismade to traverse the armature cheeks the path of a large proportion of the flux makes a large angle with the direction of the lamination, while if the cheeks are turned down below the level of the laminations in order to improve matters by concentrating the flux in the middle of the armature the air gap M.M.F. is increased two or three times.

One would consequently expect that a machine made as just described would give a figure of merit decidedly higher than could be obtained from a rotating armature machine of similar design. This has proved to be the case. In fig. 38 the figures of merit of a number of machines of different types are tabulated.

One or two further features of the machine shewn in figs. 33 to 36 may be referred to. The path of the H.T. current is very short; the leading out wire, A, which is an ample distance from any earthed part, passes into an ebonite tube B, making contact with a metal insert carrying a small brush which is pressed against the distributor segment C shewn in section. These parts are of course stationary; the distribution to the plug circuits takes place through the brush D to the rotating piece E and across a spark gap F to the distributor terminal. The condenser, fixed by the side of the armature, is shewn at G; the primary circuit connections are from the coil through an insulated flexible lead to an insulated laminated copper brush reinforced by a steel spring; this brush, as the timing lever is operated rubs



K



PLAN WITH COVER REMOVED

across an insulated brass block fixed immediately behind the fixed contact K; the circuit is completed through the moving contact and through the control spring to the frame of the machine to which the other end of the primary winding is also connected. The distributor gear wheels are shewn at

REF Nº	TYPE OF MAGNETO	UTILITY AT 2000 R.P.M.	LOWEST SPARKING SPEED 5·5 M/M GAP. FULLY ADVANCED	MAGNET VOLUME C.M³	$\frac{(BH)}{10^6}$	FIGURES OF MERIT 10^9
ZA.	ROTATING ARMATURE	7·3	100	135	260	2·1
ZU.	" "	12·5	70	276	260	2·5
2R	" "	15·2	44	318	260	4·1
AP	(ROTATING MAGNET) ×	5·25	60	130	190	5·4
AG	" " ×	9·7	50	210	190	4·9
R.M.	ROTATING MAGNET NORMAL (0·15 M/M AIR GAP)	7·4	60	18	950	6·1
R.M.	ROTATING MAGNET [redacted] (0·3 M/M AIR GAP)	7·4	160	18	950	2·7
R.C.	ROTATING MAGNET	12	52	42	900	6·0

FIG. 38

Fig. 38.

I and J; the small one is made of laminated brass and leatheroid, as described in Patent Application No. 29290/1921; the larger wheel is of gunmetal. For the convenience of the assembler, the machine is put together before being magnetised; the machine is then placed on an electromagnet, pole pieces are placed on either side connecting the shoes of the electromagnet with the stator shoes, the body casting being pannelled so as to expose the edges of the stator laminations for this purpose, as shewn at L , fig. 33, and with the rotor in the maximum flux position, an M.M.F. which applies about 3,000 H to the magnet is switched on from the electromagnet. About 400 H used to be sufficient for a tungsten steel magnet, but apparently a cobalt steel magnet is not very highly saturated even at 1,000 H, so that in order to be fairly certain that nothing is lost on account of insufficient magnetising force it is desirable to go to still higher M.M.Fs. The armature with its core is put on afterwards (so as not to present a short path to the electromagnet) but before withdrawing the machine from the electromagnet, after switching off.

I feared at one time that owing to the shape of magnet

× Not of my design – foreign types.

adopted the leakage flux might be excessive. This is not so, however. The ratio of total to useful flux is about 1.3, which is the same as for other types of machines.

As will be seen from fig. 38, the functioning of the rotating magnet machine is a considerable advance on that of the earlier types they displace, especially in slow speed sparking. Type RG, for instance, which is intended to supersede and be interchangeable as regards fixing dimensions with either types ZA, G, or Z.U., sparks at a lower speed than the largest of these machines, type ZU. The weight of the complete RG 4-cylinder machine is 7¼ lbs, while the ZA4 weighs 9½ lbs. and the ZU4 15¼ lbs.

The works cost of the new type of machine has not been referred to, but it will readily be understood that the construction described lends itself to much simplification of mechanical design, resulting in greatly reduced cost both of labour and of material.

AUTOMOBILE ELECTRIC STARTING AND LIGHTING APPARATUS.

Starting Motors.

The most usual way of starting a motor car engine by means of an electric motor is through a reduction gear of about 10 to 1, consisting of a gear ring attached to the engine flywheel which is driven by a pinion on the motor shaft. So far I have designed a series of five different motors, which are used with engines varying from about 7 to 30 H.P. These are all similar machines, differing only in size; thus most of the following remarks apply equally to all. As the motors are simply low voltage series wound D.C. machines, I shall refer below only to those special features which have to be introduced and which are not common to other classes of motors.

Starting Torque.

The torque required to overcome the resistance of the engine at starting depends partly on its compression and partly on friction. When the starting motor has run the engine up to a steady speed (which may be assumed to be 100 for a moderate sized engine or 150 R.P.M. for a small engine), the compressions moreor less balance one another and only the friction remains. It is important that the starter should give a sufficient torque under both circumstances; otherwise the starter will never overcome the first compression, or, if the starting torque is sufficient but the running torque is not, a sufficient speed will not be attained to cause the magneto to spark, or the carburation may be insufficient; in either case the engine will not fire.

At the instant of starting the friction is usually very much greater than after the engine has made two or three revolutions, thus a liberal allowance must be made on this account, and the torque necessary to overcome the compression added to it. I have found by experiment a rough relationship between cylinder volume and starting torque required; owing to the enormous variations in friction with engine temperature, thickness of oil, stiffness of bearings, and so on, it is impossible to prescribe within close limits the necessary output of the motor, and a liberal margin of torque must be provided. To give an example of the effect of temperature - I found on testing a certain engine that at an atmospheric temperature of minus 9° C. the torque required to turn the engine at 100 R.P.M. was twice as much as in a garage the temperature of which was 18°C., which in turn was twice as much as was necessary when the engine was hot. To be of real service the starting motor must be able to turn the engine under the worst conditions of temperature, stiffness, or lubrication, as it is only under these conditions that it becomes almost a necessity; when the engine is warm there is no difficulty in starting by hand and the starter is then little more than a luxury.

Design of Armature and Field Windings.

Varying with the amount of the compression, the locked torque required may amount to from two to four times the running torque. Some makers employ a two stage switch for starting; the majority connect the motor direct to the battery through a heavy, low resistance single-pole switch; I have adopted the latter method. At the moment of switching on the current is determined chiefly by the resistance of the motor. The terminal voltage of a six-cell battery, owing to the high discharge rate, may drop from 12 to 10 volts; the drop in cables, terminals, and switch may amount to 2 volts; the remaining 8 volts are applied to the motor, field, brushes, and armature winding. If it is assumed that a constant voltage is applied to the armature winding and that the copper volume is constant, the torque will vary inversely with the number of conductors. As soon as the armature begins to rotate a counter E.M.F. begins to be generated and the torque may be roughly represented by the expression

$$\frac{a(E - bC)}{C}$$

E being the applied voltage, C the number of conductors on the armature, and a and b constants. Constant flux, the circuit being highly saturated both standing and running, is assumed. With this expression the torque is again greater the fewer the conductors are. In practice there is no opportunity to reduce the number of conductors to such an extent that either of the above statements needs much qualification, as the designer is quickly limited by two considerations; the current drawn from the battery, and the number of commutator parts of the motor armature. Three hundred to five hundred amperes is all that can with safety be drawn from the batteries usually employed, the capacities of which as a rule do not much exceed 75 ampere-hours at a 20 hour discharge rate. The currents named are of course very high, but under normal circumstances the discharge takes place only for a second or two, while the plates and separaters are of specially heavy construction. As regards the number of commutator parts, it is usual to employ 4-pole motors in order to reduce the weight of yoke, and even with voltages as low as 6 or 12 - the two voltages most widely adopted - good commutation cannot be secured with fewer than about 21 commutator segments.

It will readily be understood then that the following are the most important considerations in the design of these essentially special purpose motors.

1. Good space factor in armature and field coil windings, to ensure maximum copper volume and lowest resistance.

2. Extra low resistance brushes.

3. Resistance of joints and connections must be carefully considered.

4. All magnetic material must be of the highest permeability obtainable.

1. Bare strip is employed for winding both armature and field coil. The top and bottom bars of the armature slot, (two bars per slot are usually required), are insulated from each other by leatheroid troughs, the coil ends being protected by half-lap tape on every other coil section. The filed coils are wound of bare strip with 0.2 m/m. leatheroid between successive turns.

2. I find that copper graphite brushes, with about 95 per cent of copper, are very suitable. A very heavy pressure is needed, from 10 to 12 lbs. per square inch. Owing to the extremely short time the motor is running there is no objection to so heavy a pressure on the score of wear. I have found that very high current densities may be employed, as high as 1,000 to 1,500 amperes per square inch when locked and half these figures when running, without causing any blackening of either commutator or brushes.

3. Low resistance of joints and connections in a six-volt circuit carrying 300 amperes or more is of course vital. All soldered joints are tested with heavy current and milli-voltmeter in their individual parts before assembly. Suitably heavy cable is carefully prescribed. The starting switch is referred to later. The internal connections of the motor are as shewn in fig. 39. One terminal of the battery (the positive) is connected to earth, by means of a cable bolted to the chassis. Two opposite field coils are also earthed by means of screws clamping the copper strip against the yoke. One end of each coil forms a binding post to which the flexible brush leads are attached, the two remaining field coil leads being joined together to form the sole terminal of the machine. The field coils

are thus connected two in series two in parallel with the armature placed between each pair. There are no sweated connections between adjacent field coils, and no intermediate connectors of any kind. This arrangement has the advantage that the machine is very easy to assemble, and the resistance of joints cannot well be any further reduced.

4. As regards magnetic material, 'Lohys' sheet steel is employed for armature and pole stampings. From time to time I have had considerable difficulty in obtaining suitable steel for yokes. The most convenient material to use is rolled steel tube, as engine makers generally prefer to fit a cylindrical machine, clamping it in a cradle. Some steelmakers apparently have great difficulty in supplying a mild steel in which the amount of carbon does not appreciably exceed 0.1 per cent. Many tests have confirmed that this percentage means excellent permeability, and that double this amount means relatively much inferior steel. The following figures, taken from recent tests, illustrate this well:-

Sample	A.		B.		C.	
Percentage of carbon.	0.1		0.17		0.20	
Ampere-turns/cm. and corresponding B	80.	19.2	16.	14.	16.	13.2
do.	40.	18.1	12.	13.5	12.	12.6
do.	0.	12.8	0.	10.4	0.	9.55

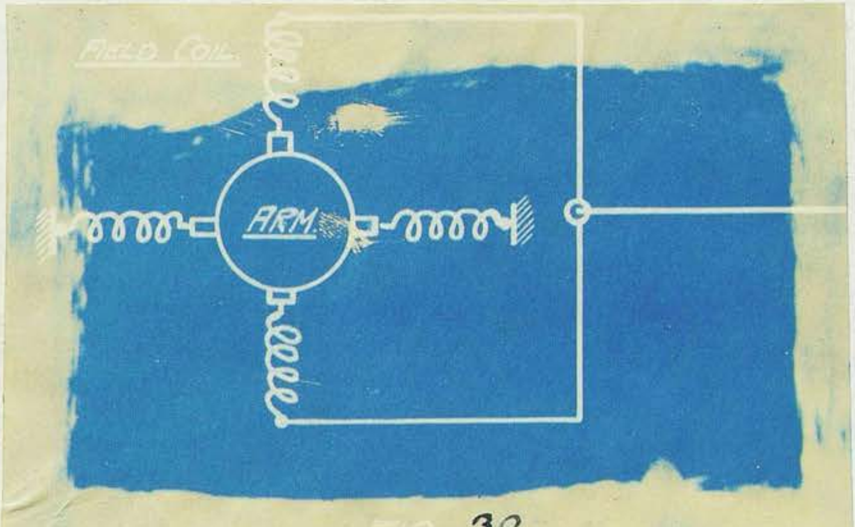


FIG. 39.

I am glad to say that as a result of having come to an understanding with the suppliers on this point tubes supplied recently are much more uniformly good, and little difficulty is occasioned by accepting material only in accordance with the following specification:-

Specification for High Permeability Rolled Steel in Tubes for Starter Yokes. B.63.

The steel shall be low carbon steel, not exceeding .1 per cent carbon, and is to be annealed so as to render it as magnetically soft as possible before delivery.

Magnetic Properties.

The steel shall be tested for magnetic properties in the form of a closed ring with a maximum magnetising force of 100 C.G.S. units. Under these conditions the flux in the ring, as measured by reversal of the magnetising force, shall be as follows:-

Magnetising Force H.	Kilolines per cm^2. B.
100	Not less than 16.5
50	Not less than 15.6

Remanence to be not less than 7, coercive force to be not greater than 3.

Notes on Mechanical Construction.

Brush Gear. The assembled brush gear is shewn in fig. 40. The boxes are formed of strip brass, punched to shape, bent, and secured in position by tangs pushed through a bakelite disc and folded flat against the back of the disc (see also fig. 49). The boxes formed in this manner are very rigid, take up very little space, and the insulation is good and robust. The terminal is shewn in fig. 41 as well as in fig. 40; the ends of the field coils, marked X, are rivetted into a slightly cupped brass disc which is insulated from the housing by a moulded part Y. The strands of which the cable is composed are folded back to a short distance; the insulation of the cable is gripped in a socket and the whole is drawn down by a clamp plate and two screws into contact with the disc carrying the leads X.

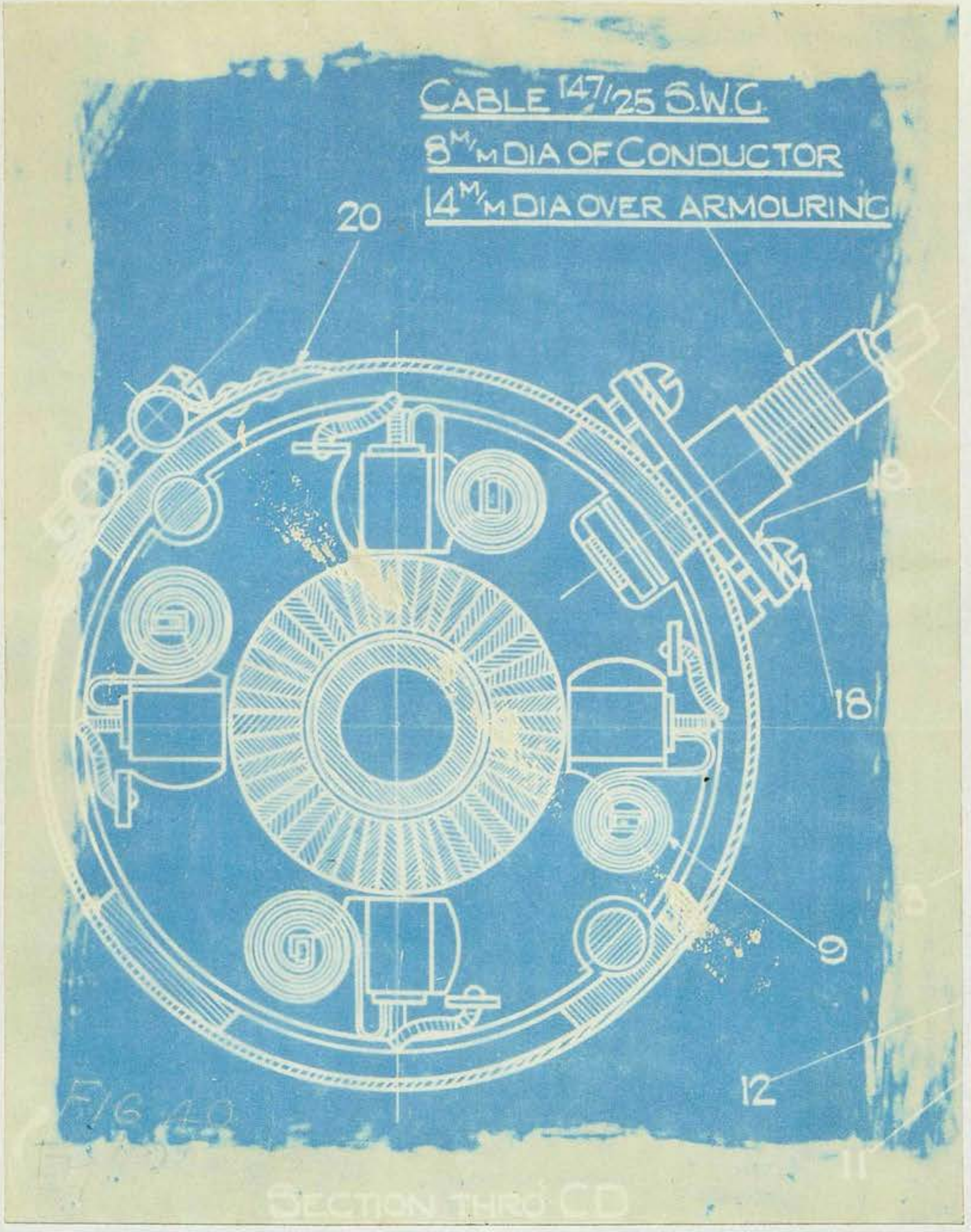


Fig. 40.

In order to keep down the weight and cost of the brush gear it is undesirable to make any provision for rocking the brushes and whatever displacement of the brushes from the neutral axis is necessary must accordingly be allowed for in winding. As the service of the motor is such that it only runs for a few seconds at a time followed by long periods of rest there is little value in testing commutation by long runs. Instead I connect the motor through an

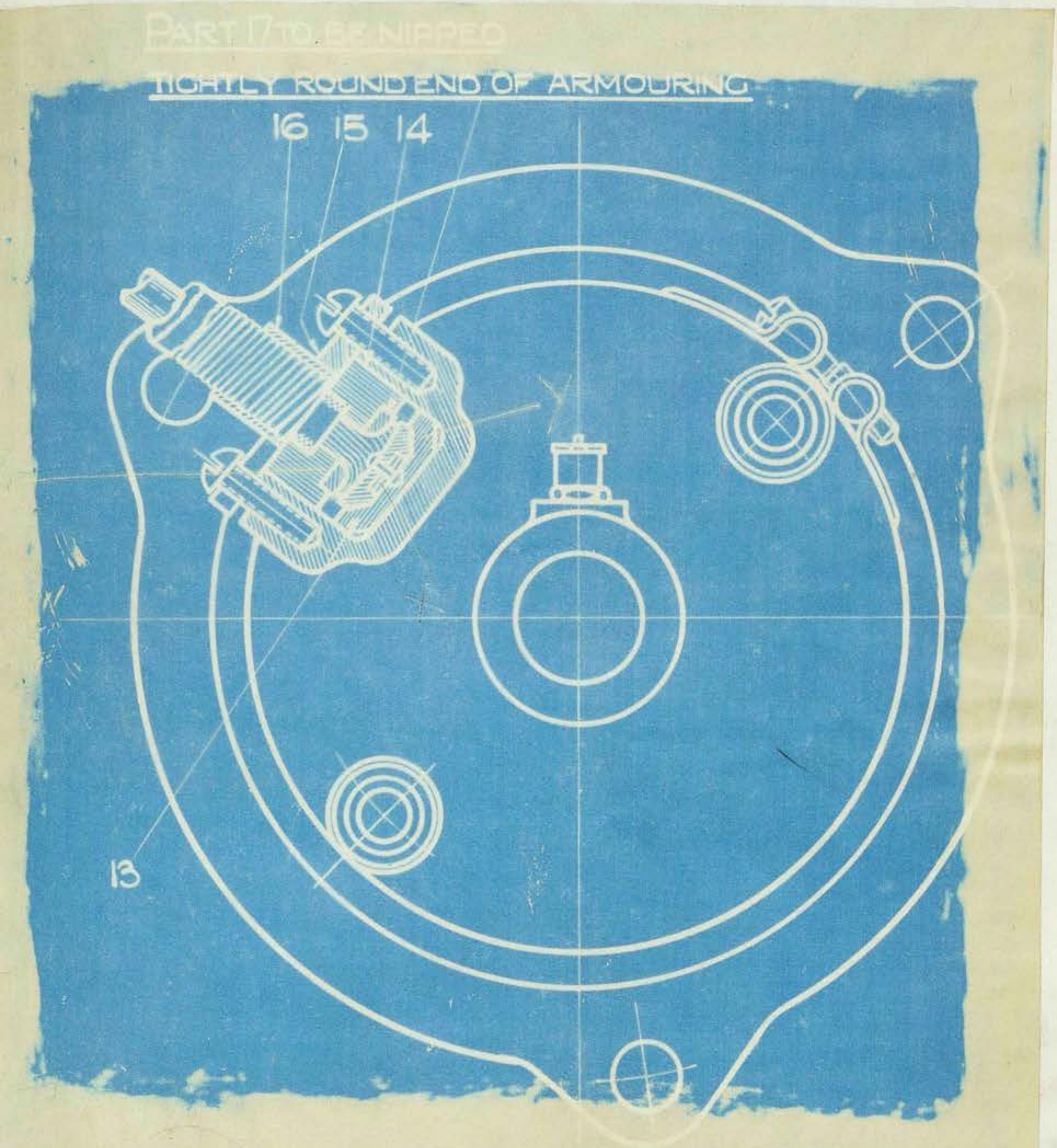

PART 17 TO BE NIPPED
TIGHTLY ROUND END OF ARMOURING
16 15 14
13

Fig.41.

intermittently acting switch, which starts the motor, say, once every ten seconds. By this means the effect on the commutator and brush gear of the current rush at starting as it actually takes place under working conditions is imitated; I find that machines which are in good condition after 20,000 such starts give no trouble in practice, though an unsuitable brush position, excessive armature reaction, and so on, is quickly shewn up.

The Starting Switch.

At first I tried to use a modified form of knife blade switch with rubbing contacts; as shewn at A, fig.42

This type did not prove very successful; the blades were inclinded to burn unduly at the points between which the arc at breaking took place, and especially at the tips of the stationary blades. Altering the latter as shewn at B made a considerable improvemnt, but after a certain amount of experimenting I cam to the conclusion that with the very heavy current which thr switch had to stand, up to 500 amperes, a switch of which the contacts consisted of massive flat plates made to form a butt contact on their faces would be most suitable, the presence of a mass of metal in the neighbourhood of any contact point being then very effective in preventing excessive local heating. Aswitch which has been developed on these lines is described in Patent Applicatio No. 27110/1921. After prolonged use ~~the surface~~ the surface of the contacts becomes slightly pitted, but this does not interfere in any way with its successful operation, as ample amount of material is left for wear, the moving contact is able to tilt sufficiently to bridge both sockets in the event of thewear being uneven, and in practice it is found that the contact voltage drop is very low.

ELECTRIC LIGHTING APPARATUS FOR MOTOR CARS.

Dynamos.

The general practice is to design and drive the dynamo so that it generates a voltage equal to that of the battery at about 8 to 10 miles per hour on top gear. If the car can be driven at 60 miles per hour there is consequently a range of speed variation of 6 to 1 or more over whichthe voltage of the dynamo must be controlled so as to charge the battery at a reasonable rate.

On commencing to manufacture this form of apparatus I spent some time in considering what was the best system of voltage regulation to adopt, and drew up a report on the relative merits of control by armature reaction and by constant voltage regulators. Extracts from this report are quoted below:-

Report on Existing Starting and Lighting Systems.

During the past few months a number of tests on starting and lighting squipments have been carried out. The object of these tests, and of similar ones now being made on machines of various types, is to obtain such technical information as will be of assistance in estimating the relative advantages and drawbacks of various types of control, etc., an in bringing out new designs of our own.

A report of the tests made is attached. As many of these have to do with details of design, the information gained is summarised, and a discussion regarding certain aspects of starting and lighting systems in general is added, in explanation of the criticism made of one particular system of dyhamo voltage regulation.

The points dealt with are arranged in the following order:-

Dependence of starter on charging system.
Conditions ensuring long life of battery.
Merit of charging system to be judged by
degree of fulfilment of these conditions.

All existing systems divided into two main classes.
Characteristics of the two classes.

Dependence of Starter on Charging System - Life of Battery.

The dynamo and the method by which it is controlled call for much greater care in design than the starting motor. The reason for this is as follows:-

Leaving the nature of the drive, etc., out of account for the moment, a starting motor - of whatever make - is a comparatively simple machine of well established design; but it depends entirely for its successful operation on the battery being maintained in good condition.

The condition of the battery depends chiefly on its receiving its charge
(a) at a proper rate, and
(b) for a certain length of time, neither less nor more.

The best values for both the rate and the duration of the charge vary from time to time within wide limits according to the previous history of the battery.

The success of a charging system may be judged by the extent to which it fulfils these two requirements, and fulfils them automatically. This constitutes the designer's problem, and is one of considerable difficulty.

Conditions Ensuraing Long Life of Battery.

It is commonly stated that automatic control is not required, and that it is only necessary to continue charging until the normal voltage, say 12, has risen to 15 or 16, when the dynamo may be switched off. On the other hand, it has been urged for years by battery experts that voltage readings alone are almost worthless, and that charging is completed only when gassing takes place freely and regularly, and the specific gravity has ceased to rise.

It is, however, a laborious matter, even for an expert, to pay the regular attention to a battery that such an examination would entail, and it is an impossible task for one who is not an expert.

The most usual consequences of charging according to the former plan is that thebattery will be steadily overcharged, and that troubles wil develop one after another - slowly, but surely. The electrolyte is gradually boiled away and the plates uncovered. If they are not topped up at once the exposed parts sulphate and degenerate, the battery losing capacity rapidly. Persistent overcharging weakens the plates mechanically, and they also suffer from the accompanying concentration of acid.

All the above occurrences lead to loss of capacity, and in the end to the refusal of the starter to operate. I have known many cases of batteries receiving spasmodic attention only, which have been ruined in a year to eighteen months, when with reasonable treatment they might quite well have lasted four or five years.

Thus it seems probable that a large percentage of the failures attributed to the battery is rather due to the inability of the lighting system automatically to control the rate and duration of the charge given to the battery.

Control Systems Divided into Two Classes.

Broadly speaking, all systems of control in use at present may be divided into two classes. Those in the first class possess what may be termed a "current limiting" characteristic. By this is meant that any rise of current, due to whatever cause, e.g., increase in speed - increases the effect of some factor - different in different systems - which tends to prevent further increase in current.

Those in the second class maintain an almost constant voltage under all conditions of running, the small variation which takes place between extremes of speed being sufficient to operate some device for controlling the shunt current within the limits to which the voltage variations correspond. The charging current is only under indirect control through the voltage.

Characteristics of the Two Classes.

The greatest advantages of the former system are its simplicity, reliability in operation with a minimum of attention, and its cheapness.

Its drawbacks are all ultimately due to one cause, namely, that the battery has to receive a current which is determined not only by its own needs, but by the speed of the car.

The latter system is of more intricate construction, and if it is not very carefully designed it is liable to require a certain amount of attention. If this difficulty is successfully overcome, however, there are a number of advantages which may be gained by using the latter system which cannot be obtained with the former. To enumerate the chief of these:-

(1) If the battery is nearly discharged energy is returned to it much more quickly by the "constant voltage" system (B) than by the "current limiting" system (A). In the following diagrams the two systems are compared with each other and with an ideal system (C):-

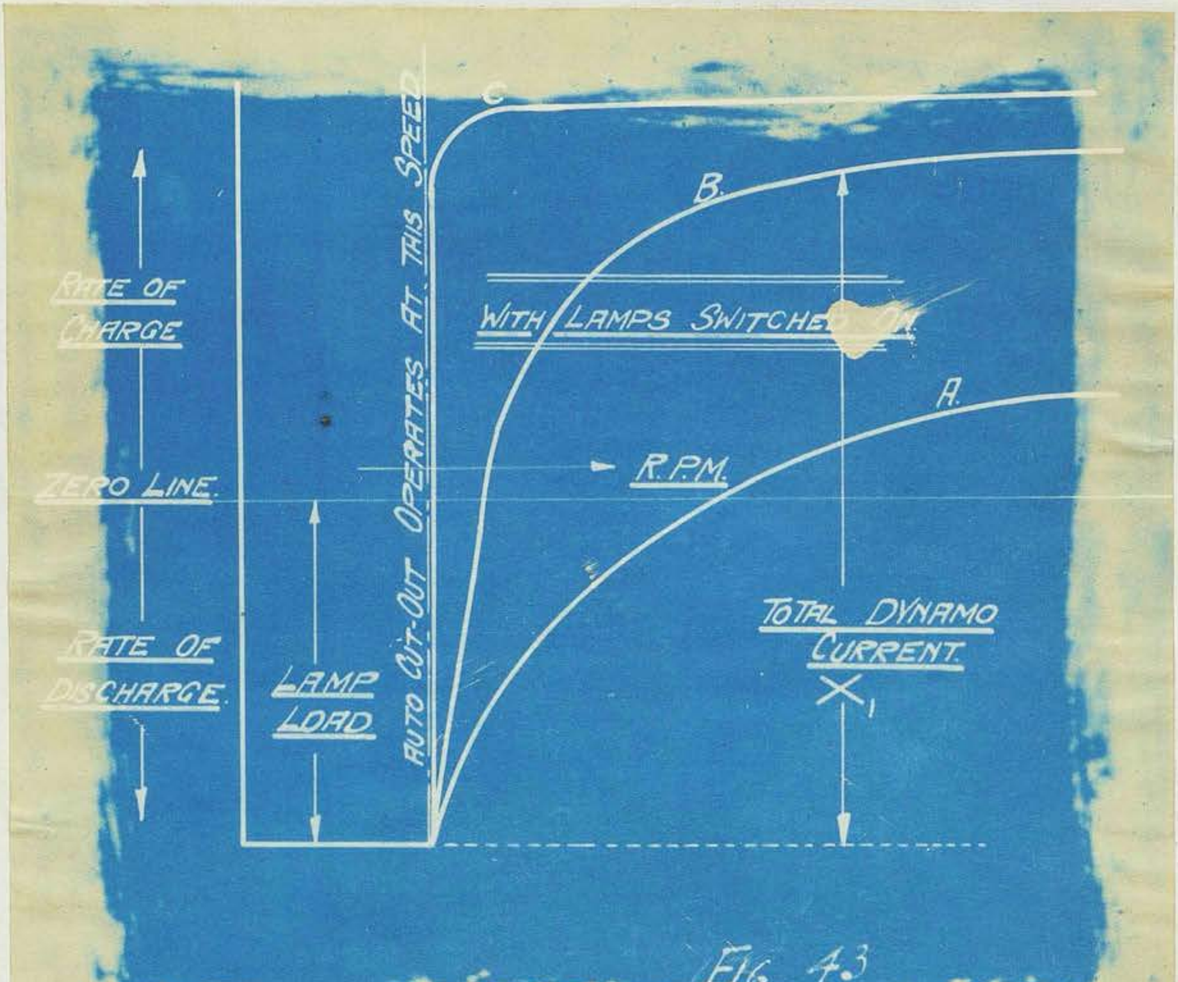
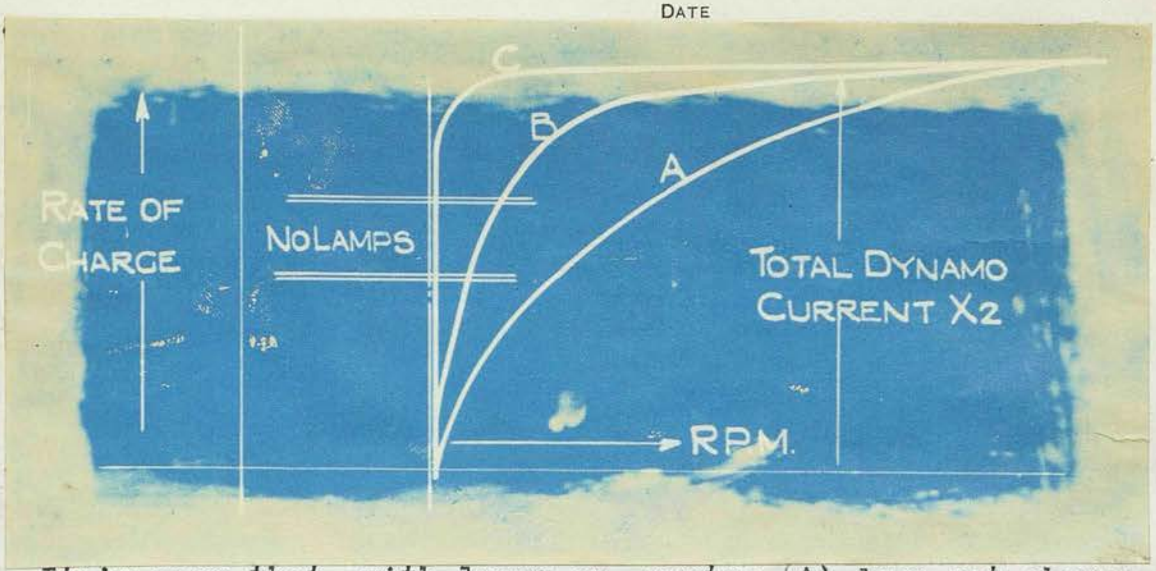


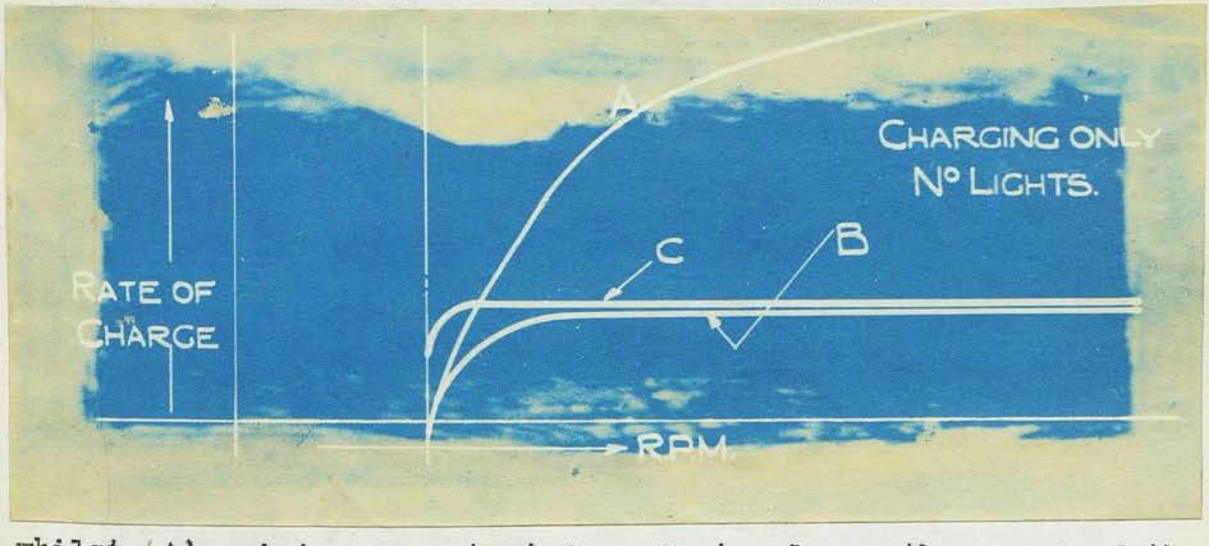
FIG 43



It is seen that, with lamps on, system (A) does not charge the battery at all, the small amount of charging obtained at high speed being offset by the discharging which takes place at lower speed. Thus, with much driving at night, or with frequent starting and stopping, it may eventually be necessary to give A's battery a separate charge, either removing it from the car, or running the engine soely for that purpose.

With "constant voltage" control more current is automatically given by the dynamo when the lamps are on - compare X_1 and X_2 - and any sudden draft on the battery is very quickly made good. This is particularly the case immdeiately after the starter has been operated, the drop in battery voltage causing the dynamo to pour back current at a much higher rate until the voltage rises again.

With the battery nearly fully discharged, the "constant voltage" system (B) prevents undue overcharge,



whilst (A), giving an output dependent only on the speed of the dynamo, overcharges badly. The grave consequences following on prolonged overcharging have already been referred to.

(3) The variation of charging rate during the time of charging has been carefully studied. All machines in class (A) are particularly unfortunate here, the rate being least at the beginning of the charge, when it should be greatest, and actually increasing towards the end of charge, instead of dying down, as is much to be preferred. Systems (A) and (B) are again compared with an ideal system (C) in the following diagram:-

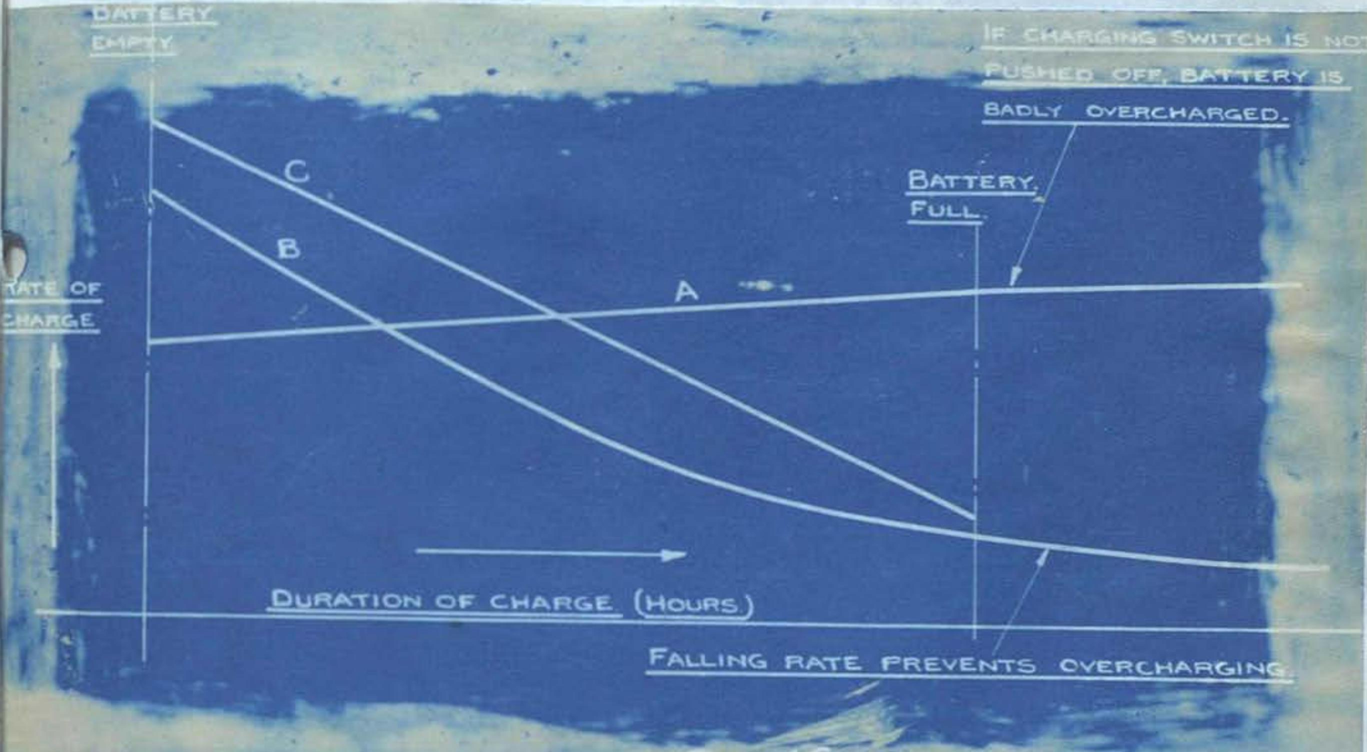


FIG 46

(4) The "constant voltage" dynamo operates almost as satisfactorily with the battery removed as when it is in circuit, although of course no light is obtained unless the engine is running. No "current limiting" dynamo can operate with battery disconnected. On increase of speed the rise of current, normally supplied to the battery, which prevents excessive rise of voltage, can no longer be obtained; consequently the voltage rises and promptly burns out the lamps.

(5) It is very desirable that arrangements should be made that the mean charging rate may be adjusted to within reasonably wide limits, so that the conditions peculiar to each car - depending on the nature of its work as well as the number of electrically controlled devices employed - may be provided for as far as possible. In "constant voltage" systems this can be effected in all cases by simply altering the tension of a control spring. In "current limiting" systems it is generally much more difficult.

(End of extract)

Dynamo Voltage Regulation by Third Brush Method.

Notwithstanding all the advantages to be gained by adopting a charging system based on constant voltage control, I eventually came to the conclusion that the only two systems so far introduced for motor cars - the vibrating regulator and the carbon granule regulator - were both rather too sensitive, were too liable to be put out of adjustment by small accidental disturbances, and were not capable of running for a prolonged period without requiring adjustment. I accordingly decided to adopt an armature reaction system, and chose the third brush method of control as being the simplest and most effieient.

After trying a number of methods of exciting the field circuit I found that the simplest winding - a single set of shunt coils connected between the third and the main brush - was quite satisfactory, and I therefore adopted this arrangement. In fig. 47 is shewn the variation of charging current

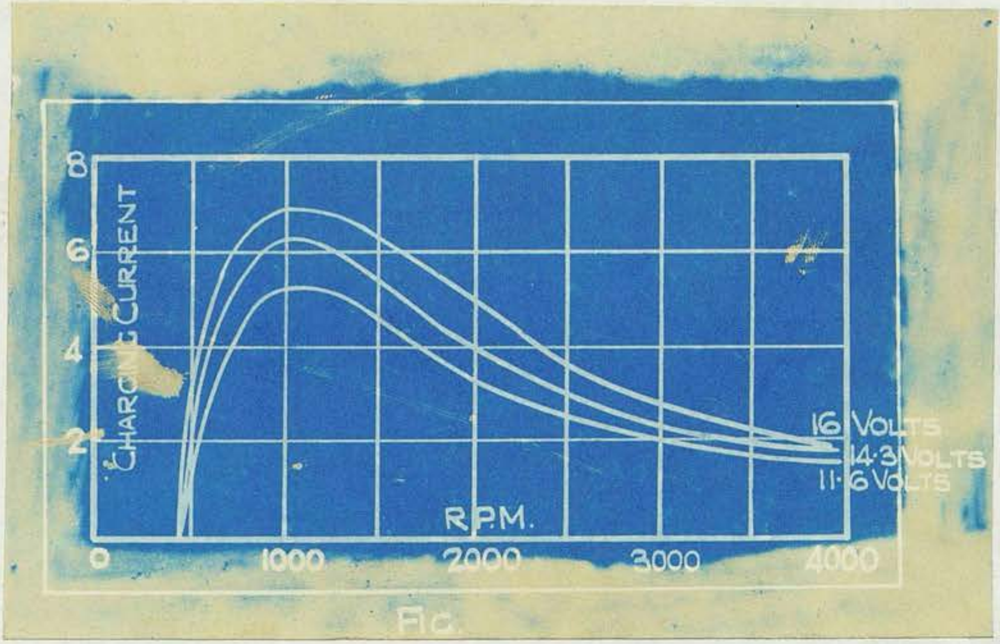


FIG.

with speed at a number of battery voltages. The dynamo is intended for charging a 6-cell battery; the variation in voltage from about 11.6 to 16 volts indicates the normal extreme variation which is met - the highest voltage when the battery is gassing during daylight running and the lowest when the battery is almost discharged and all lamps are switched on at night. The increase of charging current when the battery is gassing is unfortunate, but I have so far been unable to devise any cheap and reliable way of avoiding this. The form of each curve is typical; if the dynamo is driven so that 500

R.P.M. corresponds to 10 M.P.H., the charging current rises to a maximum at 20 M.P.H., is practically the same at 30 M.P.H. , and at higher speeds falls off. By adding a shunt winding connected directly across positive and negative brushes it would be quite easy to prevent the reduction in charging current at high speed, but I consider the form of curve shewn is preferable. For slow speed driving, as in town, or at night, the charging rate is high, whereas a car is driven at speeds exceeding 30 to 40 M.P.H. only in the country and during the daytime when a reduced charging rate is not only permissible but a slight protection against the evils of overcharging.

The output of the dynamo, depending chiefly on the difference between its voltage and that of the battery, is considerably affected by variations in permeability of the yoke, length of air gap, and armature and field resistances, and I find it necessary to provide a means of adjusting the position of the third brush and thus the field current in order to compensate for these variations. Fig. 48 shews

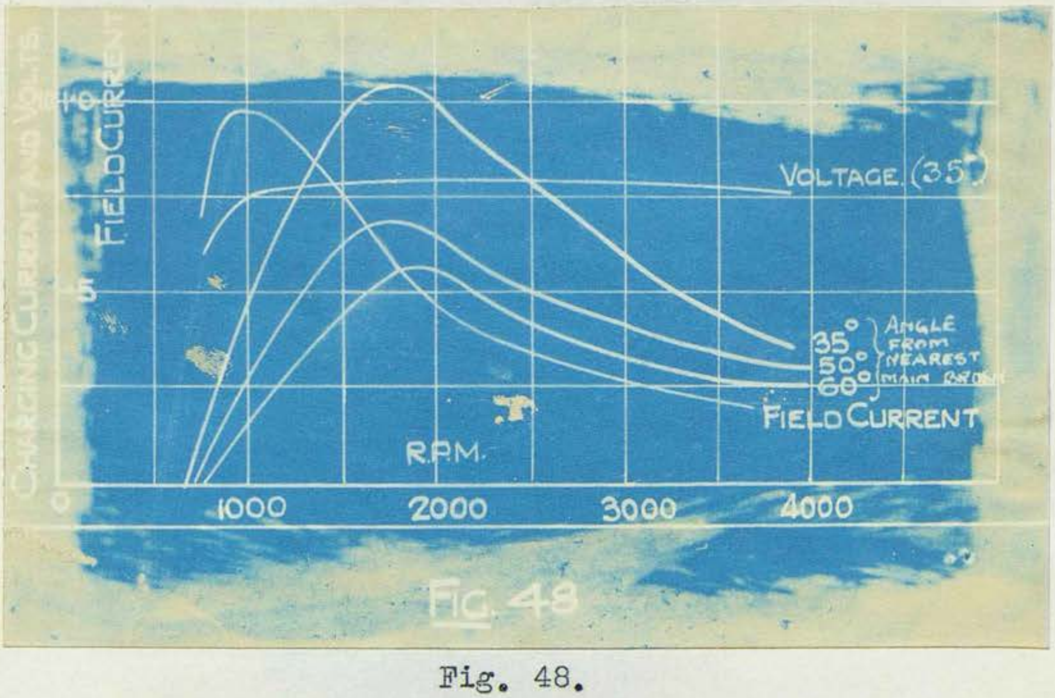
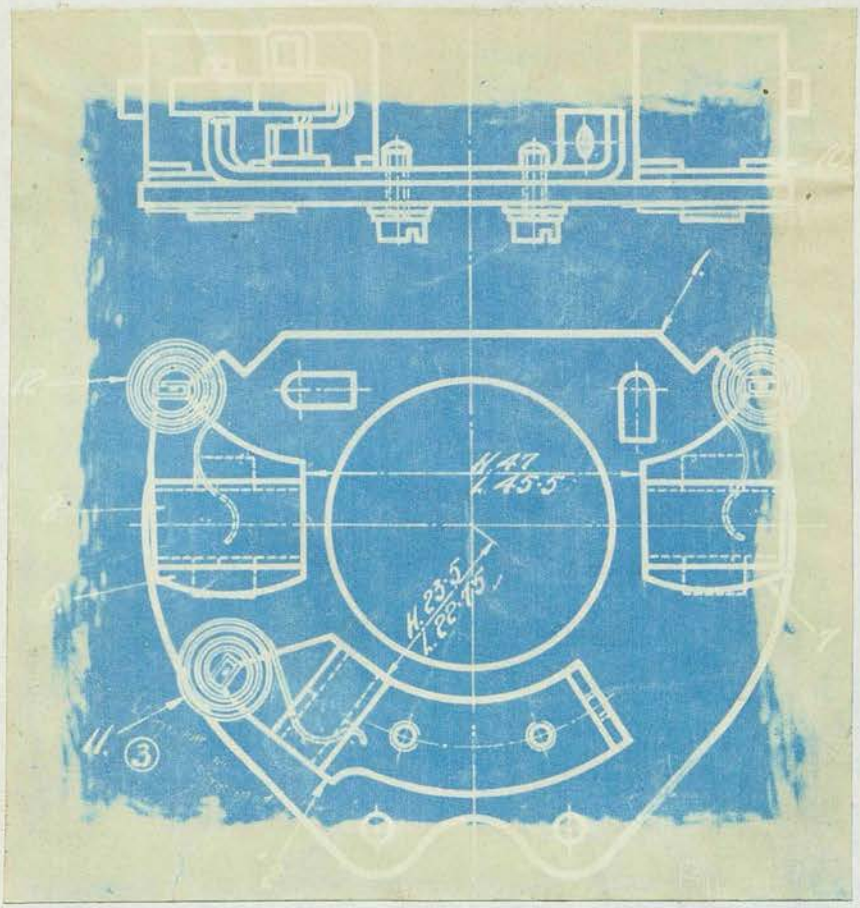


Fig. 48.

the charging current for different angles of the third brush position. The construction of the brush gear, on similar lines to the starting motor brush gear already described, is shewn in fig. 49, and the complete commutator end bracket in fig. 50.



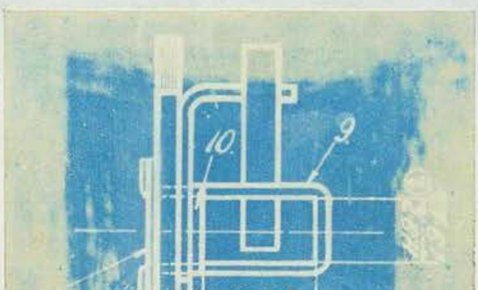


Fig. 49.

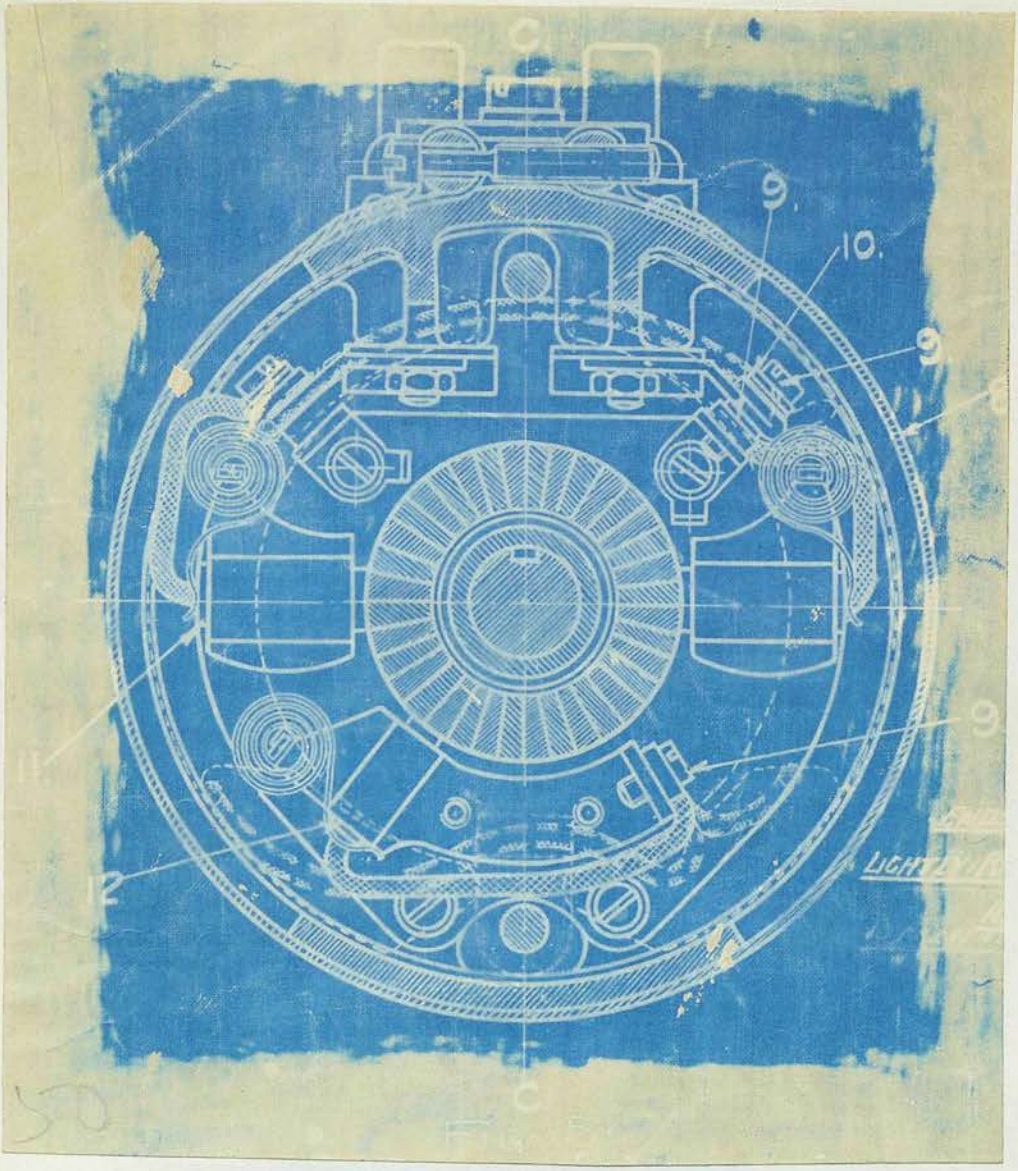


Fig. 50.

Switch Gear.

The complete circuit connections for the lighting equipment are shewn digrammatically in fig. 51. Three fuses are provided, a main fuse which operates in the case of short circuits occurringon the connections between battery and dynamo or on the five lamp circuits. An auxiliary fuse protects branch circuits such as horns, interior lights, and so on, which are often wired up carelessly, not being supplied with the car as originally delivered by the maker; the blowing of this fuse does not put out the main lights.

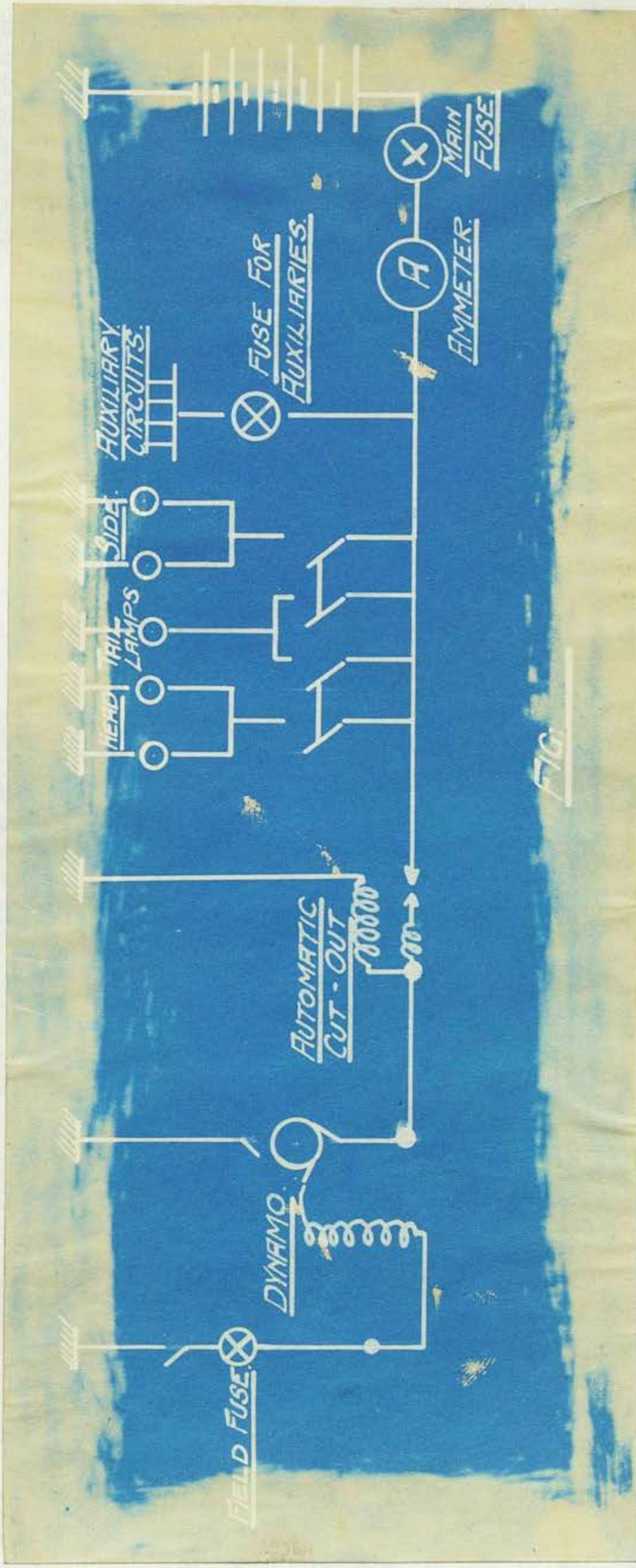

MAIN FUSE
AMMETER
FUSE FOR AUXILIARIES.
AUXILIARY CIRCUITS.
SIDE.
HEAD
TAIL
LAMPS
AUTOMATIC CUT-OUT
DYNAMO.
FIELD FUSE.
FIG.

Fig 51.

A cut-out, consisting of shunt and series windings, on a steel core, rpovided with flat cheeks, a hinged armature and tungsten contacts, is set to close the circuit as soon as the dynamo generates the normal battery voltage. The series winding is proportioned so that the circuit is opened by a reverse current not exceeding ten to fifteen per cent of the maximum charging currant. The cut-out combined with 1 or 3 fuses in a common box is illustrated in fig. 52.

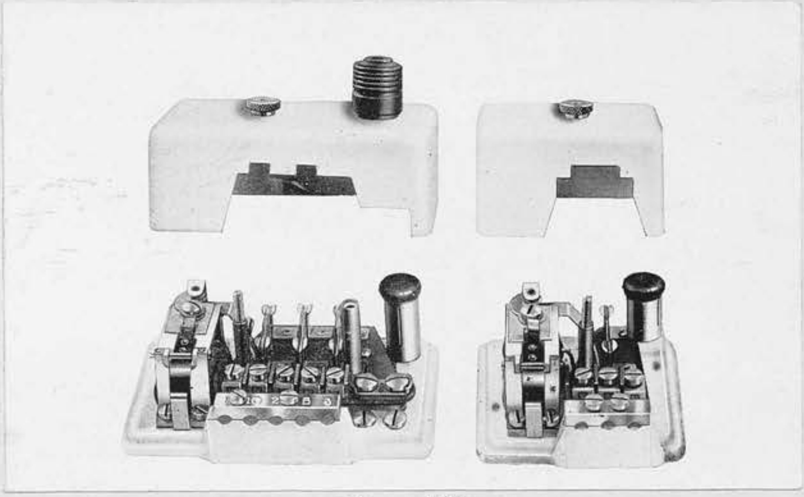
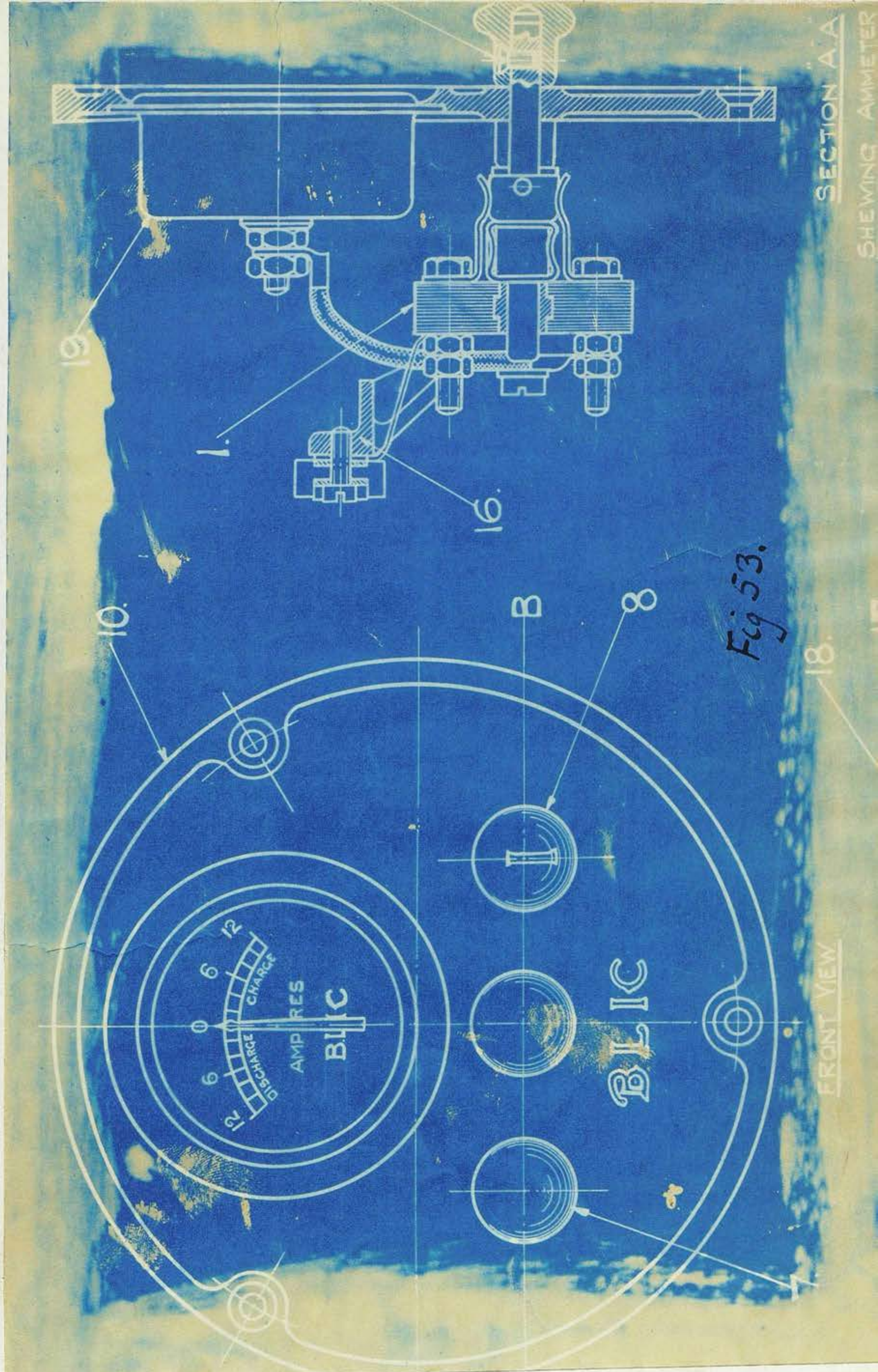


Fig. 52.

The switching arrangements have to be varied to meet differing requirements. In general each switch has to do more than merely cut-off one circuit. For instance, the five lights on a car are most conveniently controlled from two switches, one of which controls head and tail lights and the other side and tail. Again, it is a convenience if a switch in the field circuit can be interconnected with the switch operating the side and tail lamps, so that if the driver has discontinued charging during the daytime charging is automatically recommenced at night. An arrangement which I have used for this purpose is referred to in Patant No. 165,945, a copy of which is attached. Another arrangement frequently required is that the front lamps (where three only are provided) can be connected either in series or parallel, the former connection being used when the car is stationary in order to cut down the current consumption. I find that the switch unit shewn in figs. 53 and 54 can conveniently be adapted to meet these various requirements; two fixed contact blades are secured on either side of the moving contact, which has two positions corresponding to the switch knob being either in or out. There are thus four fixed points on each


SECTION A.A
SHEWING AMMETER
FRONT VIEW
Fig 53.
19
1.
16.
10.
8
B
18.
7
12 6 0 6 12
DISCHARGE
CHARGE
AMPERES
BLIC
BLIC

switch which may be insulated or interconnected at will. This arrangement provides a degree of freedom which enables the switching arrangements referred to to be worked without difficulty, although from the standpoint of manufacture one common switchboard is used throughout.

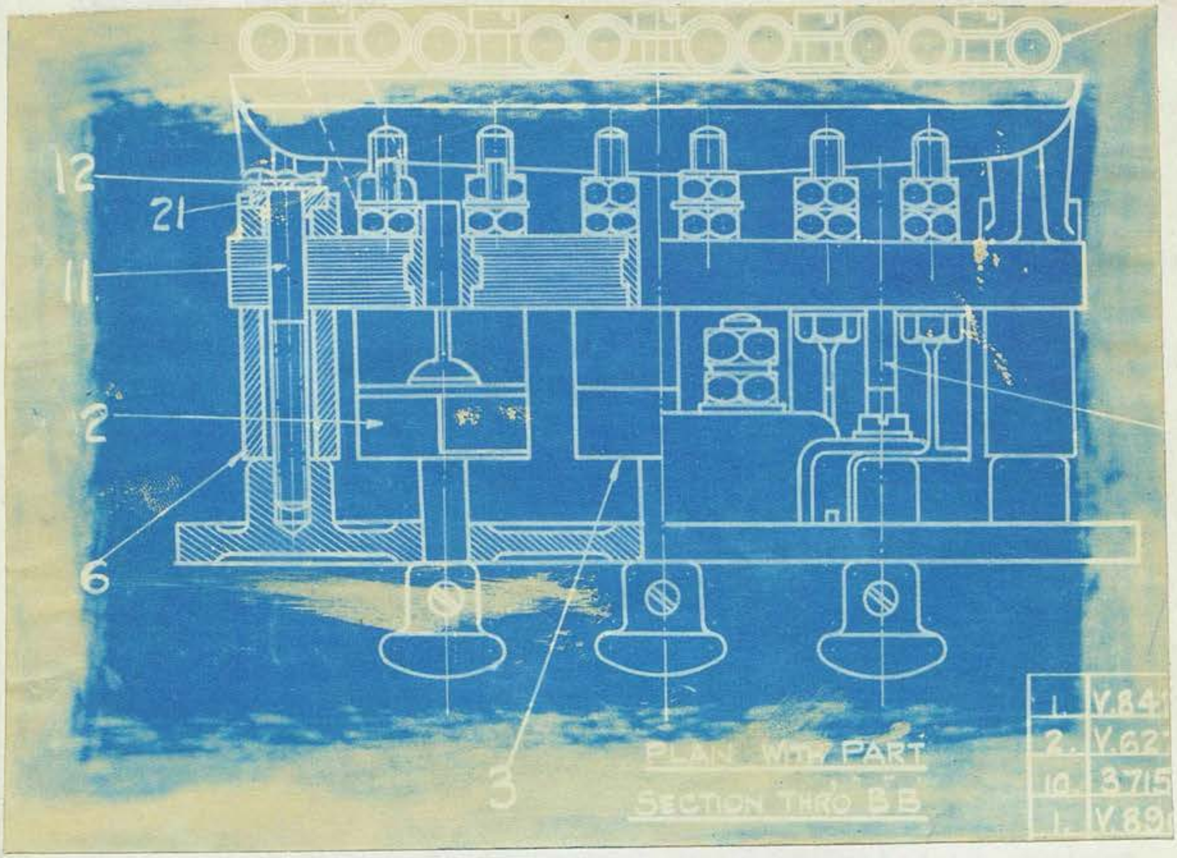


Fig. 54.

APPENDIX.

A. In addition to the patents referred to in the foregoing, copies of three others, which are connected with the matters discussed, have been included; these are Nos. 125,331, 165,862, and 24,654/21.

B. Rise of current in a saturated circuit.

In working out the current interrupted at high speed in a nearly closed circuit coil, the iron ampere-turns of which are appreciable, L_1 cannot be assumed to be constant, and I employ the following method of plotting the current time wave. The instantaneous current i_1 is given in terms of the final primary current I_1 by the expression

$$i_1 = I_1 \left(1 - \varepsilon^{-\frac{tR_1}{L_1}}\right)$$

Thus $$t = \frac{L_1}{R_1} \log \left(\frac{I_1}{I_1 - i_1}\right)$$

or inserting the value of L_1 in terms of the magnetisation curve of the coil, which, it is assumed, is known

$$t = \frac{\Phi T_1}{10^8 R_1 i_1} \log \frac{I_1}{I_1 - i_1}$$

From this expression t may be worked out for assumed values of i_1, and the value of i_1 interrupted at various speeds read off from the curve.

C. I have recently come across Professor Taylor Jones' mention (in the book referred to on page 20) of the experiments of Klingelfuss with nearly closed circuit induction coils. As he employed a gap not less than 1 cm. (apparently) the air gap ampere turns must have been predominating, but as his is a prior investigation, I wish to draw attention to it.

125,331

PATENT SPECIFICATION

Application Date, Nov. 14, 1918. No. 18,716/18.

Complete Accepted, Apr. 17, 1919.

COMPLETE SPECIFICATION.

Improvements relating to the Windings of the Armatures of Magneto Machines.

We, The British Lighting and Ignition Company Limited, and Ernest Owen Turner, Electrical Engineer, both of 204, Tottenham Court Road, London, W. 1, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In the usual arrangements of the armature windings of magneto machines, such as are used in connection with the ignition devices of internal combustion engines, the primary coils are wound on the armature core and the high tension secondary coils are wound over the primary.

It is sometimes desired to produce simultaneous sparks at two or more plugs either in the same cylinder or in pairs of cylinders, the former device effecting more complete ignition in the cylinder and the latter enabling in a four cylinder engine, for instance, the distributor, gear wheels and high tension distributing brush gear *etc.* to be dispensed with.

In one known arrangement the primary coil is first wound on the armature core in the normal manner and is then heavily insulated. The secondary coil is then wound over this in the usual manner with the exception that means must be provided to insulate the inner end of this coil which is brought out to the surface instead of being connected to the primary in the normal manner.

The thickness of insulation required between the primary and secondary windings not only reduces the available space but lessens the mutual induction between the windings and thereby decreases the efficiency of the transforming action of the windings. In addition, the heavy insulation which must be provided for bringing out the inner end of the secondary winding involves more loss of space.

In another known methed, two or more separate and independent secondary windings suitably insulated from each other are arranged in conjunction with a single primary winding. The two high tension windings are separated by an insulating partition, the inner ends of the windings being connected to the frame of the machine and their outer ends through slip rings to separate sparking plugs. In this method only half the total number of turns is operative in producing the spark at each plug and the outer ends of each secondary winding are at the same potential.

According to the present invention, in which the high tension winding is divided into two sections separated by an insulating partition, the inner layers of each sectional winding are joined together, but insulated from the primary and from the frame, at points on either side of the central partition and the sections are wound in opposite directions over the primary, the ends of the

[Price 6d.]

ONE SHILLING

sections, which are at opposite potentials of approximately equal value, being at the exterior of the coil. This arrangement has the advantage as regards the first mentioned known device that the voltage between the primary and secondary windings is reduced to a minimum, there is a considerable reduction in the thickness of the insulation between the primary and secondary coils and consequently improved inductance between these coils and a corresponding gain in the space occupied. In addition, the di-electric stress in uniformly distributed over the insulation, ignition is equally effective if either side of the secondary winding is earthed and there is no necessity for a heavily insulated conductor to be brought out from the interior of the coils.

It has the advantage over the second known arrangement mentioned above, that the full voltage of both sections of the coil is available at the terminals of the secondary coil, two sparks can be produced in series and a short circuit on one plug increases instead of lessens the energy available at the other plug.

The accompanying drawing shows partly in section an armature of a magneto machine in which the high and low tension windings are arranged according to the invention.

The primary coils B wound on the core of the armature A are separated by a comparatively thin insulating layer D from the two sections C_1, C_2 of the high tension winding.

The two sections are connected at a central point E which is insulated from the armature core and from the primary winding and the coils are wound in opposite directions towards the armature cheeks. There should be as nearly as possible the same number of turns in each section, in which case the two ends c_1, c_2 of the winding have potentials of opposite sign and equal value. An insulating partition F of known kind separates the two sections of the high tension windings. The ends of the high tension coils are connected by slip rings, or segments of one slip ring, in the usual manner to the terminals of the secondary circuit.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A magneto machine in which the high tension winding is formed of two similar sections, separated by an insulating partition, the inner layer of each section being joined together at points on either side of the partition and insulated from the armature core and from the primary winding, the ends of the winding being connected through slip rings to the terminals of the secondary circuit, substantially as described.

2. A high tension winding for magneto machines according to the preceding claim, in which both ends of the winding are on the external surface of the coils.

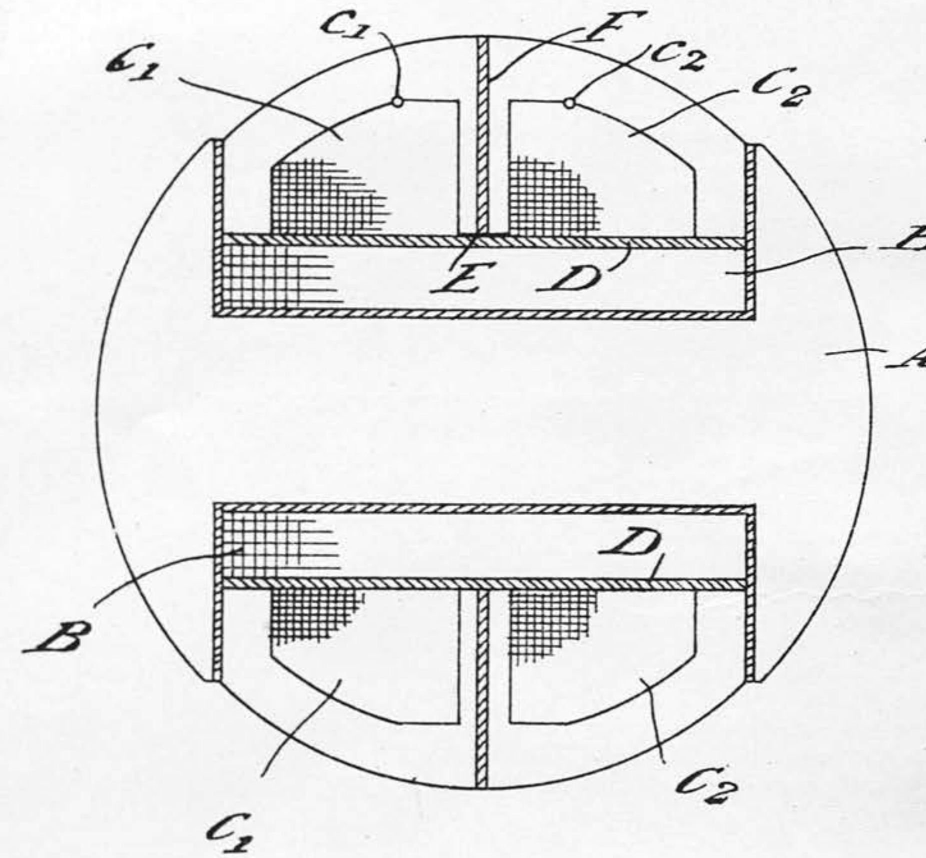
3. A magneto machine according to Claim 1 in which the high tension winding is formed of two sections with approximately the same number of turns wound in opposite directions starting from the point of junction of the two sections.

4. A high tension winding of magneto machines according to the preceding claims, adapted for the production of ignition sparks in series, either in the same cylinder of an internal combustion engine, or simultaneously in pairs of cylinders.

Dated this 14th day of November, 1918.

ABEL & IMRAY,
30, Southampton Buildings, London, W.C.2,
Agents for the Applicants.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1919.



[This Drawing is a full-size reproduction of the Original.]

136,215

PATENT SPECIFICATION

Application Date, Nov. 14, 1918. No. 18,715/18.
Complete Left, May 14, 1919.
Complete Accepted, Dec. 15, 1919.

PROVISIONAL SPECIFICATION.

Improvements in Armature Windings of Electric Alternating Current Machines.

We, The British Lighting and Ignition Company Limited, and Ernest Owen Turner, Electrical Engineer, both of 204, Tottenham Court Road, London, W. 1, do hereby declare the nature of this invention to be as follows:—

The invention relates to the arrangements of the slots carrying the armature conductors of single or polyphase alternating current machines of the type in which the armature rotates past a number of poles of alternate polarity provided in the stationary field magnets, or in which the field poles revolve past the stationary armature windings.

In such machines it is customary to provide several slots per pole for every phase in the winding, in order to dispose the winding to the best advantage around the periphery of the armature and to obtain a wave shape approximating closely to a sine curve. Where the poles are few in number and the pole pitch is large this is very easily arranged, but difficulties arise where it is reguired for any reason to provide a large number of poles, as in very slow running alternators and motors, or in machines to generate at high frequency, or to run on circuits of high frequency. If only a single slot is provided the wave-shape becomes badly distorted from the ideal sine form and if the larger number is retained the slots must be so narrow that a large proportion of the slot volume is required for insulating lining, and the space factor is so greatly reduced that it is impossible to employ a conductor of sufficient cross section to obtain the desired output.

These drawbacks are obviated according to the invention in which, preferably, only a single slot is provided per pole but the pole pitch in the armature differs slightly from that in the field magnets, with the result that the electromotive force induced in any conductor is out of phase by a constant amount with that induced in a conductor in either of the adjacent poles. The effective electromotive force at any instant is consequently the vector resultant of the separate electromotive forces induced in all the conductors which are arranged in series and the wave shape may be arranged to approximate closely to a true sine form, since it is obvious that the conditions determining the wave form are the same as if all the conductors in a given series were all symmetrically distributed over the space of a single pole pitch.

[*Price 6d.*]

Preferably, the armature poles are placed in as many different positions as possible with respect to the corresponding magnet poles. This may be effected by using a prime number of slots in the armature, or in any other convenient way.

Dated this 14th day of November, 1918.

ABEL & IMRAY,
Agents for the Applicants.

COMPLETE SPECIFICATION.

Improvements in Armature Windings of Electric Alternating Current Machines.

We, The British Lighting and Ignition Company Limited, and Ernest Owen Turner, Electrical Engineer, both of 204, Tottenham Court Road, London, W.1, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to the arrangements of the slots carrying the armature conductors of single or polyphase alternating current machines of the type in which the armature rotates past a number of poles of alternate polarity provided in the stationary field magnets, or in which the field poles revolve past the stationary armature windings.

In such machines it is customary to provide several slots per pole for every phase in the winding, in order to dispose the winding to the best advantage around the periphery of the armature and to obtain a wave shape approximating closely to a sine curve. Where the poles are few in number and the pole pitch is large this is very easily arranged, but difficulties arise where it is required for any reason to provide a large number of poles, as in very slow running alternators and motors, or in machines to generate at high frequency, or to run on circuits of high frequency. If only a single slot is provided the wave shape becomes badly distorted from the ideal sine form and if the number is increased the slots must be so narrow that a large proportion of the slot volume is required for insulating lining, and the space factor is so greatly reduced that it is impossible to employ a conductor of sufficient cross section to obtain the desired output.

These drawbacks are obviated according to the invention in which, preferably, only a single slot is provided per pole per phase but the pole pitch in the armature differs slightly from that of the field magnets, as previously proposed in connection with multipolar continuous current machines, with the result that the electromotive force induced in any conductor is out of phase by a constant small amount with that induced in the next consecutive and similarly disposed conductor of the same phase winding. By similarly disposed conductors are to be understood conductors conveying currents in the same direction in space, for example, conductors opposite field poles of the same sign. The effective electromotive force at any instant is consequently the vector resultant of the separate electromotive forces induced in all the conductors which are arranged in series and the wave shape may be arranged to approximate closely to a true sine form, since it is obvious that the conditions determining the wave form are the same as if all the conductors in a given series were symmetrically distributed over the space of a single pole pitch.

The winding may be considered as consisting of groups of conductors in series.

For the sake of simplicity, the following description refers to a single phase winding, but, of course, with the usual modifications it may equally well be applied to two-phase or other polyphase windings.

If the armature is provided with one slot per pole and the direction of the current in the conductors in any slot is opposite to that of the conductors in adjacent slots, the maximum allowable space occupied by each group would be such that the relative angular displacement between the electromotive forces induced in the conductors of the first and last slots of the group is 180 electrical degrees. If this were exceeded the vector resultant of the electromotive force would be reduced. It may be arranged, that the conductors in the first slot of the next group carry current in the same direction as the conductors in the last slot of the first group, or one or more slots can be left blank.

It is the usual practice to limit the winding to a half or two thirds of the pole pitch, since the small increase in the electromotive force obtained by windings distributed over the whole pole pitch does not compensate for the increased resistance, reactance and cost. Similarly, in the arrangement according to the invention it may usually be convenient to reduce the number of wound slots and leave a certain number unwound.

The groups are, preferably, connected in series, but they may be connected according to the requirements of the design in parallel, or series-parallel. The total number of the slots, or the number of the wound slots, may be different in the various groups.

The best wave shape and one free from ripples is obtained when there is a small phase displacement between each succeeding group of windings. This may be effected, for example, by the use of a prime number of slots in the armature.

The invention is applicable to either single or polyphase windings.

In the accompanying drawings, which represent diagrammatically examples of windings according to the invention, Fig. 1 represents a winding in which there is one blank slot between each group. In Fig. 2, three blank slots are shown between successive groups.

In Fig. 1 the slots are numbered 1—10 and the positions of the north and south poles of the magnets are denoted by the symbols ⊙ and X. It is assumed that 8 magnet poles subtend approximately the same angle at the periphery as 9 slots. There would, consequently, be a phase difference of approximately 180 electrical degrees between the electromotive forces induced by the magnet poles in the conductors contained in the first and ninth armature slots and for this reason the ninth slot is left blank.

Two conductors per pole are shown in the example, but the number would be varied according to the requirements of the design.

The connections of the ends of the coils may be varied in any manner which provides for the proper direction of the current under each pole.

The arrangement shown in Fig. 2 is similar to that of Fig. 1 except that there are six wound slots and three blank slots in each group.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A single or polyphase electric alternating current machine in which the pole pitch in the armature differs slightly from that of the field magnets and the electromotive force induced in any conductor differs in phase by a constant small amount from that induced in the next consecutive and similarly disposed conductor of the same phase winding, substantially as described.

2. An electric alternating current machine according to Claim 1, in which the conductors in adjacent slots of the same phase winding are arranged in series in groups in which the relative angular displacement between the electromotive forces induced in the conductors of the first and last slots of any group does not exceed 180 electrical degrees.

3. An electric alternating current machine according to Claim 2, in which one or more slots in each group of slots are left blank.

Dated this 14th day of May, 1919.

ABEL & IMRAY,
30, Southampton Buildings, London, W.C. 2,
Agents for the Applicants.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1919.

PATENT SPECIFICATION

Application Date: Sept. 22, 1919. No. 23,314 / 19.

165,862

Complete Accepted: July 11, 1921.

COMPLETE SPECIFICATION.

Improvements in or relating to Ignition Systems for Internal Combustion Engines.

We, THE BRITISH LIGHTING AND IGNITION COMPANY, LIMITED, of B.L.I.C. Works, Cheston Road, Aston, Birmingham, in the County of Warwick, and ERNEST OWEN TURNER, of 35, Mayfield Road, Moseley, Birmingham, in the County of Warwick, Chief Electrical Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to ignition systems for internal combustion engines and more particularly to such systems comprising an induction coil, and a circuit breaker, the direction of current through the circuit breaker being reversed for the purpose of preventing or minimising unequal wear of the contact points of the circuit breaker, this reversal being controlled by a hand operated or power driven switch.

According to one feature of this invention an ignition system comprises a single battery, an induction coil, a circuit breaker for opening the primary circuit thereof which circuit is normally closed, and a hand operated controlling switch having two "on" positions and connections such that the direction of the current through the circuit breaker is reversed as the switch is moved from one "on" position to the other.

According to another feature of the invention in an ignition system comprising an induction coil and a circuit breaker for the primary winding thereof, there is employed a power driven switch or commutator having a single pair of brushes for continuously reversing the direction of the current through the circuit breaker.

[Price 1/-]

In order that the invention may be clearly understood and readily carried into effect, the same will now be more fully described with reference to the accompanying drawings, in which:—

Figure 1 is a circuit diagram illustrating one of the methods according to this invention of preventing wear of the contact points of the circuit breaker,

Figure 2 is a similar circuit diagram illustrating another method of preventing such wear,

Figure 3 is a side elevation partly in section of a dynamo and ignition set showing the arrangement of the circuit breaker and distributor, and

Figure 4 is an end elevation of the same.

Referring to Figure 1, the ignition system comprises an induction coil C, a circuit breaker or interruptor I connected in series with the primary winding of the coil C and a distributor D connected to sparking plugs P. A battery B is shown for supplying the current, but in addition a dynamo may of course be provided.

For controlling the supply of current to the primary winding of the coil C and reversing the direction of the current a switch S is provided. This switch is only shown diagrammatically in the drawings. It comprises two switch arms S_1 and S_2 to which connection is made by straps S_3 and S_4. The arms S_1 and S_2 are rotated by a single handle and always in the same direction, for example clockwise. The switch operates as follows:— With the switch arms in the position shown the circuit of the primary winding is open. If the switch arms are rotated through 90 degrees so that the arm S_1 comes into contact with switch contact

S_5 and the arm S_1 into contact with switch contact S_6, a circuit is completed from earth, battery B, resistance R hereinafter more fully referred to, strap S_3, switch arm S_1, contact S_5 through the primary winding of the coil C, contact breaker I, contact S_6, switch arm S_2, to earth. If the switch arms are rotated through a further 90 degrees the circuit of the primary winding of the coil C is again broken. On rotating the switch arms through a further 90 degrees the circuit through the primary winding is again closed but the current through the winding is reversed in direction the circuit being from earth, battery B, resistance R, strap S_3, switch arm S_1, contact S_7, contact breaker I, primary winding of coil C, contact S_8, switch arms S_2, strap S_4 to earth. By rotating the switch arms through a further 90 degrees the primary circuit is again opened. It will therefore be seen that each time the primary circuit is closed by the switch S the current flows across the contact breaker points in a direction opposite to that in which it previously flowed thereby tending to prevent the unequal wear of the contacts.

The resistance R has a high positive temperature coefficient and acts as the "ballast resistance" hereinbefore referred to, to prevent the current in the primary circuit rising to too great a value when the engine is running slowly or should the engine be stopped by any other means than by switching off the current.

With the arrangement shown in Figure 1 it is possible that the circuit may be closed through the contact breaker with the current in one direction for a longer time than with the current in the opposite direction, thus causing unequal wear of the contacts. The circuit arrangement shown in Figure 2 is not open to this objection. In Figure 2 there is shown an induction coil C, a contact breaker I, distributor D and sparking plugs P. Current is supplied from a battery B through a reversing switch or commutator E driven by the engine. The primary winding of the coil C has one terminal connected, preferably through a ballast resistance R having a high positive temperature co-efficient and a cut-off switch G, to the middle point of the battery B and the other terminal to the contact breaker I. The switch E comprises a switch arm E_1 which makes contact with contact segments E_2, E_3 and E_4. With the switch arms E_1 in the position shown in full lines current flows over a circuit from the positive terminal of the battery, contact segment E_2, switch arm E_1, contact segment E_4, interrupter I, primary winding of the coil C, switch G, resistance R, back to the right-hand section of the battery. When the switch arm E_1 is in the position shown in dotted lines, the current flows through the primary winding in the opposite direction, the circuit being from the positive terminal at the middle of the battery, through resistance R, cut off switch G, primary winding of the induction coil C, contact breaker I, contact segment E_4, switch arm E_1, contact segment E_3 to the negative terminal of the battery. The direction of current through both the induction coil and contact breaker is with the arrangement shown reversed at each successive interruption. The peripheral length of the segments of the switch E is so arranged that current is always broken at the contact breaker. The resistance R acts as a ballast resistance in the same way as resistance R shown in Figure 1.

As an alternative arrangement, instead of the primary winding of the coil C being connected to the middle point of the battery, it may be connected to the middle point of the ballast resistance and the latter connected across the whole battery. If this arrangement is adopted it is desirable that both sections of the ballast resistance should be made considerably greater than the resistance of the primary winding of the coil, so that only a small portion of the working current in the coil is shunted in turn by either resistance.

The arrangement shown is for igniting in a four cylinder engine but by suitably modifying the number of distributor points, *etc.*, the same principle may be employed for igniting with any number of cylinders.

The switch or commutator E, the cam for operating the contact breaker and the high tension distributor are all preferably mounted with a common axis, the high and low tension brushes and the cam being mounted on a common spindle so that they are rotated together.

The contact breaker I and distributor D and the reversing switch or commutator E if a power driven switch is employed are preferably made an integral part of the lighting dynamo instead of being in the form of separate units. Such an arrangement is shown in Figures 3 and 4. The distributor and contact breaker and also the reversing switch if a power driven switch is employed a mounted in a casing F attached to one of the end brackets of the dynamo D^1. The distributor and contact breaker are driven by skew or other suitable type of gearing H from the dynamo shaft D^2, the distributor and contact breaker brushes being mounted on a vertical shaft H^1. The induction coil C may be mounted on the top of the dynamo or in any other suitable position, for example, it may be mounted co-axially with the vertical spindle H^1 or on the back of the dashboard if the ignition set is used on a motor car. By combining the distributor and contact breaker in one structure with the dynamo as described the advantage is obtained that there is only a single unit to mount on the engine frame instead of two or more units.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. An ignition system comprising a single battery, an induction coil, a circuit breaker for opening the primary circuit thereof which circuit is normally closed, and a hand operated controlling switch having two "on" positions and connections such that the direction of the current through the circuit breaker is reversed as the switch is moved from one "on" position to the other, for the purpose described.

2. In an ignition system comprising an induction coil and a circuit breaker for the primary winding thereof, the employment of a power driven switch or commutator having a single pair of brushes for continuously reversing the direction of the current through the circuit breaker, for the purpose described.

3. In an ignition system comprising an induction coil and a circuit breaker for the primary winding thereof, the employment of a power driven switch or commutator which supplies current continuously reversed in direction alternately from two sections of a battery.

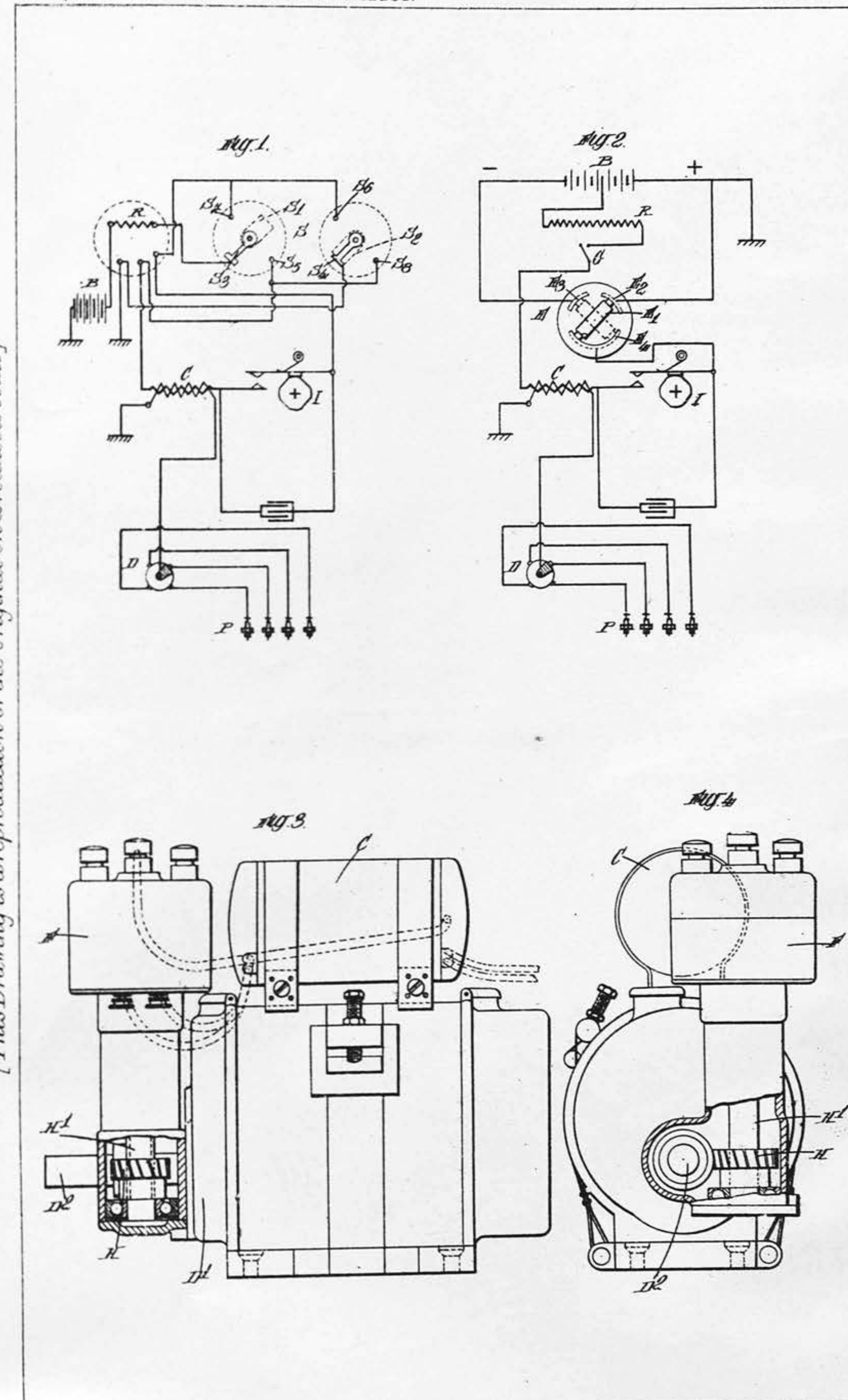
4. An ignition system arranged and operating substantially as described with reference to the accompanying drawings.

Dated this 22nd day of September, 1919.

HASELTINE, LAKE & Co.,
28, Southampton Buildings, London, England, and
55, Liberty Street, New York City, U.S.A.,
Agents for the Applicants.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1921.

[This Drawing is a reproduction of the Original on a reduced scale]



Malby & Sons, Photo-Litho

PATENT SPECIFICATION

Application Date: Apr. 6, 1920. No. 9680 / 20.

165,945

Complete Accepted: July 6, 1921.

COMPLETE SPECIFICATION.

Improvements in or relating to Dynamo Electric Systems for use on Automobiles.

We, THE BRITISH LIGHTING AND IGNITION COMPANY, LIMITED, a British company, of B.L.I.C. Works, Cheston Road, Aston, Birmingham, and ERNEST OWEN TURNER, of 35, Mayfield Road, Moseley, Birmingham, Chief Electrical Engineer, a subject of the King of Great Britain, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to dynamo electric systems for use on automobiles that is to say electric equipments comprising a dynamo and a battery which is charged thereby.

The present invention relates to the kind of dynamo electric system comprising a dynamo and a battery and in which the charging of the battery is controlled by a manually controlled switch in the circuit of the field winding of the dynamo.

According to this invention in a dynamo electric system of the kind referred to means are provided whereby the dynamo is caused to give a maximum output on the closing of one or more switches controlling a lamp or lamps or other power consuming device, these means being constituted by arranging that the operation of the last mentioned switch or switches causes the operation of the switch in the circuit of the field winding.

In order that the invention may be clearly understood and readily carried into effect the same will now be more fully described with reference to the accompanying drawing which is a circuit diagram showing one form of the switching system according to this invention.

The dynamo illustrated is of the three brush type. The main brushes B_1, B_2 of the armature A are connected to the battery B and lamps L and M or the like through a reverse-current and no voltage switch C or any suitable type. The two lamps L may be for example the head lamps on a motor car and the three lamps M the side and tail lamps. A shunt field winding F_1 is connected to the brushes B_1 and B_2 the connection to the brush B_1 however being through a resistance R the object of which is hereinafter referred to. A second field winding F_2 is connected, through the resistance R, to the brush B_1, and directly to the brush B_3. Switches S and S_2 are provided either of which when closed short circuits the resistance R thereby connecting the windings F_1 and F_2 directly to the brush B_1. With increase of current delivered by the dynamo the voltage across the winding F_2 is diminished whereby the resultant voltage induced in the main circuit is maintained substantially constant within fairly wide ranges of speed. To provide, however, for very wide variations of speed the winding F_1 is provided the influence of this winding on the voltage being small at the speed at which the dynamo voltage just balances the battery voltage. The effect of the winding F_1 is to compensate for the reduction of current in the mains due to the winding F_2 with the result that the variation of current in the mains with speed may be controlled to almost any desired extent.

The switches S and S_2 form the charging switches for the system.

[*Price* 1/-]

The resistances R, hereinbefore referred to, is employed so that when the charging switches S and S_2 are open the charging rate is reduced to a value below the maximum but not to zero. Such an arrangement may be employed particularly when an electric starter forms part of the equipment or when the current is continually required as, for example when the automobile is provided solely with battery ignition.

The switch S_1 hereinbefore referred to is mechanically connected to the switch S_2 so that the closing of the circuit of the lamps M also causes the closing of the switch S_2 to short circuit the resistance R and thereby cause the battery to be charged at the full rate. When the switch S is closed and switches S_1, S_2 and S_3 are open the dynamo charges at its full rate, this corresponding to normal running during the day time with the battery partially discharged. As soon as the battery is fully charged switch S can be opened whereby the resistance R is introduced into the circuit of the field windings F_1 and F_2 and the charging rate is immediately reduced. If while switch S is open the lamps M are switched on by closing the switches S_1 and S_2 the resistance R is once more short circuited and the charging rate is increased to its full value thus compensating for the increased output demanded. With this arrangement it is immaterial whether the charging switch is on when the lights are required as the act of switching on the lights re-establishes the full charging current independently of whether the charging switch S has been operated or not.

Instead of connecting the resistance R and switch S in the circuit of both field windings F_1 and F_2, they may be connected in the circuit of one winding F_2 only. Alternatively, the resistance may be dispensed with, and the switch connected in the circuit of the one winding F_2, the other winding F_1 remaining permanently connected across the armature terminals.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. In a dynamo electric system of the kind referred to, the provision of means whereby the dynamo is caused to give a maximum output on the closing of one or more switches controlling a lamp or other power consuming device, the said means being constituted by arranging that the operation of the said switch or switches causes the operation of the switch in the circuit of the field winding.

2. In a dynamo electric system comprising a dynamo and a battery and in which the charging of the battery is controlled by a manually controlled switch in the circuit of the field winding of the dynamo, the provision of a resistance in the circuit of the dynamo field winding, short-circuited when the charging switch is closed, but included in the circuit when the charging switch is open, the closing of one or more switches controlling a lamp or other power consuming device serving to re-establish the short-circuit of said resistance for the purpose described.

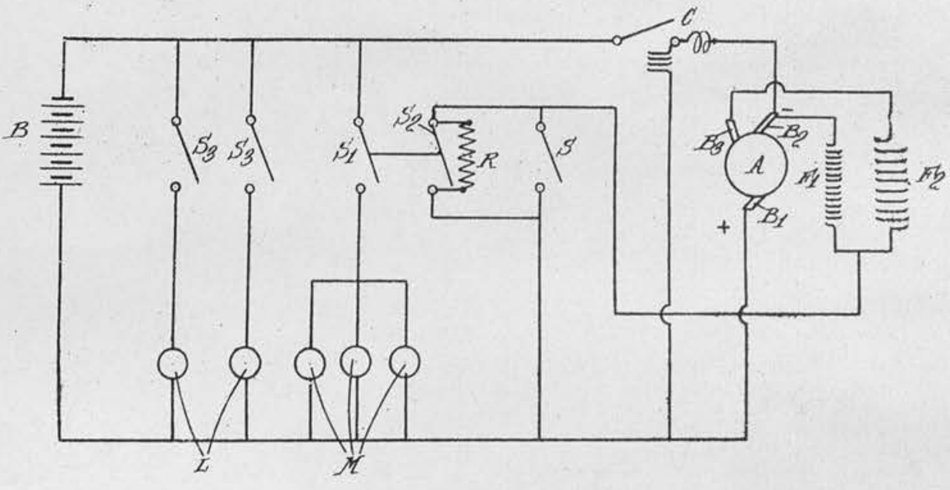
3. A dynamo electric system arranged and operating substantially as described with reference to the accompanying drawings.

Dated this 6th day of April, 1920.

HASELTINE, LAKE & Co.,
28, Southampton Buildings, London, England, and
55, Liberty Street, New York City, U.S.A.,
Agents for the Applicants.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1921.

[This Drawing is a reproduction of the Original on a reduced scale]



CASE A.

COPY.

FINAL SPECIFICATION,

of

Messrs. THE BRITISH LIGHTING AND IGNITION COMPANY LIMITED, and Mr. ERNEST OWEN TURNER'S Invention,

for

"Improvements in or relating to ignition magnetos for internal combustion engines."

No. 14777. Dated 27th May, 1921.

This invention relates to ignition magnetos for internal combustion engines said magnetos being of the type in which a rotary magnet or inductor is employed in conjunction with a fixed armature.

According to the present invention the rotary magnet of an ignition magneto of the kind referred to is constructed in such manner that the mean length of the flux path through it is appreciably greater than the mean distance between the opposite pole shoe faces of the fixed armature, the dimensions of the said magnet being such that the cylindrical volume it occupies when revolving is substantially the same as that of a cylinder the diameter and length of which are equal respectively to the diameter and axial length of the stationary armature pole shoes.

In order that the invention may be clearly understood and readily carried into effect the same will now be described more fully with reference to the accompanying drawings in which :-

Figures 1, 2, 3, 4 and 5 illustrate respectively various cross-sectional shapes for the rotary magnet in accordance with the present invention,

Figure 6 is a sectional and elevation and figure 7 a sectional side elevation of a magneto in which the rotary magnet has a cross-sectional shape as shown in Figure 1,

Figure 8 is a side elevation of a further modified construction of rotary magnet, and Figure 9 is a section through the line A.A on Figure 8.

Referring to Figures 1, 6 and 7, the magnet consists of a cylinder bored centrally, the cross-section of which is a circle, but whereof the portions a, a', between the two polar arcs b, b' are reduced in diameter. The bore of the cylinder c is made comparatively large so that the mean path of the flux passing through the curved path provided between the pole faces b and b' around the central bore c is appreciably longer than the mean distance B - B between the two pole faces. The cylinder may be either solid or built up of a number of laminated sections d as shown in Figure 7. In the latter case the laminated sections or discs may be assembled on a central spindle e (Figures 6 and 7) and held together by end plates or clamps. Alternatively while still retaining the central bore c so as to increase the flux path, holes may be punched (as shown in dotted lines at f, f in Figure 1), preferably midway between the tips of each of the pole faces b and b', and the laminated sections or discs may be rivetted together to end flanges carrying spindle extensions to form bearings and provide a drive. If thin steel laminations are employed in building up the magnet it may sometimes happen that in hardening they become slightly distorted and do not lie quite flat; this difficulty may be overcome by inserting between each pair of laminations a thin layer of material such as leatheroid or presspahn into which the steel laminations may bed slightly. This arrangement presents the further advantages that eddy currents in the pole faces are reduced by insulating each lamination from its neighbours.

In other forms of construction of the rotary magnet a long flux path may be obtained by the employment of a solid or laminated magnet of V shape (not illustrated), of "S" shape, as shown in Figures 2 and 3, or "U" shape cross-section, as shown in Figure 4.

The magnet shown in Figure 5 has a gross cross-section nearly equal to that of the complete circle in which it revolves, the flux path being lengthened to the required degree by the slots g, which divert the flux from the straight line path between the poles b, b' into a longer curved path.

As shown in Figures 3 and 4 there may be advantageously employed in conjunction with the various forms of the improved rotary magnet separate pole shoes h of soft magnetic material and preferably laminated. In the normal operation of a magneto there is considerable cyclic change of direction of flux in the pole face, which renders this portion of the rotor, if made of permanent magnet steel of much less value than these portions further removed from the pole face which are not so affected, and consequently pole shoes of softer and much cheaper material may as aforesaid with advantage be substituted, in particular since much thinner laminations may be employed than are convenient in the case of permanent magnet steel. The soft iron pole shoes may be rivetted welded or otherwise secured in place.

In the form of construction of the magnet illustrated in Figures 8 and 9 the rotary magnet comprises a body portion in the form of a rod or bar k of rectangular cross-section, though the said bar k may have any other convenient cross-sectional shape such as circular. The bar k is provided with pole shoes l attached to it at opposite ends respectively so that for the greater part of their length they are separated from the body portion of the magnet by an air space m. The outer surfaces of the pole shoes l are formed as usual so as to be concentric with the curved pole faces of the stationary armature, the pole shoes themselves being mounted so that the axis o-o of the body portion is the same as that of the armature pole faces (or the axis of revolution p-p Figure 7) as would be the case with the constructions shown in Figures 8 and 9. If desired however the pole shoes l may be mounted so that the axis of the body portion is inclined at an angle, less than ninety degrees, to the axis of revolution. The pole shoes l convey the flux from the magnet to the cylindrical faces of the opposing pole shoes r (Figure 6) of the stationary armature. The said pole shoes l may be formed as continuous extensions of the magnet, or they may be made separately therefrom and attached thereto by welding or in any other suitable manner.

Inall of the constructions of magnet above described it will be seen that the total length of the magnet along its axis of revolution is substantially the same as the length (measured in the same direction) of the armature pole shoe faces.

HAVING NOW particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:-

1. An ignition magneto of the kind referred to, in which the rotary magnet is constructed in such manner that the mean length of the flux path though it is appreciably greater than the mean distance between the opposite pole shoe faces of the fixed armature, the dimensions of the said magnet being such that the cylindrical volume it occupies when revolving is substantially the same as that of a cylinder the diameter and length of which are equal respectively to the diameter and axial length of the stationary armature pole shoes

2. An ignition magneto of the kind referred to, in which the rotary magnet has a cross-section of S, V or U form, and the length of which magnet measured in the direction of its axis is approximately the same as that of the stationary armature pole shoes measured in the same direction.

3. An ignition magneto as in claim 1, in which the rotary magnet consists of a centrally-bored cylinder having the portions comprised between the two polar surfaces of smaller diameter than the diameter of the polar surfaces.

4. An ignition magneto as in claim 1, in which the rotary magnet comprises a body portion in the form of a rod or bar having at its opposite sides pole shoes separated for the

reater part of their length from the said body portion, the xis of said body portion coinciding with or being inclined t an angle of less than ninety degrees to the axis of re-olution of the magnet.

5. An ignition magneto according to any of the preced-ng claims, in which the magnet is built up of laminated sec-ions, with or without a thin layer of insulating material etween adjacent sections.

6. An ignition magneto according to any of the preced-ng claims, in which the rotary magnet is provided with aminated pole shoes of soft magnetic material.

7. An ignition magneto constructed substantially as escribed with reference to any of the examples illustrated n the accompanying drawings for the purpose specified.

Dated this 11th day of February, 1922.

(Signed) Haseltine, Lake & Co.,

28, Southampton Buildings, London,
England,
and
Park Row Building, 15, Park Row,
New York, N.Y. U.S.A.
Agents for the Applicants.

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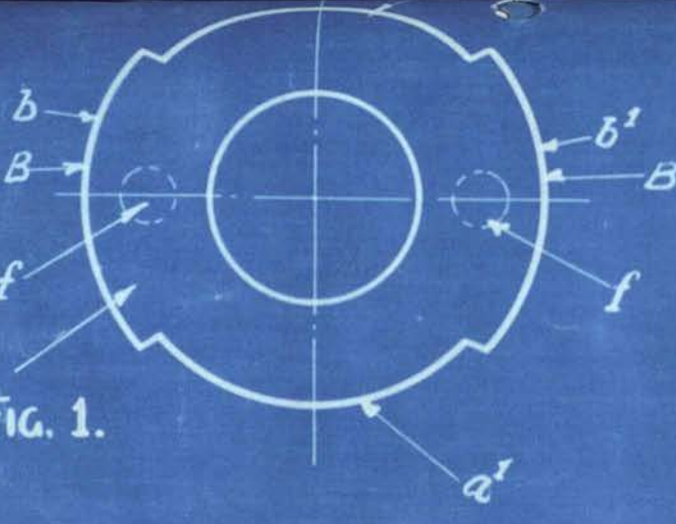

FIG. 1.

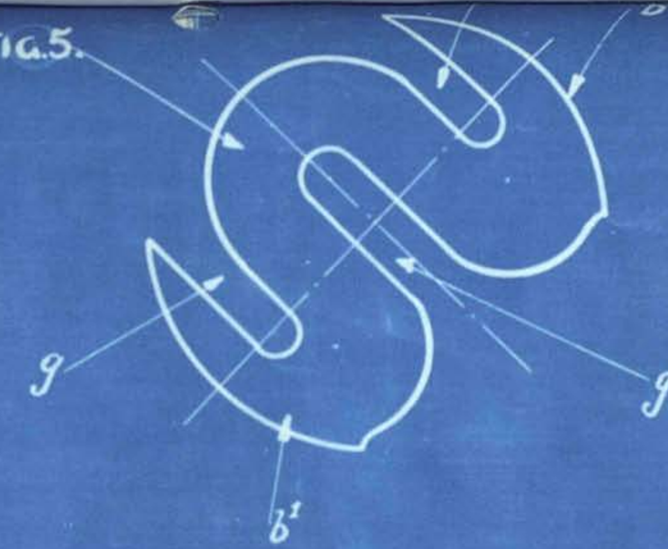

FIG. 5.

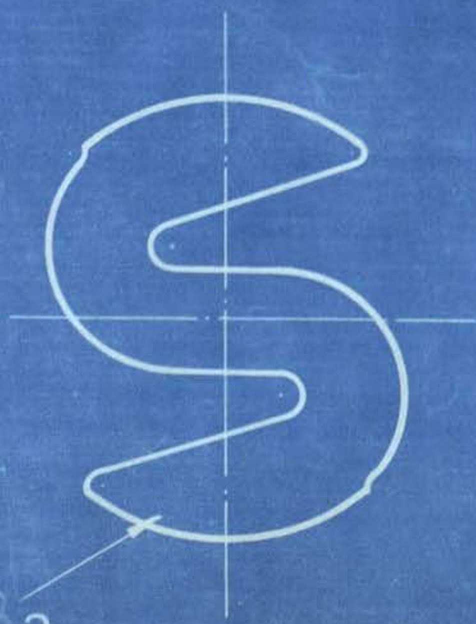

FIG. 2.

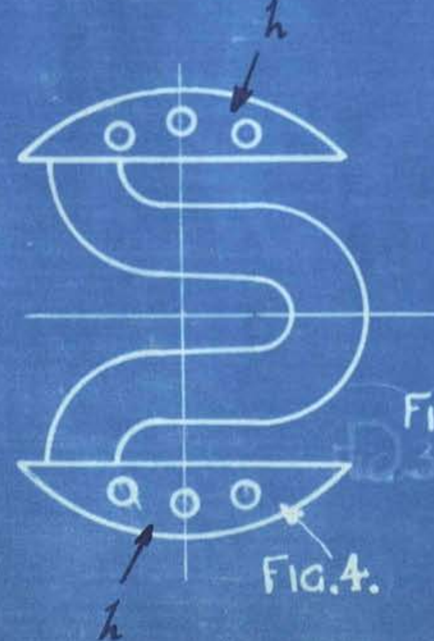

FIG. 4.

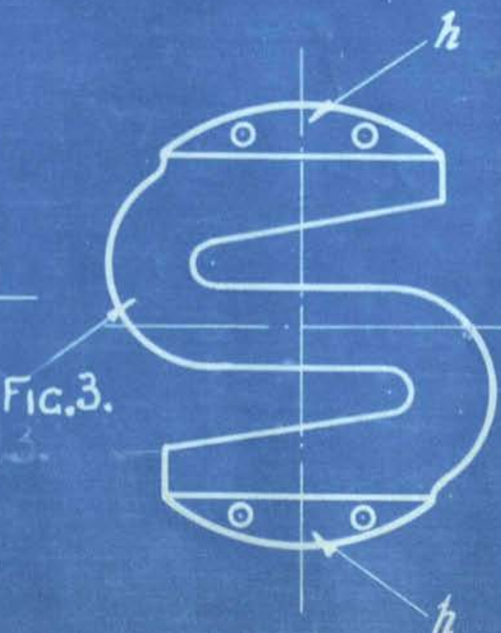

FIG. 3.

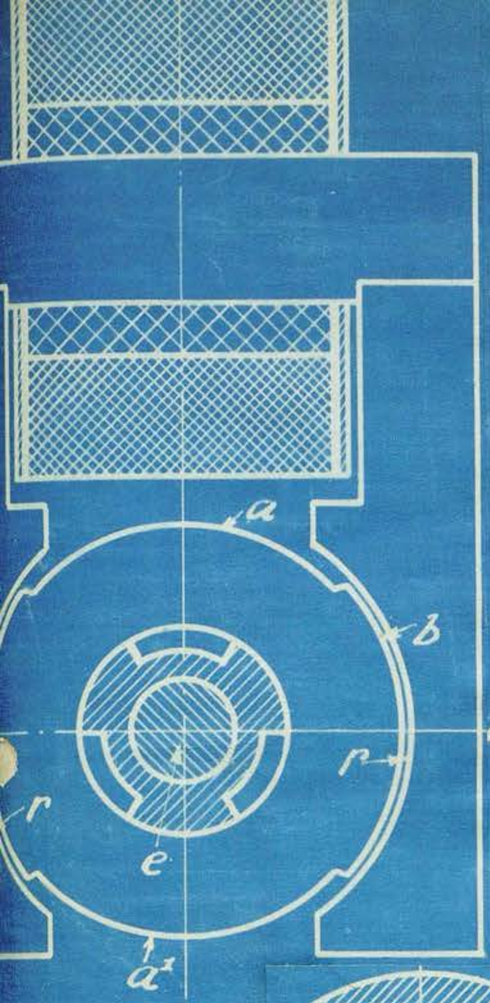

FIG. 6.

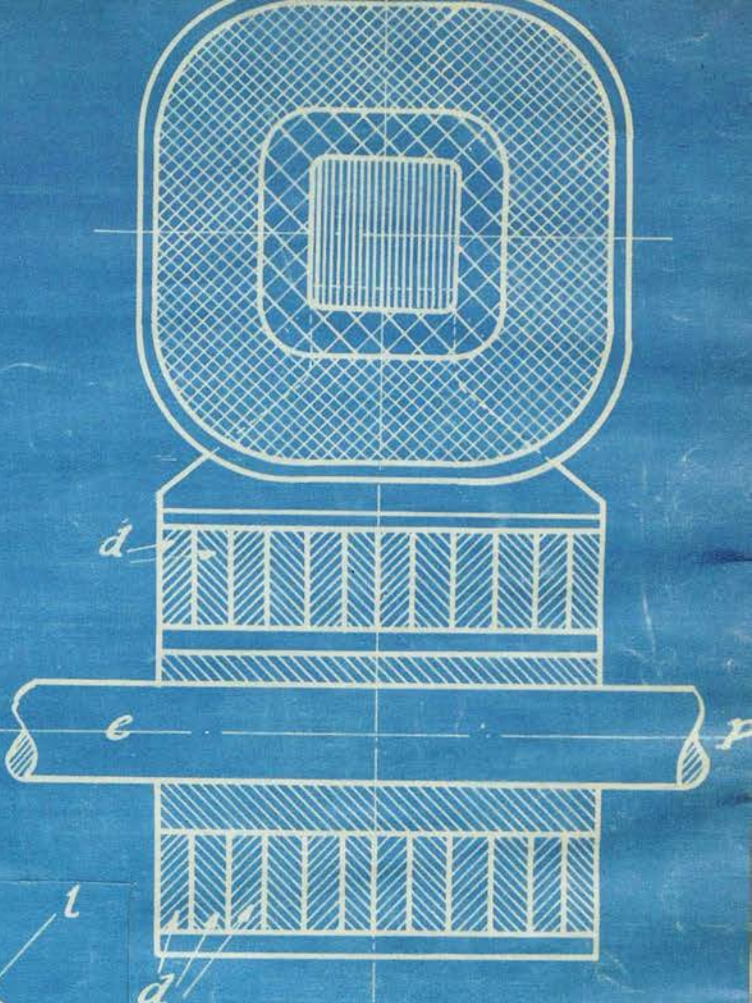

FIG. 7.

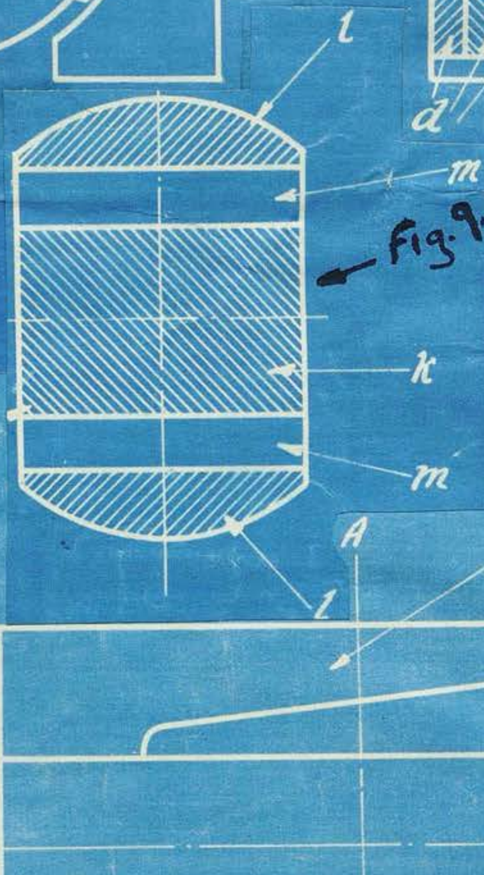

Fig. 9.

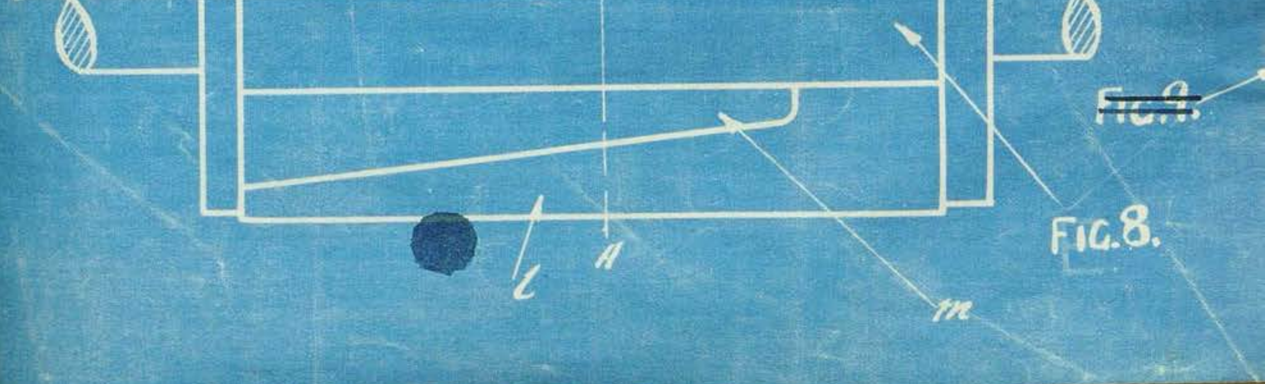

FIG. 8.

CASE B.

COPY.

FINAL SPECIFICATION,

of

Messrs. THE BRITISH LIGHTING AND IGNITION COMPANY LIMITED and Mr. ERNEST OWEN TURNER'S Invention,

for

"Improvements in or relating to ignition magnetos for internal combustion engines".

No. 14778. Dated 27th May, 1921

This invention relates to ignition magnetos for internal combustion engines of the type in which rotary magnets or inductors are employed in conjunction with stationary armatures, and has for its object to transmit with a minimum of magnetic reluctance and in a convenient manner the magnetic flux collected by the armature pole shoes faces at a low density from the rotary magnet or inductor poles, and to convey it at a higher density to the stationary yoke piece or core around which the low and high tension coils of the armature are wound.

The flux density at which the flux is most conveniently transmitted across the air gap from the rotary magnet or inductor pole shoes to the opposing armature pole shoes of the magneto is, for various reasons, comparatively low. The remanence of a permanent magnet is in the neighbourhood of 10,000 lines per square centimetre or less, and this value is considerably reduced by the conditions which obtain in the magneto; thus on account of the reluctance of the air gap and other parts of the circuit and also owing to the reaction of the armature, the actual working flux density in the magnet may be not more than 5,000 to 7,000 lines per square centimetre. In many cases it may prove convenient to maintain approximately the same flux density in the air gap and consequently in the armature pole shoe faces. The flux density in the stationary armature core or yoke pieces however, is best maintained at a much higher value say 14,000 to

18,000 lines per square centimetre, partly because high permeability steel is generally employed for this part of the circuit, and partly in order to reduce as much as possible the length of mean turns of the primary and secondary windings. Further, in order to keep the length of mean turns of the coil winding as low as possible, it is desirable that the cross section of the armature core should be either a circle or, if as is more usually the case, it has the form of a rectangle, it should be square or nearly so; consequently it is desirable that the breadth of the armature core (measured in the same direction as the axial length of the rotor) should be much less than the length of the stationary pole shoe face, measured in the same direction.

If solid steel or iron be employed for leading the flux from the armature pole shoe faces to the armature core or yoke piece, the cross section of the pole shoes may be suitably varied, so that the flux density is higher on entering the yoke and lower at the pole faces; in order however to minimise the formation of eddy currents, it is desirable to laminate the whole of this portion of the magnetic circuit, and if laminated pole shoes were made up in the simplest form to obtain this result, that is by reducing their length (measured in the direction of the axis), as the shoe approaches the junction with the armature coil core, or alternatively by leaving the pole shoe the same width as at the pole shoe air gap face and by arranging for the armature coil core to come in contact with the shoes for only a portion of their length, the disadvantage arises, that, starting from a certain portion of the air gap face of the pole shoe, flux will have to pass transversely through a number of laminations in order to enter the armature coil core or yoke, the insulation between these laminations adding considerably to the total reluctance of the circuit, which is undesirable.

According to the present invention an ignition magneto having a rotary magnet or inductor and stationary armature pole shoes, the length of which at the cylindrical face of the shoe opposite to the rotot poles is greater than the length of the shoe at its junction with the armature coil core, both lengths being measured in the direction of the axis of the rotor, is characterised by the said stationary armature pole shoes being formed of laminated sections constructed and arranged in such manner that only a very short length of the flux path is in a direction transverse to the direction of the laminations. The cross section of the core may be formed as a square or with sides as nearly equal as may be desired. By this method of construction the flux collected from the magnet or inductor pole-shoe faces is transmitted with a minimum of reluctance to the armature yoke or core. For this purpose the stationary armature pole shoes are built up from laminated sections which are not all of the same length, as hereinafter described, the longer sections serving to lead the flux to the armature core, the shorter sections terminating with the pole shoes proper.

In order that the invention may be clearly understood and readily carried into effect the same will now be described more fully with reference to the accompanying drawings in which:

Figure 1 is a sectional and elevation and Figure 2 a side elevation of a magneto constructed in accordance with the present invention.

As will be seen from Figure 2 the armature pole shoes a are formed of laminated sections comprising the longer strips b between which are positioned one, two or three shorter strips c, the shorter strips being equal to the height of the pole shoe proper and the longer strips being of a length sufficient to lead the flux from the pole shoes to the armature core d. The strips b and c are first rivetted at the top and bottom of the pole shoes, and the free ends of the longer strips b are then pressed together so as to assume the form shown in Figure 2 and rivetted at their upper ends. With this construction the total reluctance between the armature pole faces and the armature core will be low; in the case when the laminated sections consist of long and short strips alternating with one another, the flux collected from any part of the pole shoe faces will only have to pass transversely through one strip in order to pass from the pole face to the armature core, the same result being obtained if two short strips are interposed between consecutive long strips, while in the case of there being three adjoining short strips as shown at the left hand side of Figure 2, the flux from the two outer short strips c' has again only to pass transversely through one strip, and the flux from the central short strip c'' through two strips, in order to reach the armature core.

The breadth of the pole shoe at the junction c with the armature yoke or core d (measured in the same direction as the axis of the rotor) may be made as much shorter than the full length of the pole shoe as is desired by varying the ratio to each other of the long and short strips b and c.

HAVING NOW particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:-

1. As ignition magneto having a rotary magnet or inductor and stationary armature pole shoes, the length of which at the cylindrical face of the shoe opposite to the rotor poles is greater than the length of the shoe at its junction with the armature coil core, both lengths being measured in the direction of the axis of the rotor, characterised in that the said stationary armature pole-shoes are formed of laminated sections constructed and arranged in such manner that only a very short length of the flux path is in a direction transverse to the direction of the laminations for the purpose specified.

2. An ignition magneto as in claim 1, in which the stationary armature pole shoes are formed of alternate long and short laminated sections, the short sections approximately

terminating with the pole shoe proper and the longer sections serving to transmit the flux from the pole shoes to the armature core.

3. An ignition magneto as in claim 1, in which the stationary armature pole shoes are formed of long and short laminated sections, the short sections being positioned between consecutive long sections in such number as to accord with the desired ratio between the maximum length of the pole shoe and the length of the pole shoe at the junction with the armature coil core, both being measured in the direction of the axis of the rotor, substantially as described and for the purpose specified.

4. An ignition magneto constructed substantially as described with reference to the accompanying drawings for the purpose specified.

Dated this 11th day of February, 1922.

(Signed) Haseltine, Lake & Co:

28, Southampton Buildings, London, England,
and
Park Row Building, 15, Park Row, New York, N.Y. U.S.
Agents for the Applicants.

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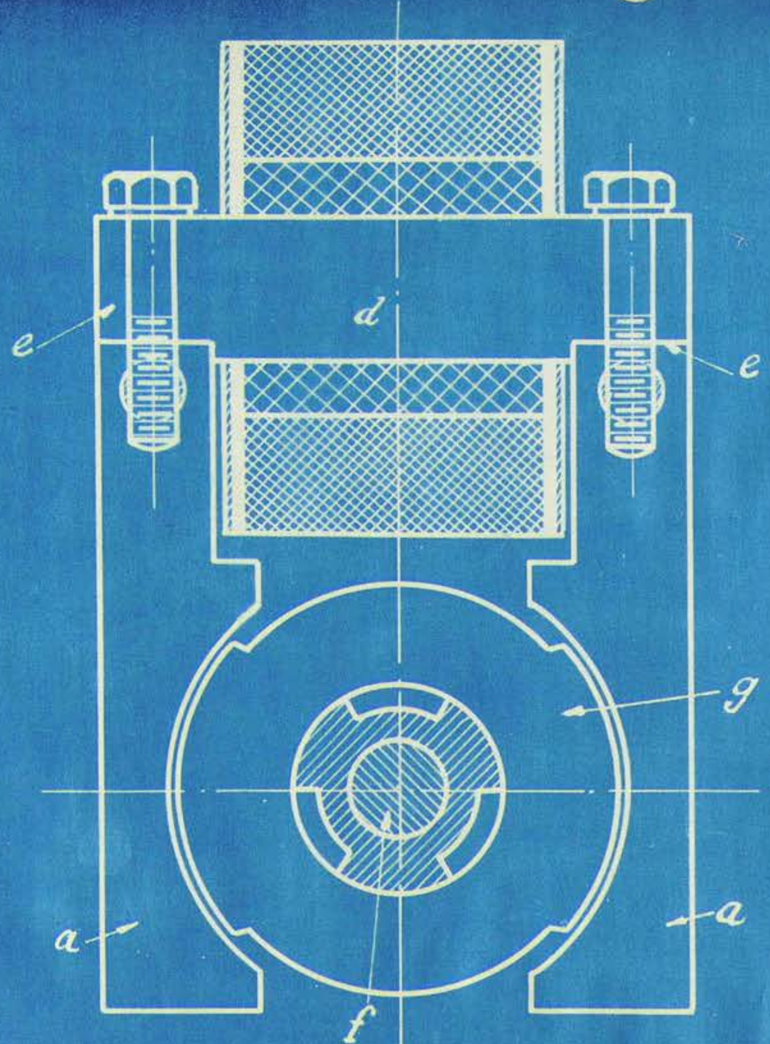


FIG. 1.

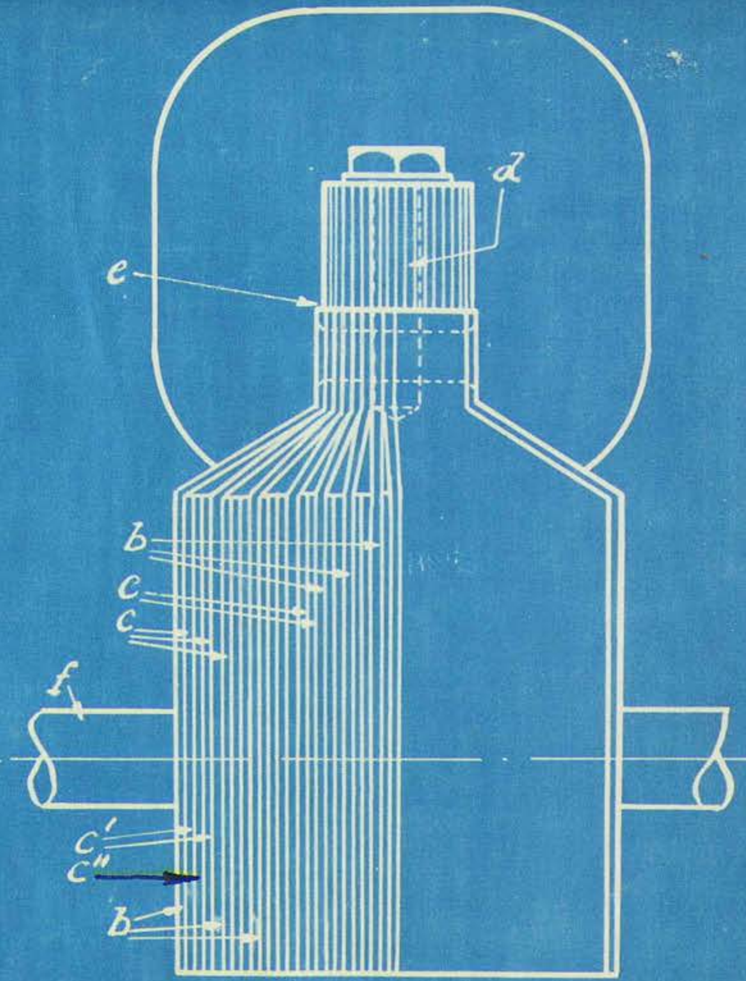


FIG. 2.

POLESHOE & YOKE CONSTRUCTION.

COPY.

PROVISIONAL PATENT SPECIFICATION.

No. 24654/1921.

PATENTS AND DESIGN ACTS, 1907 and 1919.

PATENTS FOR NO.2.

PROVISIONAL SPECIFICATION.

"Improvements in or relating to electrical contact breakers"

We, THE BRITISH LIGHTING & IGNITION COMPANY LIMITED, a British Company and EDWARD BROWNE TUPPEN, a subject of the King of Great Britain, both of Cheston Road, Aston, Birmingham, in the County of Warwick, do hereby declare the nature of this invention to be as follows:-

The present invention relates to electrical contact breakers and more especially to contact breakers for the ignition apparatus of internal combustion engines of the kind in which a rotating cam causes a pivoted breaker arm to oscillate, whereby an electrical circuit is broken intermittently.

A contact breaker arm as employed in apparatus of the kind referred to commonly comprises a thin tabular bush of metal of fibre or other material serving for the bearing of the arm upon a fixed pivot pin, this bush being forced into a metal container or fastened in some other way, and a heel constituted by a block of fibre or like material riveted to the body of the breaker arm, against which heel the cam is adapted to strike.

According to the present invention both the cam operated heel and the pivot bearing are formed in a single suitably shaped member of fibre or other suitable material.

A constructional form of contact breaker arm according to the present invention may comprise two similarly shaped plane punchings of thin steel or other metal each in the form of a strip having substantially parallel edges with an enlargement at one end at an obtuse angle to the edges. Between the two metal punchings is received by rivetting or otherwise the aforesaid member of block of fibre or other suitable material which may extend from the enlarged ends of the punchings throughout the whole or a portion of their length. The contour of the fibre or other block may correspond in the main with that of the punchings but at one part, preferably at a part relatively remote from the enlarged end and at the same side the block is formed with a projecting portion to constitute the heel. The punchings with the block between them, form the contact breaker arm, the contact being carried at any suitable part and the enlarged end being bored to form the bearing for the fixed pivot pin. The punchings may be provided each with two lugs projecting one to either side so that when the parts are assembled the corresponding lugs may be turned down at right angles to the plane of the punchings to form on one side of the arm, preferable the heel side a support for the contact (which may lie beyond the heel or between the heel and pivot) and on the other side of the arm a retaining slot for one end of a leaf spring the other end of which bears against a fixed post and the function of which is to press the arm and its contact towards the fixed contact. A strip of copper may be laid along this leaf spring and suitably secured. The block of fibre or other suitable material may be made of laminations rivetted or otherwise secured between the punchings so as to form the equivalent of a single block.

One advantage of the form of construction described is that with the employment of fibrous or other material having a definite grain it may conveniently be arranged that the direction of the grain at the bush is perpendicular to the axis of the bush and that the direction of the grain at the heel coincides with the direction of motion of the rubbing face of this cam; at both points the wear takes place among the edges and not across the edges of the laminae. These conditions ensure the best conditions for wear at these two points.

The arm may if desired be madewith a single metal flanged plate folded up to embrace the non-metal portion of the arm, or alternatively a single metal plate may be rivetted at one side of or interleaved with the non-metal part. As a further alternative the metal may be entirely dispensed with except in so far as it is required to form a suitable support for the contact.

With the present construction of arm, having the bearing of the pivot and the heel in the same unit, the usual thin walled bush is eliminated and a substantial bush provided which cannot rotate and the heel, owing to its support by a considerable body of the same material, is stronger than theusual heel, and is not liable to work loose.

Dated this 16th day of Sepetmber, 1921.

COPY.

COMPLETE PATENT SPECIFICATION.

No.27110/1921.

PATENTS AND DESIGNS ACTS, 1907 and 1919.

PATENTS FORM NO. 3.

COMPLETE SPECIFICATION.

"Improvements in or relating to electric switches".

We, THE BRITISH LIGHTING & IGNITION COMPANY, LIMITED, a British Company, of B.L.I.C. Works, Cheston Road, Aston, Birmingham, in the County of Warwick, a British Company, ERNEST OWEN TURNER, of 35, Mayfield Road, Moseley, Birmingham, in the County of Warwick, and EDWARD BROWNE TUPPEN, of 96, Court Lane, Erdington, Birmingham, in the County of Warwick, a subject of the King of Great Britain, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:-

COPY.

COMPLETE PATENT SPECIFICATION.

No. 27110/1921.

The present invention relates to electric switches of the kind having stationary insulated contacts located in a housing and adapted to be engaged by a movable contact operable by neams extending outside said housing.

The chief object of the invention is to provide a switch of this kind of simple and robust construction especially suitable for use as a foot-operated switch in connection with electric starting motors for internal combustion engines wherein large low-voltage currents are usually employed. Further objects are to provide a switch of this kind wherein the risk of a short-circuit between the fixted contacts or the bared parts of the leads attached thereto is reduced to a minimum, and which permits of ready examination of the contacts in their operative positions and of the operative movements of the switch.

According to one feature of the invention a switch of the kind referred to is provided with insulated fixed contacts consisting of plugs or blocks of conducting material the inner ends of which are adapted to be engaged by the movable contact and the outer ends of which are formed with sockets into which the ends of the conducting wires may be sweated. According to another feature a switch of the kind referred to is provided with fixed contacts consisting of plugs or blocks of conducting material which are maintained in position in surrounding insulation by tongue-and-groove, dovetails or like connections. Further features lie in the form of fixed contact, hereinafter described, and in the general construction and arrangements of parts described constituting a switch in which the several objects hereinbefore referred to are attained.

In order that the invention may more clearly be understood and readily carried into effect, it will now be more fully described with reference to the accompanying drawings which will illustrate one preferred constructional form of switch embodying the present invention. In these drawings.

Figures 1 and 2 are vertical sections taken on planes at right angles to one another, figure 3 is a sectional plan on the line a-b of figure 1, and figure 4 is a perspective view of one of the fixed contacts.

Referring now to these drawingsl,1 are the fixed contacts and 2 is the movable contact, these being located in a housing 3 which is of rectangular form open at the bottom and one side, the open side being adapted to be closed by a cover-plate 4. The upper part of the housing which may be of any suitable material such, for example, as cast aluminium, is formed as a plate 5 provided with screw holes and serves for attachment of the switch to the floor board of a motor vehicle. The plate 5 has a central aperture for the passage of the spindle 6 upon which the movable contact 2 is mounted and am upwardly projecting cylindrical housing 7 which serves to accommodate the said spindle and the spring 8 which serves normally to maintain the movable contact out of engagement with the fixed contacts.

The top of the spindle carries a cap 9 which is preferably of non-rusting metal of suitable hardness and which makes a sliding fit with the cylindrical housing 7. This cap serves for the operation of the switch by the foot and owing to its shape and the manner in which it co-operates with the housing 7 it serves also to exclude entrance of dirt or moisture and as a guiding device for the spindle 6. The lower end of the spindle is reduced in diameter and carries the movable contact 2 the latter being insulated from the former by suitable non-conducting material 10. A metal washer 11 is provided over which the end of the spindle is rivetted to hold the parts in position. As will be seen from the drawings the movable contact is mounted somewhat loosely upon the spindle so that it may adjust itself in relation to the fixed contacts when the switch is closed. The housing 3 is lined on three sides with insulation consisting of a sheet of fibre or other insulating material 12 which is held in position by rivets 13 which also hold in position as insulating block 14. The fixed contacts 1 are in the form of ralatively massive blocks or plugs preferably of copper having sockets 15 into which the bared ends of the conducting leads may be sweated.

The insulating block 14 is formed with a tongue on each side as shown in figure1. and one side of each fixed contact is formed with a corresponding groove so that on the contacts being slid into position from the side they interlock with the block 14 and are thus held in position primarily by the said block and secondarily by the rivets 13 by which the said block and the insulation 12 are fixed in the housing 3. The shape of the fixed contacts 1 will be more readily seen from the perspective view, Figure 4. The open side of the housing 3 is covered by a plate 4 which is provided on its inner side with a sheet of insulating material 15 maintained in position by rivets 17. The cover plate 4 is removable and is held in position by the screw 18 which traverses holes formed in the cover and the block 14 and screws into a threaded hole in the back of the housing. It will be noted on reference to figures 2, and 3 that a little clearance is provided between the insulation on the cover plate and the block 14, the object of this being to ensure that the contacts 1 are held firmly in position when the cover plate is applied and the screw 18 tightened up. It will also be noted that the insulation 12 and 16 and the insulating block 14 are extended downwardly to assist in preventing any accidental contact between the bared ends of the conducting leads. As will be readily understood the block 14 may be made up of several pieces of the shape shown in figure 1 punched out of sheet material and it will further be understood that the shape of the tongues on the block 14 and the grooves inthe contacts 1 may very from that shown, they may, for example, be of dovetail shape. Further, the tongues may be provided on the contacts and grooves in the block 14, or tongueand groove or like connections may be provided between the contacts 1 and the insulation 12. In the case of providing grooves in the insulation 12 it would of course be advisable to employ insulation of greater thickness than that indicated in the drawings.

HAVING NOW particularly described and ascertained the nature os our said invention and in what manner the same is to be performed, we declare that what we claim is:-

1. An electric switch of the kind referred to having insulated fixed contacts comprising plugs or blocks of conducting material the inner ends of which are adapted to be engaged by the movable contact and the outer ends of which are formed with sockets into which the ends of the conducting wires may be sweated.

2. An electric switch of the kind referred to having fixed contacts comprising pkugs or blocks of conducting material maintained in position in surroud-insulating material by tongue-and-groove, dovetail or, like connections.

3.

3. An electric contact consisting of a plug or block of conducting material having a tongue or groove on one or more of its sides substantially as and for the purpose described.

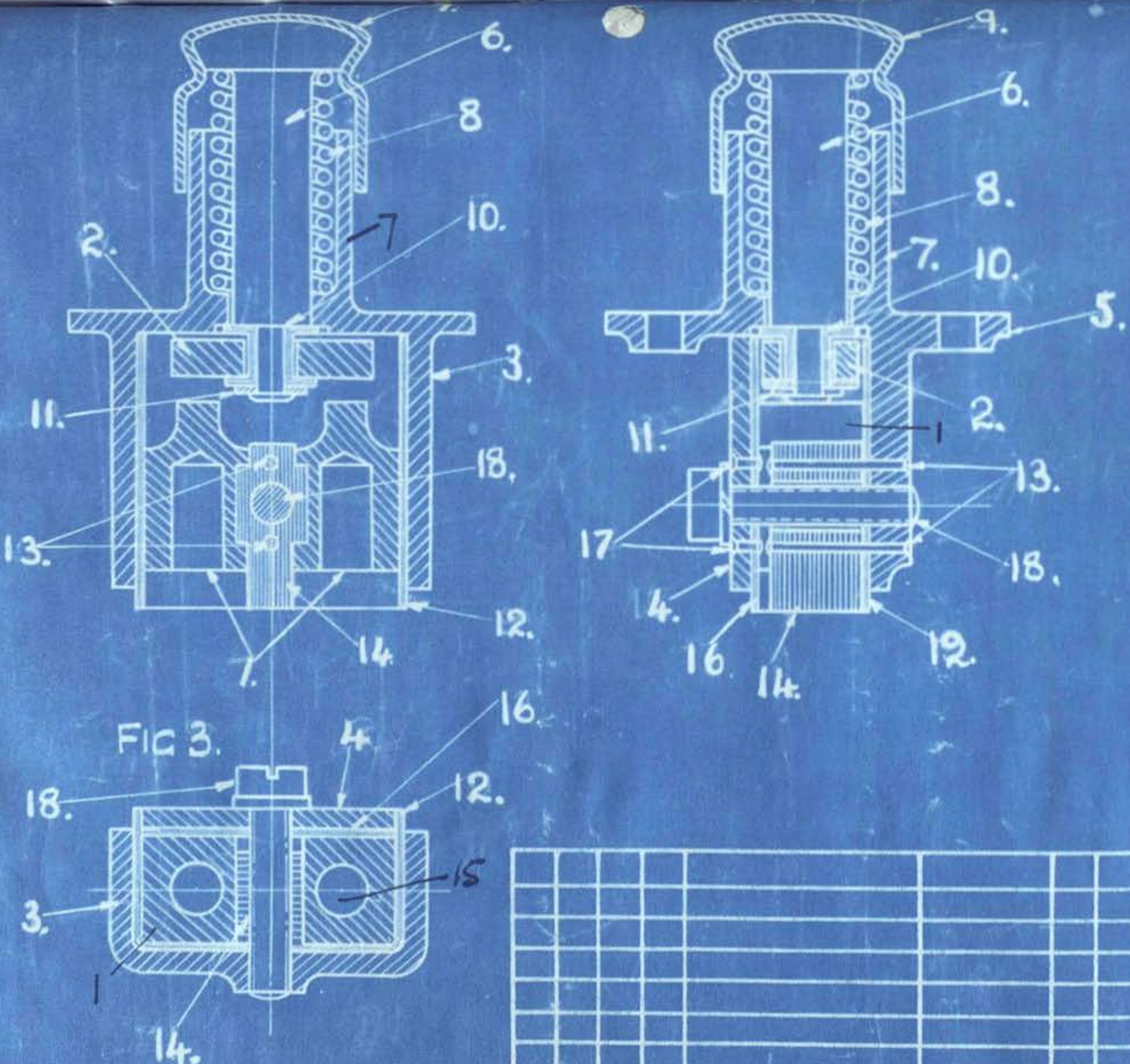
4. An electric switch having its parts constructed and arranged substantially as described with reference to the accompanying drawings.

Dated this 12th day or October, 1921.

(Signed.) Haseltine, Lake & Co.,

28, Southampton Buildings, London, England, and

Park Row Buildings, 15, Park Row, New York, N.Y., U.S.A. Agents for the Application.



G.4.
G.3.
G.2.
G.1.

REVIS

STARTING SWITCH TYPE X/C

THE

COPY

PROVISIONAL PATENT SPECIFICATION.

No. 29290/1921.

PATENTS AND DESIGNS ACTS, 1907 and 1919.

PATENTS FORM NO. 2.

PROVISIONAL SPECIFICATION.

"Improvements in or relating to the construction of gear wheels."

We, THE BRITISH LIGHTING & IGNITION COMPANY, LIMITED, a British Company, ERNEST OWEN TURNER, and EDWARD BROWNE TUPPEN, both subjects of the King of Great Britain, all of B.L.I.C. Works, Cheston Road, Aston, Birmingham, in the County of Warwick, do hereby declare the nature of this invention to be as follows:-

This invention relates to the construction of gear wheels, especially those employed in electrical ignition apparatus for use with the internal combustion engines of motor vehicles, where it is desirable to eliminate noise as far as is practicable, such vehicles as usually constructed frequently giving rise to noises due partly to the meshing of the teeth and to the ringing sound set up in the solid wheel by the impact of the teeth on one another Such wheels have frequently been made, in one piece of metal, such as steel, brass or gun metal, giving them a characteris ring when struck.

According to this invention the gear wheel (either one or both of the gear wheels in the pair employed with the ignition apparatus) is made of laminated metal sheets and between adjacent metal laminae are placed thinner laminae of sound deadening material, the complete set of laminae being rivoted or otherwise firmly secured together to form a solid wheel. The sound deadening material may be fibre, leatheroid, tough papar or other textile material or any other substance which will damp down vibrations set up in the metal.

The wheel may be of plain disc or ring form with rivets firmly gripping the outer metal laminae and binding them on the intervening layers, the rivets if required terminating in studs projecting from the face of the wheel for attachment purposes. Or the laminae forming the body or central part of the wheel may have additional laminae secured to them at the edge, making a toothed rim of increased thickness, in which case the main laminae may be dished to give rigidity, rivets or other securing mean[s] being provided both at the rim and at the thinner middle portion of the wheel. In the case of the pair of gear wheels of ignition apparatus the second construction is especially suitable for the larger or half speed wheel, while the first of flat construction can be employed for the small or full speed wheel.

Dated this 3rd day of November, 1921.

(Signed) Haseltine, Lake & Co.,

28, Southampton Buildings, London, England
and
Park Row Building, 15, Park Row, New York, N.Y., U.S.A.,
Agents for the Applicants.

COPY.

PROVISIONAL PATENT SPECIFICATION.

No. 34662/1921.

PATENTS AND DESIGNS ACTS, 1907 and 1919.

PATENTS FORM NO. 2.

PROVISIONAL SPECIFICATION.

"Improvements in or relating to ignition magnetos for internal combustion engines"

We, THE BRITISH LIGHTING & IGNITION COMPANY LIMITED, a British Company, ERNEST OWEN TURNER and EDWARD BROWNE TUPPEN, both subject of the King of Great Britain, and all of B.L.I.C. Works, Cheston Road, Aston, Birmingham, in the County of Warwick, do hereby declare the nature of this invention to be as follows:-

This invention relates to ignition magnetos for internal combustion engines said magnetos being of the type in which a rotary magnet is employed in conjunction with a fixed armature, and has special reference to the mechanical construction of the magnet rotors for ignition magnetos of the type described in the specification of patent application No.14777 of 1921, and in particular of rotaors of the type in which solid magnetos with pole shoes of laminated soft iron are employed.

According to the present invention magnet rotors for use in ignition magnetos of the type referred to and having pole shoes of laminated constructions are provided with one or more plates of non-magnetic material interleaved at suitable intervals with the iron laminations constituting the said pole shoes, whereby there may be effected a rigid fastening of the pole shoes in position with but little or know reduction of their effective cross-sectional area by the space usually ocupied by rivets or like fastenings. The plates of non-magnetic material may be shaped so as to occupy a proportion of the space which, to avoid undue magnetic leakage, is left between shoe and magnetic limb, between magnetic limbs of opposite polarity, or between the magnet and the surrounding stationary shoes of the armature. In the space referred to bolts or rivets may conveniently be placed without encroaching on the laminated portion of the shoe to fasten the shoes to flanged spindle extensions at each end, or, if desired, such holes may intersect the shoes over a part of their periphery, the other part being in the non-magnetic plates only,

By connecting together a plurality of the non-magnetic interleaving plates for oposite pole shoes by extensions bridging the tips of the shoes across the magnet from pole to pole, the advantage is obtained that the shoes for north and south poles of the magnet are held together in a kind of cage, into which, after rivetting or otherwise securing the iron laminations constituting the shoes and the non-magnetic connecting pieces referred to above, the magnet may be introduced prior to the final attahcment of one or both of the flanged spindle extensions which support the bearings on which the complete rotor revolves. A further advantage of the cage referred to above is that the sides between the north and south pole shoes may be used to prevent the magnet from being displaced in either of these two directions, and the pole faces of the magnet are kept in close contact with the corresponding faces of the pole shoes. With this construction a U-shaped magnet is preferably employed, and this can be disposed so that it is mechanically balanced, or alternatively extra balance weights may be added to whichever side is the lighter.

With a cage construction similar to that mentioned above formed by connecting together a plurality of non-magnetic interleaving plates by extensions bridging the tips of the shoes across the magnet from pole to pole, the pole shoes may be provided each with a wedge or other suitably shaped slot, into which the ends of the magnet are fitted, thus preventing sideways displacement of the magnet without ~~without~~ the necessity of using non-magnetic interleaving plates suitably shaped for this purpose. An advantage of this construction is that the area of contact between the magnet and pole shoes may be thus increased with a corresponding reduction of the reluctance at the joints, and by employing an S shaped magnet, as is preferable in this modified construction, the further advantage may be secured of a symmettrical disposition of the magnet, shoes, and non-magnetic plates, so that these various parts (care being taken to secure this when necessary) are mechanically balanced during rotation of the complete rotor.

The magnetic may also if desired be made up of a number of magnetos of correspondingly reduced axial length, a small space being left between each individual magnet for a non-magnetic partition, which in this case may be made stronger if required, as the portion of the area that otherwise would be taken up by the magnet, is set free, and advantage of this may be taken by stiffening up the partition very considerably if it is desired. The advantage of the use of non-magnetic partitions in the manner described is that the pole shoes are thereby made much more rigid and less of their cross sectional area need be taken up by rivets or screws.

While in the case of ignition magnets of the type that spark symmettrically twice per revolution the pole shoes are usually so designed that the pole arcs subtend an angle of 90^{o} at the point constituting the centre round which the said arcs are described, in the case of the present invention the pole shoes may be designed so that they subtend any desired angle, and in particular an angle substantially less than 90^{o} and in this latter case the length of the pole arc of the stator shoes is increased by an amount dependent on the extent to which the aforesaid angle has been decreased from the normal angle of 90o. By means of this construction the magnetic leakage between the, shoe tips and the neighbouring portions of the magnet, cam be considerably reduced.

The present invention is appricable to devices having various forms of magnet, either straight or curved in such shapes as those of an S or U, and in which the pole shoes, whiling comprising a number of portions to admit of interleaving with plates of non-magnetic material, having the said portions either of solid or laminated construction.

Dated this 23rd day of December, 1921.

(Signed) Haseltine, Lake & Co. Ltd.,

28, Southampton Buildings, London, England, and Park Row Buildings, 15, Park Row, New York, N.Y.,U.S.A.
Agents for the applicants.

COPY.

~~PROPOSED~~ PROVISIONAL SPECIFICATION.

of

THE BRITISH LIGHTING & IGNITION COMPANY, LIMITED of B.L.I.C. Works, Cheston Road, Aston, Birmingham, a British Company and ERNEST OWEN TURNER, of 35, Mayfield Road, Moseley, Birmingham, a subject of the King of Great Britain,

for

"Improvements in or relating to induction coils".

No. 11727/1922.

This invention relates to induction coils and has particular reference to ignition coils intended for use with internal combustion engines.

Hitherto induction coils have been made with open magnetic circuits, that is to say, the magnetic circuit associated with the windings of the coil was composed partly of iron and partly of air. As the reluctance of the air part of the magnetic flux path is so much greater than that of the iron, the magneto-motive force of the primary windings is spent almost entirely in overcoming the reluctance of the air gap. In the various forms of induction coils heretofore employed, although the air path has been made of various lengths, in all cases the length has been greatly in excess of that required, as will be hereinafter explained, for obtaining in the most economical and advantageous manner a given output from the apparatus.

With ignition coils, and especially in the case of those which are intended to operate with high speed internal combustion engines having a large number of cylinders, for example 6, 8 or more cylinders, the interval of time which can be allowed for the current.

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to rise in the primary winding prior to its being interrupted, is extremely short, and in many cases the current is interrupted at a value which is only a small fraction of the value of the current when the interruptions take place at a low speed, so that the energy available in the secondary circuit is lowered. The rate of rise of current in an inductive circuit is governed by the time constant or the ratio of the inductance to the resistance of the circuit, which may be represented by the expression

$$\frac{\text{Flux X Turns}}{\text{Voltage}}$$

Assuming therefore no alterations of the flux to take place, and that the voltage and current consumption of the coil are allowed to remain the same, a great reduction of the length of the air gap, or in other words a replacement of this part of the path by iron, will lead to a great reduction in the number of ampere turns required and thereto a considerably fewer number of turns in the primary winding will be required. The effect of this is to bring about a greatly reduced time constant, and thereby to overcome the difficulty referred to above and in providing a coil which will give an adequate performance when used with high speed engines. For example, with a certain size of coil having its secondary winding positioned intermediate between the iron core and the primary winding, a flux of 10,000 lines was produced by 1300 ampere turns; in a coil of the same design but having its air gap reduced to the lowest limit (as will be hereinafter referred to), the same flux was obtained with 200 ampere turns. The time constant of the coil was thus reduced to less than one-sixth of its former value. As in many cases so great a reduction in the time constant is unnecessary for overcoming the difficulty in operating at high speeds referred to above, the factor of 6, or whatever figure this may amount to, may be advantageously employed in other ways. For example, instead of the turns being reduced to one sixth they may be halved, the flux doubled and the extra turns available used in overcoming the increased reluctance of the extended iron circuit.

It will generally be found that the best performance of the coil is not obtained merely by by the provision of a single air gap placed at random in the magnetic circuit. A better performance may frequently be obtained by splitting up the total length of air gap required into two or three separate air gaps at different positions in series in the magnetic circuit.

We have also found that certain positions in the magnetic circuit give more favourable results than others; for example, if the primary winding consists of a simple coil over which the secondary is wound, it is advantageous if one air gap be made in the very middle of the coil, that is to say, at an equal distance from either end of the layers of the primary winding, and other gaps be then made, as, for instance, at each end of the core, thus providing, in this case, at least three gaps in the circuit. These gaps may be made equal in length, or the respective lengths of the gaps may be so arranged as to give the best performance of the coil as found by experiment. The performance of the coil is furthermore affected by the way in which the gap is made, by the direction of lamination of the iron on either side of the gap, and by the amount of flux which leaves the iron in the neighbourhood and on both sides of the gap, thus forming a fringe. In designing the gaps in the magnetis circuit, particular care must be taken that the flux path does not form itself in a plane at right angles to the plane of lamination of the iron, as the resultant eddy currents which are formed at the opening of the primary circuit greatly reduce the benefit which can be gained by a reduction in the air gap length.

Various forms of construction in accordance with the invention are hereinafter described, whereby the flux path in the neighbourhood of the joints is designed so as to approach as nearly as possible to the ideal, that is to a path wholly confined to the direction of the laminations. Amongst the advantages arising through the reduction in the air path of the magnetic circuit in accordance with the present invention are the following:-

1. The time constant can be halved or decreased to some still greater proportion.

2. The number of secondary turns, in consequence of the increase of flux, may be halved or altered in some other proportion; this brings about a very considerable saving of space in the apparatus at the same time reducing the cost of material and labour.

3. As a result of the increased saturation of the iron, the performance of the coil with a varying voltage applied to the primary winding is rendered more uniform.

4. Another advantage which may be derived dependant on the foregoing, is that with the saturation density of the iron being approached and the performance being more nearly uniform, the generation of a higher sparking voltage from whatever cause, such as greatly increased primary volt-

age, increased spark gap length ,or disconnection in the external high tension circuit, is prevented, and consequently the safety gap most usually provided on ignition coils, may be dispensed with.

5. The magnetic circuit being almost a closed one there is practically no field external to the coil, which consequently may be enclosed in an almost closely fitting tube of brass, iron or other metal, which need not be slotted in the direction of the flux path to prevent excessive eddy-currents, as is commonly the case with coils having an open magnetic circuit as heretofore employed.

6. It has been found that a much smaller condenser is necessary to suppress sparking at the contact breaker, and this again effects a substantial saving in cost especially if a mica condenser be employed.

The present invention comprises an induction coil in which the flux path for almost the whole of the magnetic circuit is of iron or other magnetic material, the dimensions of the air gaps left in the circuit being relatively small but of a size sufficient to ensure a low value for the idle flux and quick magnetisation when the primary current is broken. If no air gap at all were provided the flux would fall, at the opening of the contact-breaker points, to a value equal to the product of the remanence of the steel and its cross sectional area; in such a case the resulting flux drop, in which the value of the secondary voltage product depends, might only amount to 50 per cent of the total flux associated with the windings, or even less. By the provision however of the air gaps in the circuit, the flux falls to a lower value, the air gaps helping to de-magnetize the iron. If sufficient air gaps be left to reduce the magnetism to a comparatively small fraction of the working value of the flux, it can be assumed that the entire coercive force of the steel is effective in maintaining the flux ign the air gaps, and consequently the product of the coercive force of the steel and the mean length of the magnetic circuit is approximately equal to the product of the series of the lengths of the air gaps and the average flux density in the said gaps after the primary circuit has been opened. From the above considerations it will be seen that suitable dimensions of the air gaps can readily be determined, the chief factors being the amount of inactive flux which is best permitted, the length of the magnetic circuit, and the coercive force of the iron. For example with a coil having 300 turns, a magnetic circuit of length 10 centimetres and a total flux of 15000 lines, (the coercivity of the soft steel used being taken for the sake of example as 1.5.C.G.S. units) then assuming the inactive flux to be one tenth of the total, the area of each of the air gaps faces, (the sum of the individual gaps being one millimetre) would be about 10 square centimetres and the number of ampere turns absorbed by the air gaps would be approximately 120, the balance of 180 out of the total 300 turns being required for the iron parts of the circuit.

We have found in practice that the best performance is not always given with air gaps determined by the above considerations, but that a greater total length of air gaps may be required; the difference is to be accounted for largely by the insufficient lamination of the circuit, and in particular to the ineffectiveness of the laminations in the neighbourhood of the joints, to which reference has already been made. The degree of closeness of the air gap length determined by the above theoretical considerations to which this value may be approached in practice to obtain the best result is a measure of the success in laminating the circuit.

As examples of coils having their magnetic circuits arranged in accordance with the present invention, the following forms of construction may be instanced. The core, over which the primary and secondary windings are wound, may be provided with lateral iron extension pieces projecting slightly beyond the outermost winding, so that the core and extension pieces present an H shape appearance, taking a longitudinal section through the coil. The magnetic circuit is completed by iron members which are arranged so as nearky to close the top and bottoms portions of the H, and an air gap or gaps may be left betwean the lateral extension pieces which form the side members of the H and the core, in the core as already described, or elsewhere, in accordance with the extent of the air space it is desired to leave in the magnetic circuit. In a modification of this mode of construction, and air gap or gaps may be provided between one or both ends of the core and the lateral extension pieces, and the top and bottom pieces of the H may be completely closed by iron junction pieces, or two of the air gaps may be formed around the core, where it passes at each end through the lateral extension pieces. In another modification the core may be provided with extension pieces which enclose either the top or bottom half of the coil alone, one or more air gaps being left where desired, in the magnetic circuit constituted by the core and its extension pieces.

In order to ensure that the flux as each joint shall pass as much as possible in the plane of the laminations, various forms of construction may be adopted, for example, when the mechanical construction is such that it is necessary to make a break in the magnetic circuit but it is not desired to introduce an air gap at that spot the iron lamination at the junction of the members may be interleaved with one another. Where flux is to be carried from one direction to another at right angles, the edges of the laminations in the two planes may be bevelled so as to make a joint similar to that in the corners of a picture frame. Another method which may also be employed where the joint is to be made between planes of laminations at an angle to each other is to bend portions of one set of laminations more nearly into the plane of the other set so that the flux being conveyed to this portion of the laminations, is conveyed across the gap into the adjoining laminations without being constrained to leave the plane of the lamination.

Still another method may be adopted, as, for example at the joint between the core and the extension pieces when the latter are braader than the width of the core; a hole may be formed in the extension pieces, through which the core may be introduced and the air gaps between core and extension pieces so arranged that the flux is constrained to pass from the one to the other across only the edges of the laminations.

In all moded of construction above described, the primary winding may be wound over the core, and the secondary winding over the primary, or the windings may be reversed in position, alternatively there may be two cores, a portion of the whole of each winding being wound over each core. The section of the core may be of any desired shape, and may be made up of flat laminations, or of wire, square or round insection, whilst the extension pieces forming the remainder of the magnetic circuit may be made up of laminations, rivetted, or otherwise held together. Means may also be provided for obtaining a very definite and exact extent of air gap or gaps, in a manner well suitad to commercial manufacture by introducing non-magnetic material of a definite thickness into the air gap, or gaps, left in the magnetic circuit. Slots may of course be provided if necessary, to reduce eddy current losses in the usual manner. Further the magnetic current may be so screened so as to eliminate any leakage or fringing magnetic fields outside the active structure of the coil, which may be enclosed in a relatively closely fitting metal case of brass, iron, or other material which may be constructed without joints or slits in the direction of the flux path or at right angles to the direction of the windings.