H. Kristiansen.

EO 15-5AD-2

ROYAL CANADIAN AIR FORCE

DESCRIPTION AND MAINTENANCE INSTRUCTIONS

SCINTILLA AIRCRAFT MAGNETO

ISSUED ON AUTHORITY OF THE CHIEF OF THE AIR STAFF

18 OCT 56

LIST OF RCAF REVISIONS

DATE	PAGE NO	DATE	PAGE NO

FOREWORD

The object of this EO is to describe the fundamental operating theory of high tension and low tension ignition systems in such a manner that personnel will have a better conception of how sparks are generated and distributed in the correct firing order of the engine. The use of technical terms has been avoided as much as possible. It is hoped that the information contained herein will serve the purpose for which it is intended.

TABLE OF CONTENTS

TITLE	PAGE
MAGNETS AND FLUX LINES	1
GENERATING AN INDUCED VOLTAGE	1
THE EFFECT OF CURRENT IN THE COIL OF A GENERATOR	3
THE EFFECT OF INTERRUPTING THE CURRENT	4
THE REQUIREMENTS FOR AIRCRAFT IGNITION	5
APPLICATION OF FUNDAMENTAL PRINCIPLES	6
THE HIGH TENSION IGNITION SYSTEM	13
THE LOW TENSION IGNITION SYSTEM	21

LIST OF ILLUSTRATIONS

FIGURE	TITLE	PAGE
1		1
2		1
3		2
4		3
5		4
6		5
7		5
8	Four Pole Rotating Magnet	6
9	Magnet in "Full Register" Position	6
10	Magnet in "Neutral" Position	7
11 and 12	Graphic Representation of Factors of Operation of Four Pole Magneto	8
13		10
14	Model for Demonstrating the Effect of Using Breaker Points and Condenser to Interrupt Primary Current	11
15	Graphic Representation of Factors of Operation of Magneto with Breaker and Condenser but with Secondary Open-Circuited	12
16	Evolution of Coil for High Tension Magneto	13
17	Graphic Representation of Factors of Operation of Four Pole Magneto Firing Plug in Engine Cylinder	15
18	Aircraft Ignition System (Schematic Diagram)	16
19		18
20	Simplified Circuit of Low Tension System	23
21	Schematic of Low Tension Ignition System	24
22	Schematic Diagram of Electrical and Magnetic Circuits	25
23	Magnetic Circuit of Double Magneto	26
24	Typical Low Tension Transformer Coil "Telescoped" to Show Design	26
25	Circuit of Low Tension System at Instant Breaker Opens	27

SCINTILLA AIRCRAFT MAGNETO

MAGNETS AND FLUX LINES

1 The operation of Bendix Aircraft Magnetos is based on the properties of the permanent magnet. A permanent magnet has a magnetic field consisting of many individual paths of invisible magnetic flux commonly known as "lines" of flux. Each "line" of flux extends from the north pole through the intervening air space to the south pole, thereby forming a closed loop as indicated in Figure 1.

2 The presence of the lines of flux can be shown by placing a magnet under a piece of paper on which iron filings are sprinkled. The iron filings will arrange themselves in definite positions along the lines of flux, indicated in Figure 1, which compose the magnetic field.

3 The lines of flux have the characteristic of repelling one another. Consequently, they will spread over a considerable portion of the air space between the poles as represented graphically in Figure 1.

4 The lines of flux also have a natural tendency to seek the path of least resistance between the magnet poles. A laminated soft iron bar provides a much easier path for the flux than does the air, and for this reason the lines will crowd together and pass through such a bar if it is placed near the magnet.

5 This can be seen in Figure 2 where the "lines" of flux composing the magnetic field are shown concentrated in a defined path within the bar instead of occupying a large portion of the air space. Therefore, the density of "lines" of flux within the bar is very high. The application of the laminated soft iron bar to magnetos will be explained subsequently in this Engineering Order.

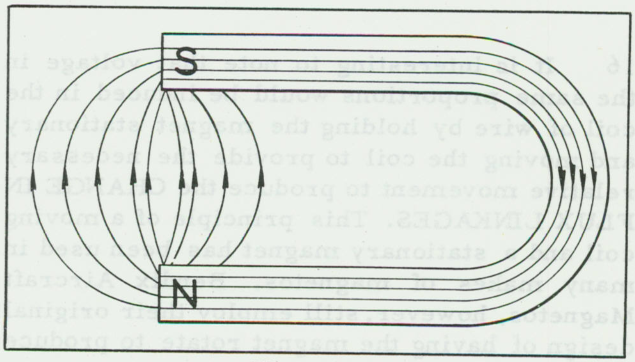


Figure 1

6 The direction of the flux in the laminated soft iron bar when placed in a magnetic field is determined by the polarity of the permanent magnet.

7 The permanent magnet is made of a special alloy steel which has the characteristic of being able to retain a large portion of the magnetism induced in it when it is "charged" by passing through it lines of flux from a strong electro-magnet. The laminated bar is of magnetically "soft" iron, which does not retain an appreciable amount of magnetism when magnetic lines of flux are passed through it.

8 Therefore, should the magnet in Figure 2 be turned over so that the north pole was at the top of the picture, the direction of the lines of flux would be reversed in the iron bar.

GENERATING AN INDUCED VOLTAGE

9 Experiments can be made with a magnet to show how a voltage is generated or induced in a coil of wire. The coil should be made with a few turns of heavy copper wire and connected, as shown in Figure 3, to a meter which indicates any voltage by deflection of its needle.

10 The lines of flux of the magnet, when in

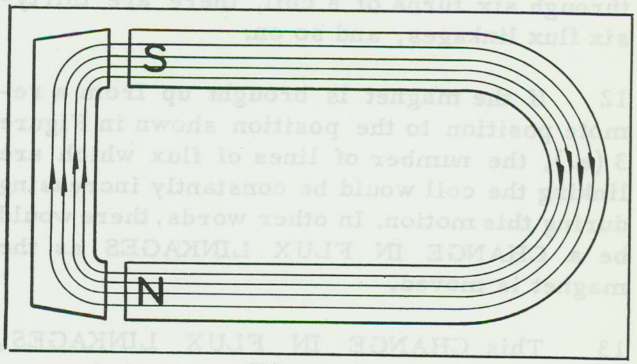


Figure 2

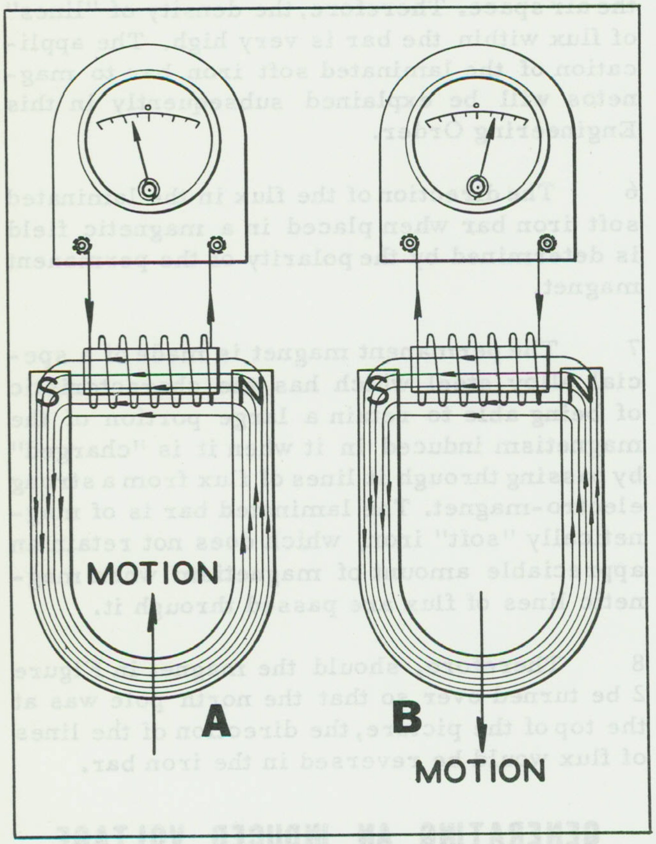


Figure 3

the position illustrated in Figure 3, pass through or "link" the turns of wire in the coil. When one line of flux passes through one turn of a coil, it is known as one "flux linkage". If one line of flux passes through six turns of a coil, six "flux linkages" are produced.

11 Accordingly, if six lines of flux pass through six turns of a coil, there are thirty-six flux linkages, and so on.

12 If the magnet is brought up from a remote position to the position shown in Figure 3 (a.), the number of lines of flux which are linking the coil would be constantly increasing during this motion. In other words, there would be a CHANGE IN FLUX LINKAGES as the magnet is moved.

13 This CHANGE IN FLUX LINKAGES, produced by moving the magnet, induces a voltage in the coil of wire. This voltage (or force) will be indicated by the deflection of the meter needle. Should the magnet be moved back away from the coil as shown in Figure 3 (b.), the FLUX LINKAGES would be constantly decreasing during this motion, inducing voltage in the coil in the OPPOSITE direction as indicated by the meter needle.

14 The voltage induced in the coil is proportional to the RATE OF CHANGE OF FLUX LINKAGES. The flux linkages can be increased by adding more turns in the coil of wire or by using a stronger magnet having more lines of flux. The rate can also be increased by moving the magnet faster thus increasing the speed of the flux change. The deflection of the meter needle will indicate the magnitude of the voltage when any of the foregoing experiments of increasing the RATE OF CHANGE OF FLUX LINKAGES ARE TRIED.

15 No voltage will be induced in the coil of wire if the magnet is held stationary even though the lines of flux link the coil turns because the RATE OF CHANGE IN FLUX LINKAGES IS ZERO. This experiment shows that there must be a CHANGE IN FLUX LINKAGES to induce voltage. This is an important principle when applied to a magneto because it points out that the lines of flux must be given a magnetic path through the coil and, also, that there must be a movement of either the coil or the magnet to produce a CHANGE IN FLUX LINKAGES.

16 It is interesting to note that voltage in the same proportions would be induced in the coil of wire by holding the magnet stationary and moving the coil to provide the necessary relative movement to produce the CHANGE IN FLUX LINKAGES. This principle of a moving coil and a stationary magnet has been used in many makes of magnetos. Bendix Aircraft Magnetos, however, still employ their original design of having the magnet rotate to produce the CHANGE IN FLUX LINKAGES.

THE EFFECT OF CURRENT IN THE COIL OF A GENERATOR

17 Nearly everyone is familiar with the common electro-magnet in which a temporary magnetic field is produced by sending a current through a coil of wire. Figure 4 is a sketch of a simple electro-magnet in which the energizing voltage is obtained from a dry cell.

18 The magnetic field of the electro-magnet consists of flux lines and has the same properties as the field of the permanent magnet previously discussed, the only difference being that if the battery is disconnected from the electro-magnet, the field will disappear. It might be said that the iron core becomes a temporary magnet during the time the current is "on" and is just an ordinary iron bar when the current is "off".

19 This principle of an electro-magnet can be used to further investigate the properties of the coil and magnet pictured in Figure 3, with interesting results. For example, short-circuit the terminals of the meter in Figure 3 and the voltage induced in the coil of wire will cause a current to flow through the circuit. Note that there is now a coil of wire wound on an iron core with a current passing through the wire.

20 This is essentially the same condition that was had with the battery in Figure 4, except that the voltage is now provided by the motion of the magnet instead of the battery.

21 When a change in flux linkages sets up a current in a coil, the direction of the current is always such that its magnetic field opposes the motion or change in flux linkages which produced the current. This phenomenon is known as Lenz's Law and is of the greatest importance to the operation of the magneto, as explained later in this EO.

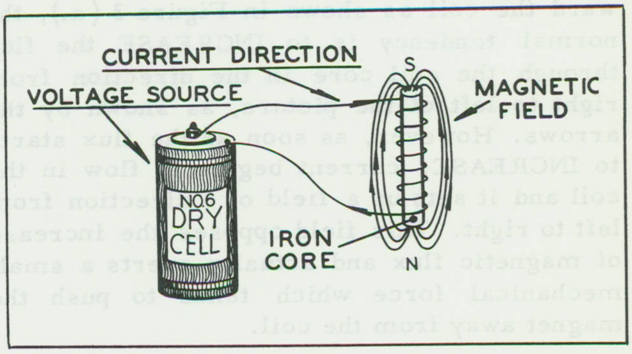


Figure 4

22 This will be clearer if reference is made to Figure 3. Here it was demonstrated that when the magnetic lines through the coil were increasing (magnet moving toward the coil), the voltage induced was of the opposite direction to that induced when the lines of flux were decreasing (magnet moving away from the coil).

23 If the experiment shown in Figure 3 was performed, using an ammeter instead of a voltmeter, and observing to make sure that the direction in which the coil was wound and the polarity of the magnet were as shown in Figure 3, it would be found that when the magnet was moved up to the coil, the current would flow up the right hand wire through the ammeter and down the left hand wire.

24 If the "right hand rule" * was applied to this current, it would be found that the field which it sets up opposes the field of the magnet; that is, it sets up a field which repels the field of the magnet and tries to push the latter away.

25 While the magnet is being moved up to-

---

*This is a convenient means of determining the polarity of a magnetic field when the direction of the current and the direction of the winding of a coil are known. If the fingers of the right hand extend around the coil in the direction of the current, the thumb will always point in the direction of the flux, or the North end of the field.

ward the coil as shown in Figure 3 (a.), the normal tendency is to INCREASE the flux through the coil core in the direction from right to left of the picture, as shown by the arrows. However, as soon as the flux starts to INCREASE, current begins to flow in the coil and it sets up a field of a direction from left to right. This field opposes the increase of magnetic flux and actually exerts a small mechanical force which tends to push the magnet away from the coil.

26 When the magnet is moving away as shown in Figure 3 (b.), the current in the coil will flow up the left hand wire, through the meter, and down the right hand wire. By the "right hand rule", the field of the coil is now aiding the field of the magnet. As the magnet is moved away from the coil, the flux linkages decrease. Here again, however, just as soon as the flux linkages start to decrease, current begins to flow in the coil and this current sets up a magnetic field which, in accordance with Lenz's Law, opposes the change. Since the change is now a DECREASE, the coil field will not in this case oppose the magnet field, but will rather aid it, trying to keep it from dying out or decreasing. Actually, a small mechanical pull is exerted on the magnet by the coil, tending to resist the motion of the magnet away from the coil.

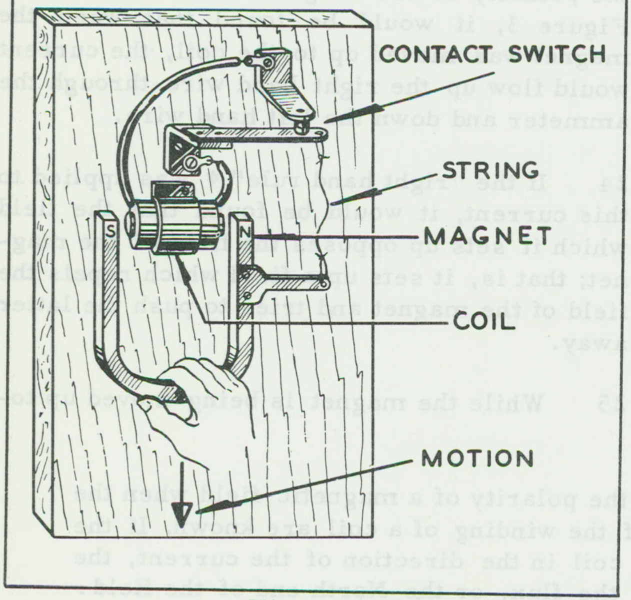


Figure 5

27 To sum up an understanding of what is happening in these experiments consider the magnet and coil as a simple type of generator. If the generator is operated (magnet moved) without a load connected (such as would be the case if a voltmeter were connected across the coil terminals) no current will flow and only voltage will appear across the terminals. If the generator is operated in a short-circuited condition (such as with an ammeter connected across the coil terminals) a current will flow but the voltage will be low. This effect of decreasing output voltage when an increased output current is taken, can be observed on any simple unregulated generator.

THE EFFECT OF INTERRUPTING THE CURRENT

28 Suppose the apparatus is set up as shown in Figure 5 with a contact switch connected across the coil, and the spring of the contact switch connected to the magnet with a piece of string such that as soon as the magnet has moved a slight distance from the coil, the string will pull the switch open.

29 Now, as the magnet is moved away from the coil, the flux through the coil core will decrease, Figure 6. This decrease in flux will induce a voltage in the coil and since the coil ends are connected together through the contact switch, a current will flow in the coil. This current will cause the coil to act as an electro-magnet and try to prevent the flux in the coil core from decreasing. In other words, the coil will, by its electro-magnetic action, keep most of the original amount of flux in the coil core even though the magnet has moved away from the core.

30 By the time that the magnet has been moved far enough to pull on the string, it will be so far away from the coil that it actually contributes very little to the amount of flux in

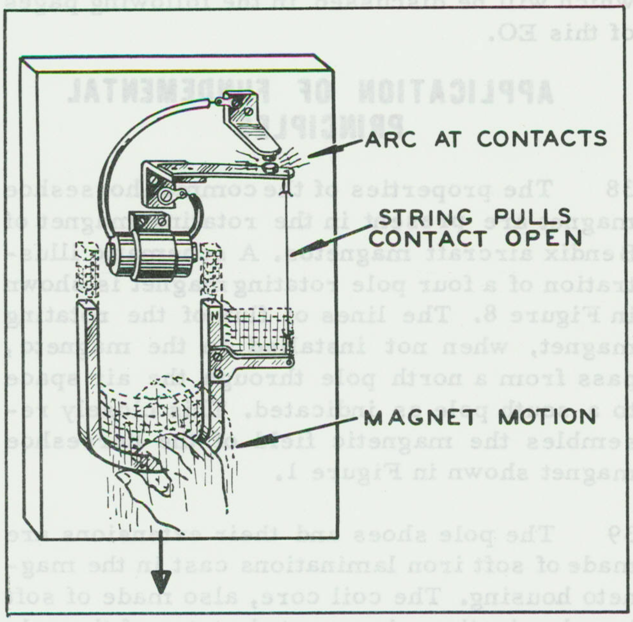


Figure 6

the coil core, most of the core flux being produced by the electro-magnetic action of the current in the coil itself.

31 When the magnet pulls the string, the contacts open. As soon as this happens, the current in the coil must stop flowing, since the circuit is open. When the current stops, the coil ceases to be an electro-magnet and thus the field of flux which was being held in the coil core by this electro-magnetic action very quickly disappears. This action produces a very rapid change of flux in the coil core during the time that the contacts are separating, inducing a voltage which causes an arc at the switch contacts, see Figure 6.

32 To make clearer just what happens at the instant of opening of the contact switch, the magnetic circuit of the device is redrawn in simplified form in Figure 7. Just before the switch opens, the electro-magnetic action of the coil is retaining most of the original field in the coil, Figure 7 "A". But as soon as the switch contacts start to separate, the current in the coil decreases, thereby allowing the flux to "escape" from the core, Figure 7 "B". The effect of the contact switch and coil is to hold back, or delay the flux change until there is a stress or "stretch" in the flux lines, at which time the opening of the switch releases the flux and lets the change occur very rapidly.

THE REQUIREMENTS FOR AIRCRAFT IGNITION

33 Actually the device pictured in Figure 5 is a form of magneto. In fact some old fashioned stationary gasoline engines can still be found in operation which employ an ignition system very similar in principle to this simple demonstration apparatus. Such engines have the breaker contacts inside the engine cylinder instead of a spark plug, one contact being pivoted so that it can be moved away from the other at the instant ignition is desired to occur in the cylinder. The arc which occurs at the breaker points then ignites the gas in the cylinder. The magnet, coil, and breaker contacts are moved in the correct relation by a cam driven through gears from the crankshaft of the engine. Obviously such an arrangement is not suitable for aircraft ignition for a variety of reasons, but the principle involved forms the basis of design for all types of magnetos, as will be pointed out later in this EO.

34 It is not too difficult to "draw" an arc between two contacts while they are in the process of separating. This is because the voltage required is quite low. As a matter of fact the arc which is "drawn" by the operator of an electric welding apparatus is usually

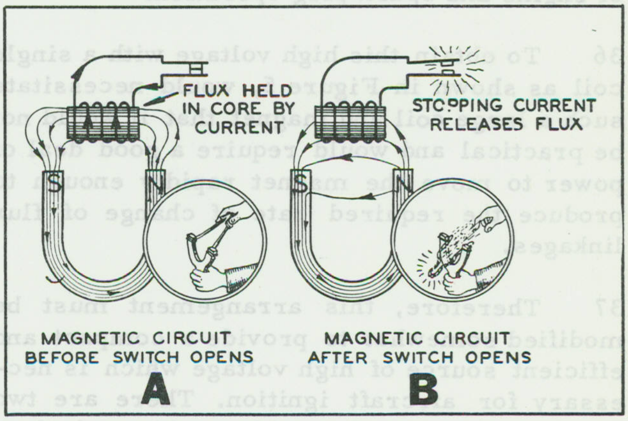


Figure 7

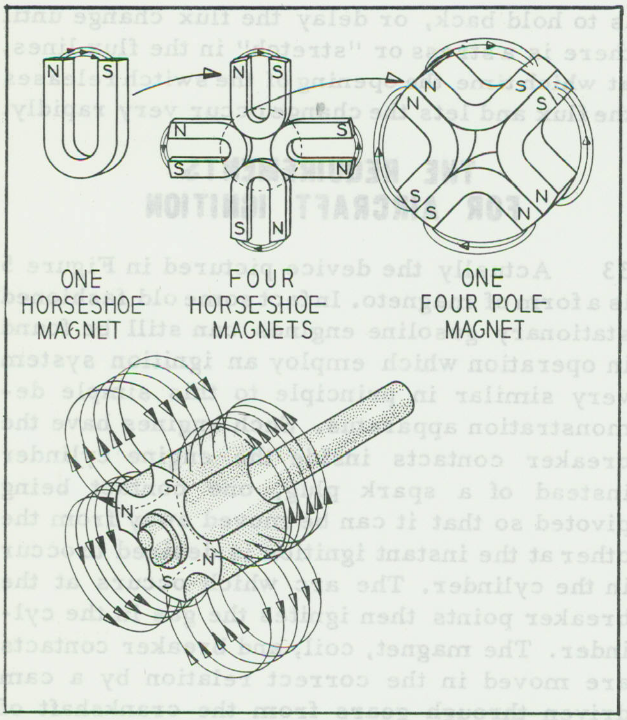


Figure 8 Four Pole Rotating Magnet

produced from a source of less than 100 volts.

35 It is quite a different matter to produce the voltage required to break down a spark plug gap in an engine, since this latter process is not one of "drawing" an arc but is rather one of puncturing or breaking down the layer of gas between the spark plug electrodes. The voltage required to do this may be as high as 12,000 to 15,000 volts under some conditions of engine and spark plug operation.

36 To obtain this high voltage with a single coil as shown in Figure 5, would necessitate such a large coil and magnet that it would not be practical and would require a good deal of power to move the magnet rapidly enough to produce the required rate of change of flux linkages.

37 Therefore, this arrangement must be modified somewhat to provide a compact and efficient source of high voltage which is necessary for aircraft ignition. There are two avenues of approach to this problem, both of which will be discussed in the following pages of this EO.

APPLICATION OF FUNDEMENTAL PRINCIPLES

38 The properties of the common horseshoe magnet are present in the rotating magnet of Bendix aircraft magnetos. A schematic illustration of a four pole rotating magnet is shown in Figure 8. The lines of flux of the rotating magnet, when not installed in the magneto, pass from a north pole through the air space to a south pole as indicated. This closely resembles the magnetic field of the horseshoe magnet shown in Figure 1.

39 The pole shoes and their extensions are made of soft iron laminations cast in the magneto housing. The coil core, also made of soft iron laminations, is mounted on top of the pole shoe extensions.

40 The pole shoes (D) and their extensions (E), together with the coil core (C) as shown in Figure 9, form a magnetic path similar to that made by the coil core illustrated with the common horseshoe magnet in Figure 5. This magnetic path produces a concentration of flux in the core of the coil when the magnet is in

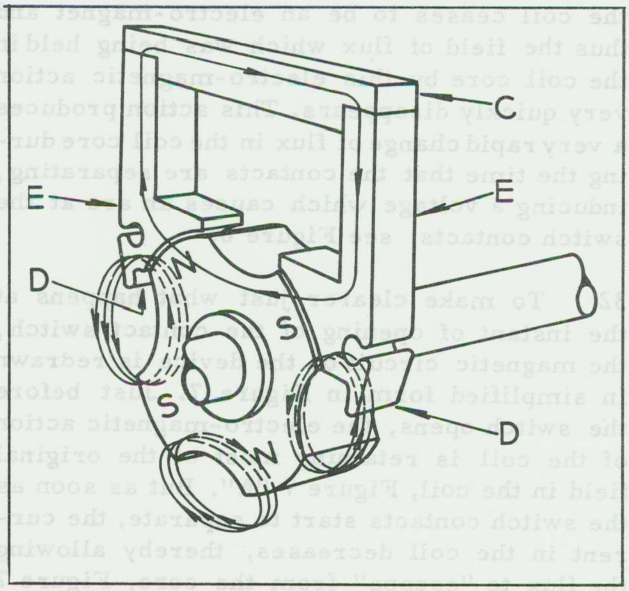


Figure 9 Magnet in "Full Register" Position

the positions shown in Figure 9. This is known as the "full register" position of the rotating magnet.

41 When the magnet is rotated to the position where one of the pole pieces is centered between the pole shoes in the magneto housing Figure 10, lines of flux do not pass through the coil core because they are "short-circuited" by the pole shoes. This is known as the "neutral" position of the rotating magnet.

42 It should be noted that no primary or secondary windings are shown on the coil core in Figures 9 and 10. These have been omitted to permit a clearer description of the magnetic action. By first observing the action without the windings, a better understanding of their function in the magneto can be later obtained.

43 If the magnet shown in Figures 9 and 10 is rotated, it will pass through four full register positions and four neutral positions during one complete revolution. Each time the magnet is in a full register position, a maximum number of lines of flux pass through the coil core. And each time the magnet is in a neutral position, the magnetic flux through the coil core is zero.

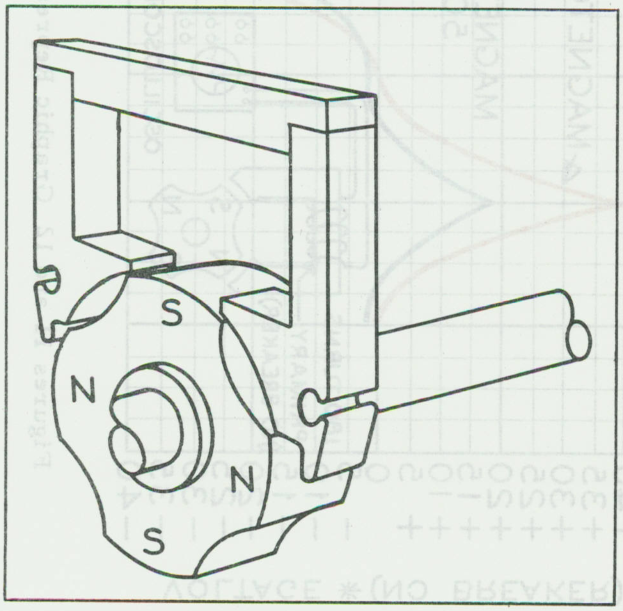


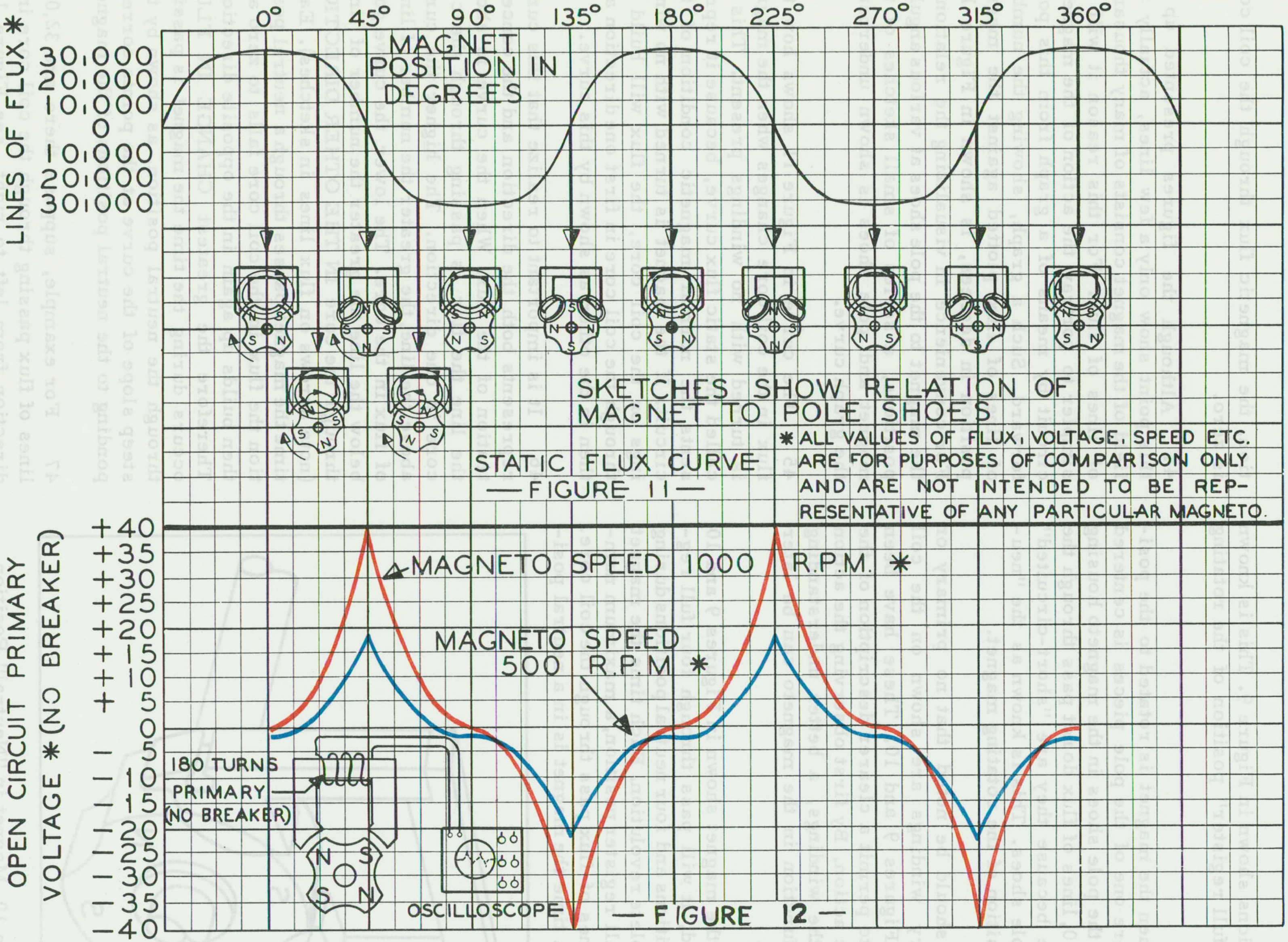
Figure 10 Magnet in "Neutral" Position

44 Although the figures presented up to this point show only a few lines, actually the field of the magnet consists of many thousands of lines of flux. For this reason it will be simpler to portray the action of the magnetic circuit by means of a graph from this point forward. Such a graph, showing the number of lines of flux plotted against the magnet position in degrees, is shown in Figure 11. For convenience in visualizing the relation of the magnet to the pole shoes at various angular positions, a series of small sketches of the magnet and pole shoes is shown underneath the graph curve.

45 The curve in Figure 11 shows how the flux in the coil core changes when the magnet is turned with no windings present. This is called the static flux curve, because it represents the normal magnetic condition of the circuit. If the magnet is turned with no windings on the coil core, the flux will build up through the coil core in first one direction and then in the other as shown by this curve.

46 It is important to realize that this curve represents both the direction and the concentration of the flux. When the curve is above the line the flux is passing through the coil core in one direction. The higher the curve above the line, the greater the number of lines of flux in the core. The lower the curve goes below the line the greater the number of lines through the core IN THE OTHER DIRECTION (note arrows on flux lines in sketches). Each time the magnet passes through a neutral position the flux in the coil core falls to zero and then builds up again in the opposite direction. Therefore the greatest CHANGE IN FLUX occurs during the time the magnet is passing through the neutral position, as shown by the steep slope of the curve at the points corresponding to the neutral positions of the magnet.

47 For example, suppose there are 32,000 lines of flux passing through the coil core in a direction from left to right, see Figure 11,



Figures 11 and 12 Graphic Representation of Factors of Operation of Four Pole Magneto when the magnet is in the full register position indicated by "zero degrees" of the graph.

48 If the magnet is turned clockwise, the flux value will decrease along the curve indicated by the graph, until at the 45° position zero flux in the coil core has been obtained. Thus in 45° of rotation of the magnet a flux change of 32,000 lines in the coil core has been produced.

49 If the magnet is further turned, the flux through the coil core will increase again, this time it is passing through the core in the opposite direction, that is - from right to left (see sketch with arrow under 90° position of graph). When the 90° position of the magnet has been reached it will be found (see graph) that 32,000 lines of flux in the coil core has again been produced, but this time of the opposite direction.

50 As far as the coil core itself is concerned, the total change in flux produced by this 90° turn of the magnet is 64,000 lines, since the flux changed from a positive value of 32,000 lines, to zero, and then changed further to a negative value of 32,000 lines.

51 Continue to turn the magnet in a clockwise direction and the flux value will again reach zero at the 135° position of the magneto. It will then start to increase in a positive direction until a value of 32,000 lines is reached at the 180° position of the magnet.

52 In turning the magnet from its 90° position to its 180° position a change of 64,000 lines has again been produced, since it started with a value of 32,000 below the zero axis of the graph, and ended with a value of 32,000 above.

53 In the same way as just described, a flux change of 64,000 lines is produced for the 180° to 270° interval and the 270° to 360° interval of rotation of the magnet.

54 From the above description it should be clear that the four pole magnet provides four flux changes for each complete revolution through which it is turned, and that further, each of these flux changes has a value of approximately twice the number of flux lines which the magnet is capable of forcing through the coil core.

55 Having now obtained an elementary understanding of how the static flux curve, Figure 11, is produced, see what the effect is when a primary winding is installed on the coil core. Do not connect the breaker points into the circuit just yet, but observe first the open-circuit voltage of the primary without the breaker installed.

56 The primary winding is made up of, say, 180 turns of heavy, insulated copper wire, and is wound directly around the coil core, see Figure 12. Now, any change in flux in the coil core will cause a change in flux linkages in this winding and induce a voltage in it.

57 The voltage induced in this coil will depend on how fast the magnet is being turned when the voltage is being measured. This is because the amount of voltage produced is proportional to the rate of change of flux linkages, as explained in connection with Figure 3.

58 This can be proved by connecting an oscilloscope across the primary winding and measuring its open circuit voltage while the magnet is being rotated. If the magnet is turned at 500 rpm a voltage curve something like that shown in blue in Figure 12 will be obtained. (Note that Figure 12 is plotted to the same scale of magnet degrees as was used in Figure 11.) If the magnet is driven at 1000 rpm, a curve like the one shown in red in Figure 12 will be obtained, which, since the rate of change of flux linkages has been doubled (speed of magnet doubled) gives, for all practical purposes, twice as much voltage as was obtained at 500 rpm.

59 As was expected, the open circuit voltage curve reaches its maximum value peaks at the neutral positions of the rotating magnet, which represent the positions where the rate of change of flux is greatest.

60 While the voltage values shown in Figure 12 are not presented as being actual values for the open circuit primary voltage of any particular magneto, they are nevertheless approximately correct in a general way for most magnetos, and can serve to show on a comparison basis, that something less than 20 volts is available from the primary at low speed. A little simple figuring will show that it would require a coil of over 100,000 turns to get 12,000 volts from a coil-and-magnet generator of this type, and even to do that would require that the magnet turn at 500 rpm or over. Such a coil would be nearly as big as an entire modern magneto.

61 Further, even if the difficulties of getting proper voltage could be worked out, it would be impossible to time such a unit to an engine. This is because the slope of the voltage curve shown in Figure 12 is quite gradual, and depends on engine speed. As an example, suppose the voltage values shown in Figure 12 could be stepped up one thousand times by increasing the number of coil turns. Then 12,000 volts would be obtained at the point on the graph indicated by 12 volts on the voltage scale of Figure 12. But 12 volts is not reached at the same position of the magnet on the red curve (1000 rpm) as it is on the blue one (500 rpm). Since the magnet is driven mechanically from the engine crankshaft, the engine spark timing or firing position would be different for every different speed of the engine. Further, since no two spark plugs fire at exactly the same voltage, the engine spark timing would also vary for every spark plug.

62 By using a current interrupter of the type described in Figure 5, the requirements for precisely timed sparks can be met with a mechanism of minimum size and weight. Further, the speed of the flux change can be greatly increased, so that high voltage can be obtained with a relatively small coil.

63 However, it will be recalled in connection with Figure 5, that the opening of the contacts caused a considerable arc at the contact surfaces, this arc having been used for ignition purposes in some of the early gasoline engines.

64 While this arrangement might pass on a stationary engine, the arc is destructive, and it will very quickly burn away the surfaces of the contact points, causing their life to be short. In order to use the interrupter or breaker in an aircraft magneto where long periods of dependable service are required, the arc must be eliminated.

65 This can be done by connecting a condenser across the contact points of the breaker as shown in Figure 13.

66 The action of the condenser is comparable to that of the elastic diaphragm shown in the water analogy in Figure 13. In this comparison, the elastic diaphragm prevents "banging" of the valve when the water is suddenly shut off. It does this by providing a by-pass route for the water to flow around the valve during the time the flow is being stopped. Similarly, the condenser prevents arcing of the contacts of the breaker as they are being opened, by allowing a "by-pass route" for the current

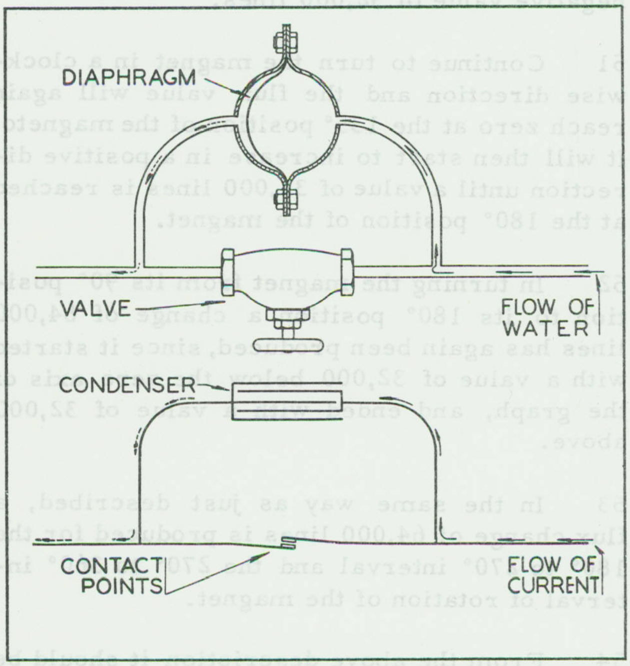


Figure 13

during the time the contacts are being separated. The action which takes place in the condenser and breaker circuit is as follows: Before the breaker opens, the condenser is in a completely discharged condition, since the breaker itself forms a connection across the condenser terminals. During the time the breaker points are separating,the current will be by-passed around them in the form of a charging current in the condenser. During the time the condenser is charging, the breaker contacts move further apart, so that by the time the condenser is fully charged and brings the current to a stop, the contacts are so far apart that an arc cannot "jump across" between them.

67 The breaker contact points are electrically connected across the primary coil, and the magneto breaker mechanism is timed to the magnet so that the contact points close at the position where there is a maximum of flux in the coil core. The condenser is connected across the contact points of the breaker as shown in Figure 14.

68 With breaker points, cam and condenser added to the circuit as in Figure 14, the action which takes place when the magnet is turned will be somewhat different from that portrayed by Figures 11 and 12 for a magnet and coil with no breaker points.

69 The action of the device shown in Figure 14 is depicted by the graph curves shown in Figure 15. At the top of the figure the original static flux curve of the magneto is shown for reference purposes, together with degrees of magnet rotation.

70 Underneath the static flux curve is shown the sequence of opening and closing of the magneto breaker. Note that the breaker is timed by means of the breaker cam to close at a position where a maximum amount of flux is passing through the coil core (34° before neutral), and to open at a position 11° after neutral. Note also that there are four lobes on the cam, so that the breaker will close and open in this same relation to each of the four neutral positions of the magnet. Note also that the point opening and point closing intervals are approximately equal.

71 Now, starting at the maximum flux position (marked "0°" at the top of the figure), the following sequence of events will take place.

72 As the magnet is turned toward the neutral position, the amount of flux through the coil core starts to decrease, see resultant flux curve Figure 15. This decrease or change in flux linkages induces a current in the primary winding, as depicted by the curve marked "Primary Current" in Figure 15.

73 As previously stated, a current-carrying coil produces a magnetic field of its own. Accordingly, the current induced in the primary winding will set up a magnetic field of its own.

74 In accordance with Lenz's Law, the magnetic field set up by this current will oppose the CHANGE OF FLUX LINKAGES, inducing the current. This is shown graphically by the curve marked "Resultant Flux" in Figure 15. Without current flowing in the primary winding, the flux in the coil core would decrease to zero as the magnet was turned to neutral, and then start to increase in the opposite di-

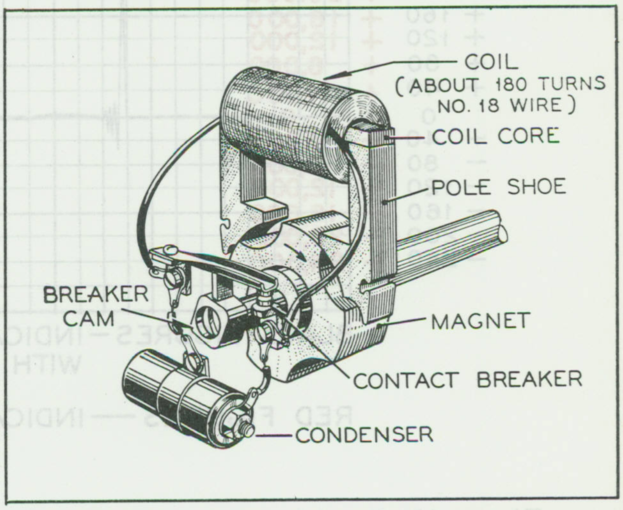
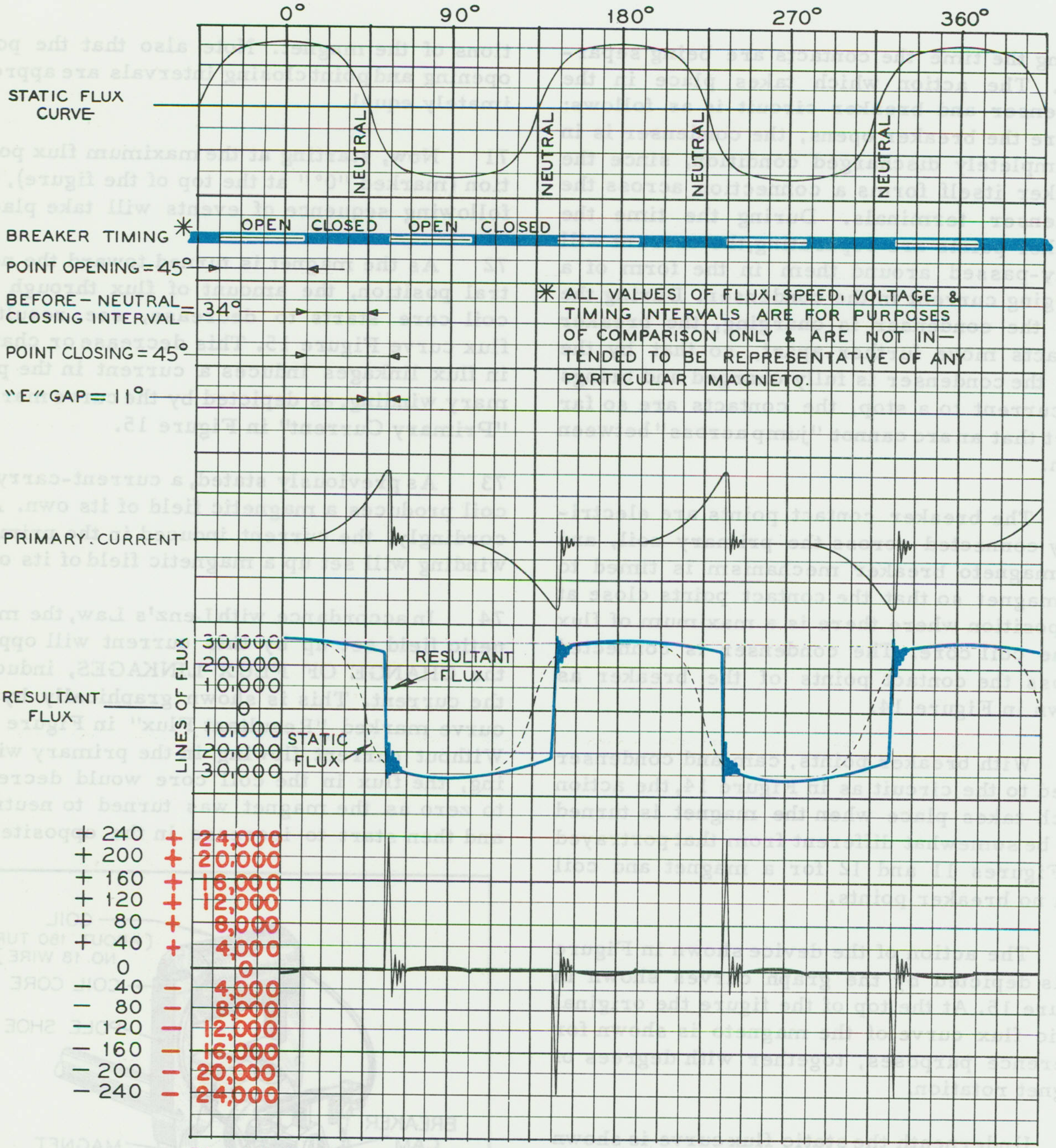


Figure 14 Model for Demonstrating the Effect of Using Breaker Points and Condenser to Interrupt Primary Current



BLACK FIGURES — INDICATE OPEN CIRCUIT PRIMARY VOLTAGE *
WITH BREAKER AND CONDENSER

RED FIGURES — INDICATE OPEN CIRCUIT SECONDARY VOLTAGE
⊕ (SEE TEXT)

Figure 15 Graphic Representation of Factors of Operation of Magneto with Breaker and Condenser but with Secondary Open-Circuited rection as represented by the dotted "static flux" curve. However, the electro-magnetic action of the primary current prevents the flux from changing as explained above, and temporarily holds the field in the coil core instead of allowing it to change. This is represented by the curve shown in blue which is known as the "resultant flux" curve.

75 As a result of this process, there is great stress in the magnetic circuit by the time the magnet has reached the position where the contact points are about to open, a few degrees past the neutral position. The condition in the circuit now resembles that depicted in Figure 7 "A".

76 At this time, the primary current is maintaining the original field in the coil core where the magnet has already turned past neutral and is now attempting to establish a field through the coil core in the other direction.

77 The contact points, when opened, function with the condenser as described in connection with Figure 13, to interrupt the flow of primary current in the coil, causing an extremely rapid change in flux linkages. In less than a thousandth of a second, the flux linking the coil changes from a positive value of nearly 30,000 lines, see resultant flux curve, Figure 15, to a negative value of nearly 30,000 lines. This change of nearly 60,000 lines, occurring in less than a thousandth of a second, gives a tremendous rate of change of flux linkages, inducing several hundred volts in the coil. The voltage is shown in graphic form directly underneath the resultant flux curve in Figure 15. The values of voltage indicated for this curve are not intended to represent those for any particular type of magneto, but are for comparison purposes, to show that with a breaker and condenser installed, the same magnet and coil which formerly produced about 20 volts at 500 rpm, Figures 11 and 12, now can produce 12 times this much voltage.

78 The very rapid flux change produced by the use of breaker points and a condenser makes it possible to obtain the high voltage required for ignition without the need for an extremely large coil. Further, the timing of the rapid flux change is accurately controlled, by the breaker, and this together with the very steep nature of the rise of the voltage wave, Figure 15, complies with the requirement for precise timing of the spark in an engine cylinder.

THE HIGH TENSION IGNITION SYSTEM

79 There are two ways in which the rapid flux change discussed in connection with Figure 15 can be made to produce the necessary high voltage for firing a spark plug. One way to do this would be to remove the coil from the assembly shown in Figure 14 and to wind a secondary winding of about 18,000 turns of fine wire directly over the 180 turn primary already on the coil core.

80 Upon re-assembling the unit, see Figure 16, it would be found that since the secondary contains 100 times as many turns as the primary, and, since the primary was capable of producing 240 volts, Figure 15, the secondary is capable of producing 24,000 volts.

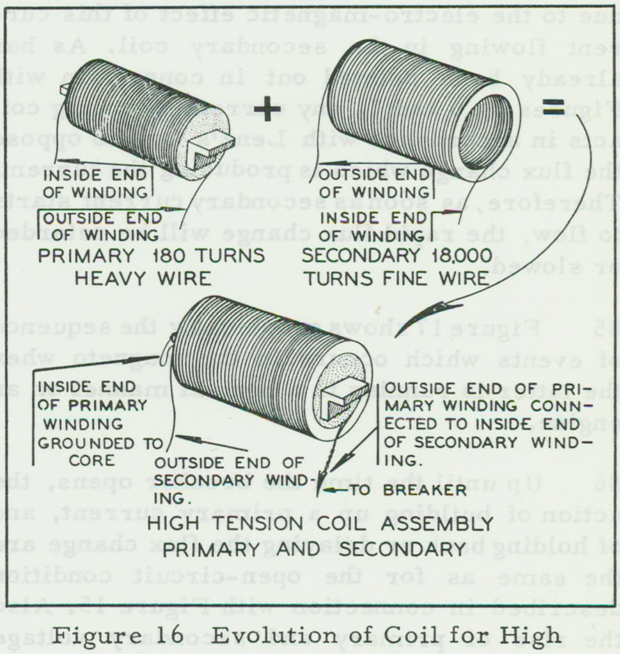


Figure 16 Evolution of Coil for High Tension Magneto

81 This type of coil is used with minor variations in all conventional high tension magnetos.

82 This secondary winding, containing 100 times as many turns of wire as the primary, gives a voltage equal to 100 times that of the primary. Therefore the open-circuit secondary voltage graph will look exactly like that shown for the open circuit primary voltage in Figure 15, except that the voltage values would be multiplied by 100. See red figures Figure 15.

83 However, the magneto does not develop its full open-circuit voltage when operating in a normal manner on the engine. In fact the voltage required for a well-maintained spark plug is usually less than 5000 volts during cruise power operation of the engine. This means that as soon as the magneto secondary voltage has risen to the firing or sparking voltage of the plug, the plug gap becomes conductive and a current starts to flow in the secondary winding of the magneto.

84 The flow of secondary current to the spark plug alters considerably the shape of the voltage and resultant flux curves. This is due to the electro-magnetic effect of this current flowing in the secondary coil. As has already been pointed out in connection with Figures 5, 6 and 7, any current-carrying coil acts in accordance with Lenz's Law to oppose the flux change which is producing the current. Therefore, as soon as secondary current starts to flow, the rapid flux change will be retarded or slowed.

85 Figure 17 shows graphically the sequence of events which occurs in the magneto when the latter is running in a normal manner on an engine.

86 Up until the time the breaker opens, the action of building up a primary current, and of holding back or delaying the flux change are the same as for the open-circuit condition described in connection with Figure 15. Also the rise of primary and secondary voltage takes place when the breaker opens in the same manner as previously outlined.

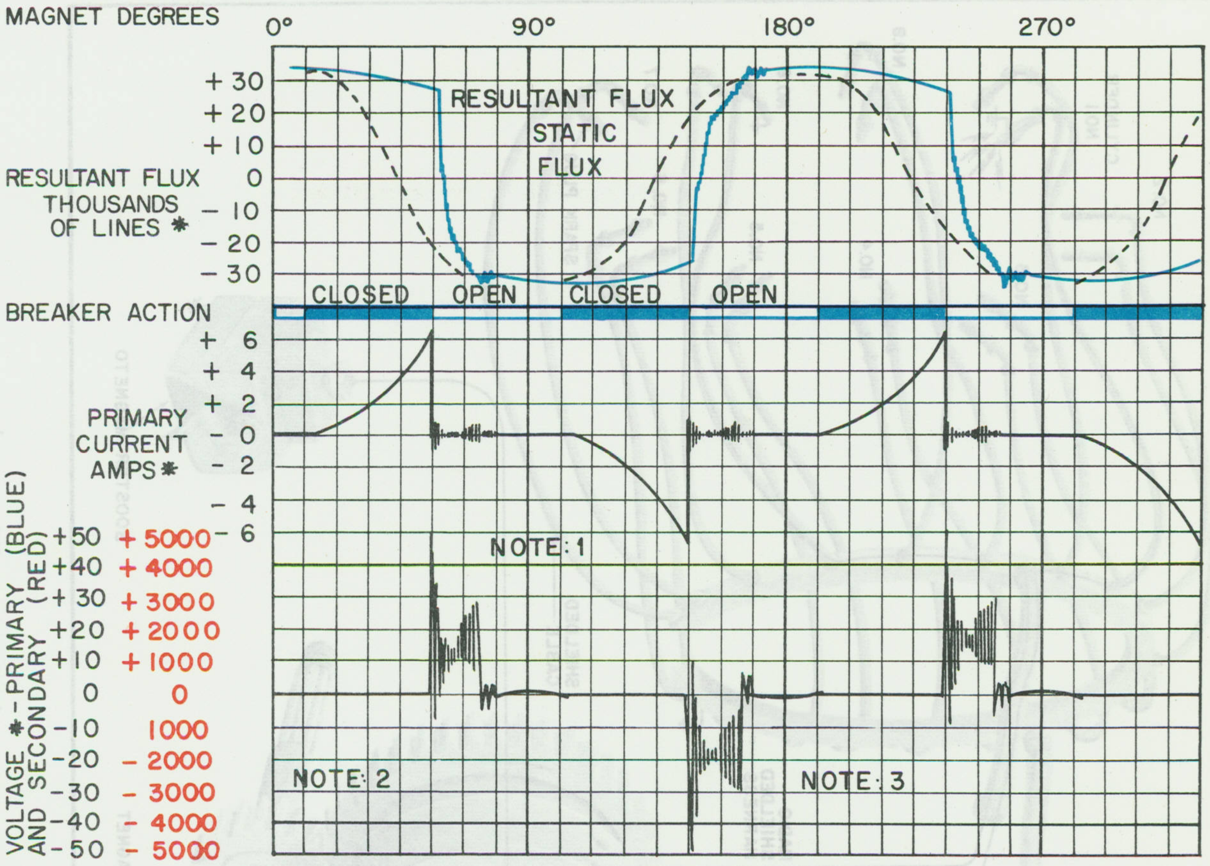
87 However if the magneto is connected to a spark plug which "fires" at 5000 volts, the plug will "break down" and become conductive when this voltage is reached, and current will start to flow. This is shown graphically in Figure 17, in which the factors of Resultant Flux, Static Flux, Breaker Timing, Primary Current, Primary and Secondary Voltage are shown plotted against magnet degrees for a magneto in actual operation on an engine.

88 When the high voltage in the secondary winding discharges, a spark jumps across the spark plug gap which ignites the fuel in the cylinder. Each spark actually consists of one peak discharge, after which a series of small oscillations occur as indicated by the secondary voltage curve carrying brief explanatory notes in Figure 17. During the time it takes for the spark to completely discharge, current is flowing in the secondary winding.

89 However, just as soon as current flows in the secondary winding, a magnetic field is set up which will oppose the CHANGE IN FLUX which produced it. Therefore, the flux change is slowed up, as indicated by the tapering portion of the resultant flux curve.

90 In spite of the "slowing up" effect of the secondary current the spark normally becomes completely discharged before the next "closing" of the contact points. That is, the energy or stress in the magnetic circuit is completely dissipated by the time the contacts close for the production of the next spark. This is shown in Figure 17 where it will be seen that the resultant flux curve has tapered off so it exactly coincides with the static flux curve at the time the contact points close. In other words, all the electro-magnetic action of the coil has dissipated, and the magnetic circuit has returned to its normal or static condition and is ready to begin the build-up of primary current for the next spark, which is produced in the same manner as the first.

91 Figure 18 illustrates a complete high



* All values of flux, current and voltage are for purposes of comparison only, and are not intended to apply to any particular magneto.

Note 1 - Transition point caused by very low resistance of plug gap when burning gas is present in gap.

Note 2 - Initial oscillations due to sudden current load placed on coil when secondary starts to conduct current.

Note 3 - "Quench" oscillations caused by the effect of turbulence and pressure on the current flowing across the spark plug gap.

Figure 17 Graphic Representation of Factors of Operation of Four Pole Magneto Firing Plug in Engine Cylinder

tension ignition system consisting of two magnetos, radio shield harness, spark plugs, switch, and a booster magneto. One magneto is illustrated completely assembled and the other is in skeleton form showing electrical and magnetic circuits.

92 One end of primary winding is grounded to the magneto. The other end is connected to the insulated contact point of the breaker. The other breaker point is grounded. The condenser is connected across the breaker.

93 The ignition switch terminal on the magneto is electrically connected to the insulated contact point. A wire connects the switch terminal on each magneto with the ignition switch. When the switch is in the "OFF" position, this wire provides a direct path to ground for the primary current. Therefore, when the contact

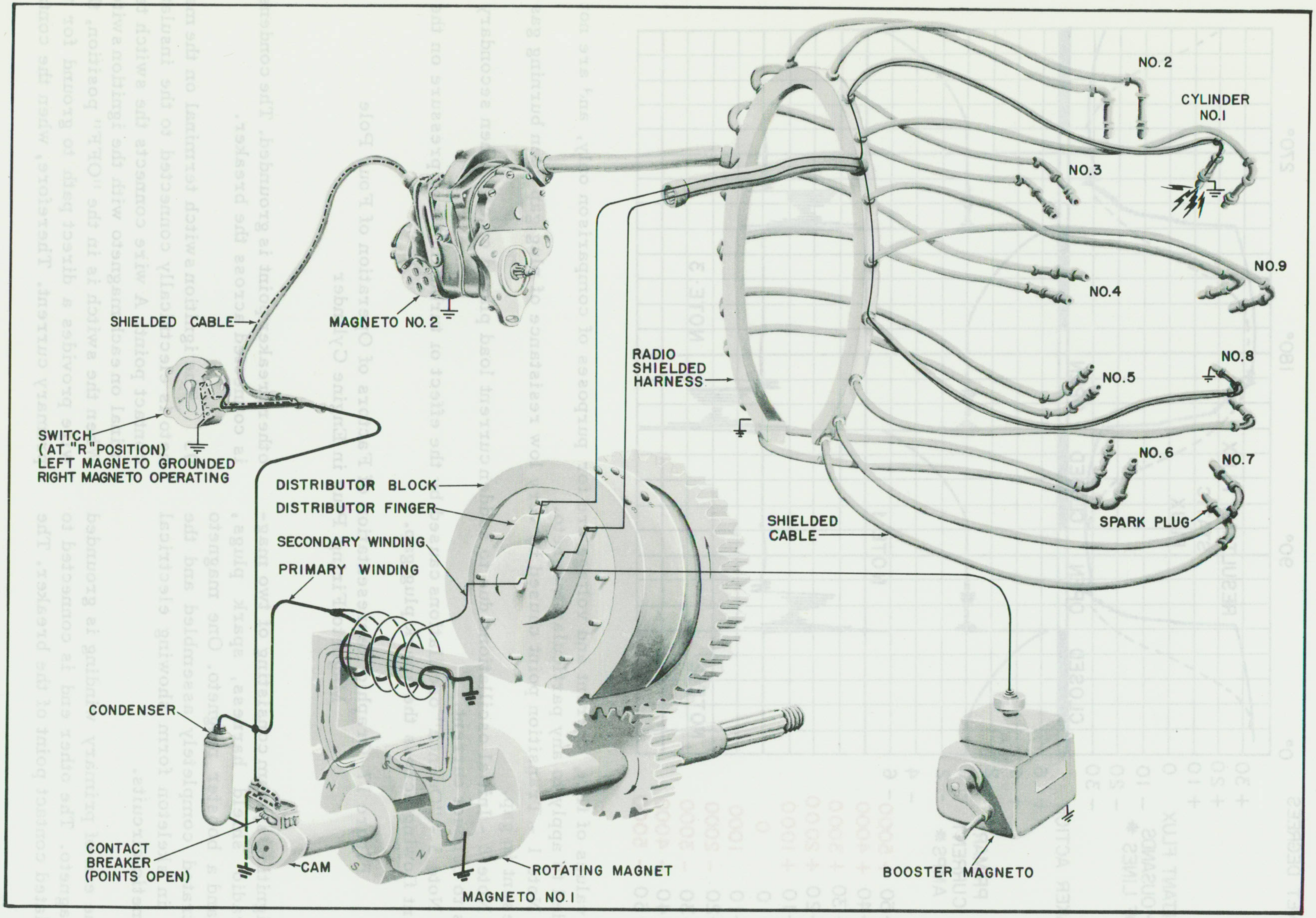


Figure 18 Aircraft Ignition System (Schematic Diagram)

points open, the primary current is not interrupted. This prevents the production of high voltage in the secondary winding.

94 One end of the secondary winding is grounded to the magneto. The other end terminates at the high tension insert on the coil. The high tension current produced in the secondary winding is then conducted to the central insert of the distributor finger by means of a carbon brush. From here, it is conducted to the high tension segment of the distributor finger and across a small air gap to the electrodes of the distributor block. High tension cables in the distributor block then carry it to the spark plugs where the discharge occurs.

95 The distributor finger is secured to the large distributor gear which is driven by a smaller gear located on the drive shaft of the rotating magnet. The ratio between these two gears is always such that the distributor finger is driven at one-half engine crankshaft speed. This ratio of the gears ensures proper distribution of the high tension current to the spark plugs in accordance with the firing order of the particular engine.

96 Practically all aircraft engines operate on the four stroke cycle principle. Consequently, the number of sparks required for each complete revolution of the engine is equal to one-half the number of cylinders on the engine. The number of sparks produced by each revolution of the rotating magnet is equal to the number of its poles. Therefore, the ratio of the speed at which the rotating magnet is driven to that of the engine crankshaft is always half the number of cylinders on the engine divided by the number of poles on the rotating magnet.

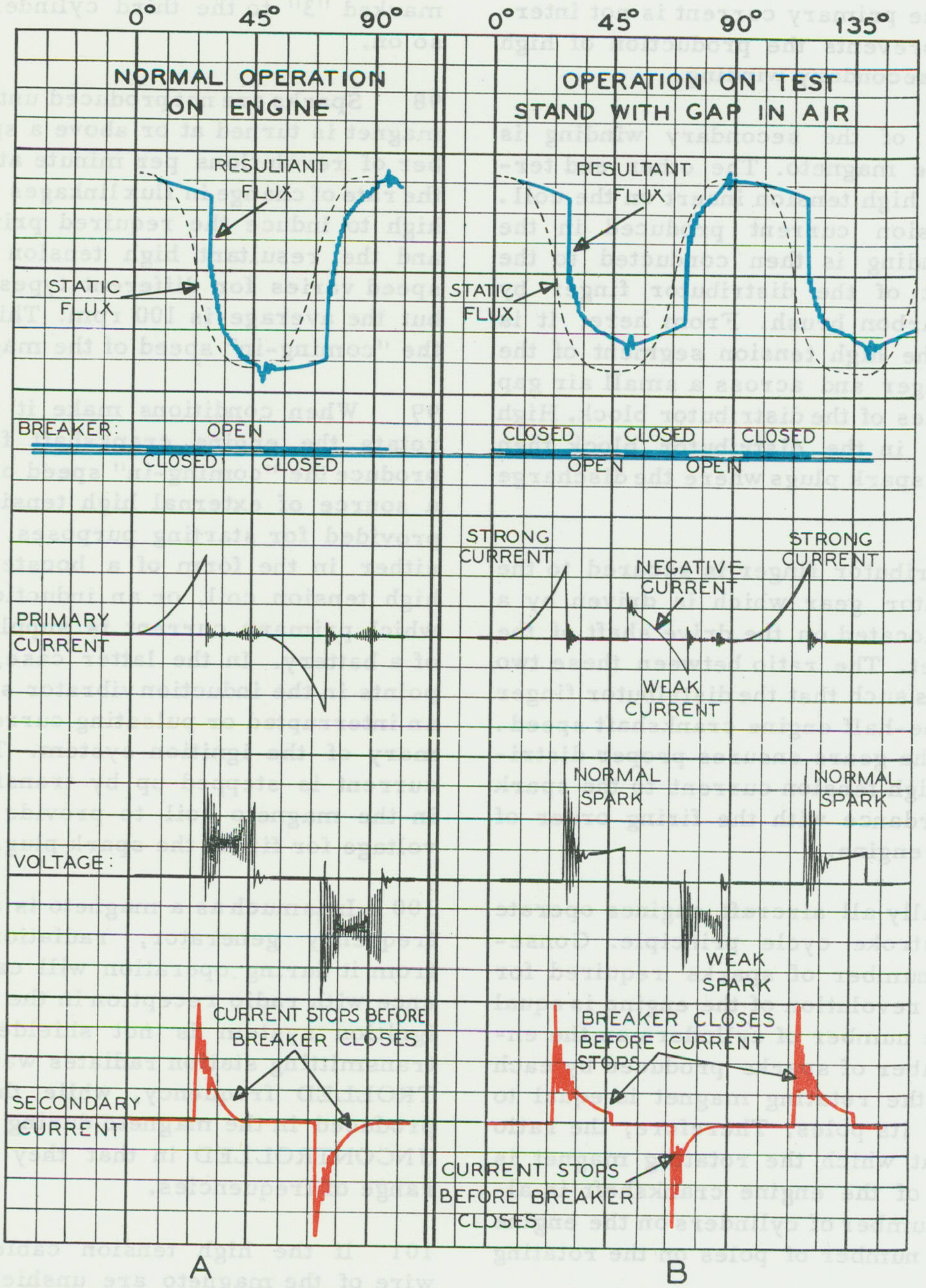
97 The numbers on the distributor block denote the magneto sparking order and do not represent engine cylinder numbers. Therefore, the distributor block position marked "1" must be connected to No. 1 cylinder, distributor block position marked "2" to the second cylinder to fire, and the distributor block position marked "3" to the third cylinder to fire, and so on.

98 Sparks are not produced until the rotating magnet is turned at or above a specified number of revolutions per minute at which speed the rate of change in flux linkages is sufficiently high to induce the required primary current and the resultant high tension output. This speed varies for different types of magnetos but the average is 100 rpm. This is known as the "coming-in" speed of the magneto.

99 When conditions make it impossible to rotate the engine crankshaft fast enough to produce the "coming-in" speed of the magneto, a source of external high tension current is provided for starting purposes. This may be either in the form of a booster magneto, a high tension coil, or an induction vibrator to which primary current is supplied by means of a battery. In the latter case, the vibrator points in the induction vibrator serve to supply an interrupted or pulsating current to the primary of the ignition system. This pulsating current is stepped up by transformer action in the magneto coil to provide the required voltage for firing the spark plug.

100 Inasmuch as a magneto is a form of high frequency generator, radiations emanating from it during operation will cause interference with radio reception in the aircraft if the ignition system is not shielded. The radio transmitting station radiates waves of a CONTROLLED frequency, while the oscillations produced in the magneto during operation are UNCONTROLLED in that they cover a wide range of frequencies.

101 If the high tension cables and switch wire of the magneto are unshielded, they can serve as antennae from which these UNCONTROLLED frequencies are radiated. Since the receiving aerial on the aircraft is relatively close to the ignition wiring, the uncontrolled frequencies will be picked up by the aerial along with the controlled frequencies from the radio station, thus causing interference to be heard in the radio receiver in the aircraft.



A 8-POLE MAGNETO RUNNING WITH NORMAL CYLINDER PRESSURE– ON ENGINE.

B 8-POLE MAGNETO RUNNING WITH TEST GAPS IN AIR. (ATMOSPHERE)

Figure 19

102 To prevent this interference, the entire ignition system is enclosed in a special metallic covering known as "radio shielding". The various parts of the shielding are bonded together and grounded to the engine, to prevent the undesirable radiations from reaching the receiving aerial.

103 When the magneto is required to supply ignition for a relatively large number of cylinders it has been found desirable to employ rotating magnets having more than four poles. This has led to the development of six, eight, and fourteen pole rotating magnets.

104 Since the number of sparks which can be produced by a magnet in one revolution is equal to the number of poles on the magnet, the greater the number of poles, the more sparks the magnet can produce at a certain speed of rotation. Thus an eight pole magneto, if used on a fourteen cylinder engine would be driven at 7/8 engine crankshaft speed, whereas it would be necessary to drive a four pole magneto at 2 x 7/8 = 1 3/4 times engine crankshaft speed.

105 The number of degrees of rotation available for the occurrence of each event in the magneto operating cycle becomes smaller as the number of poles on the magnet is increased. For example, the interval available for the discharge of the spark which is shown as 45° for the four pole magneto in Figure 17, would be only 22 1/2° on an eight pole magneto.

106 As long as the magneto is operated under conditions where the spark becomes completely discharged before the next closing of the breaker, this shorter interval does no harm. But were anything to make the spark last longer, or the breaker to close earlier, there would still be current flowing in the secondary when the breaker closed.

107 Two very practical examples of this type of operation are:-

(a) A magneto (8-Pole) operated on a test stand with test gaps in atmospheric air. Such gaps do not have the "quenching" effect which is present in the engine cylinder, (see Note 3, Figure 17) therefore the test gap spark is of longer duration than the spark in the engine cylinder. As a result the spark is not yet extinguished at the instant the breaker closes.

(b) A magneto operated on an engine with the breaker of the magneto improperly adjusted, so that the breaker does not remain open for the required number of degrees. Since the breaker closes too early, it does so before the spark is extinguished.

108 When either of these things happen, the result is that the breaker closes before the energy of the magnetic circuit has been completely dissipated.

109 The effects of this are shown in graphical form in Figure 19, "A" and "B". In Figure 19 "A" are shown the factors of operation under normal engine conditions. In Figure 19 "B" are shown the effects of operating the same magneto on a test stand with gaps in air.

110 In Figure 19 "A" it will be noted that before the breaker closes the secondary current has tapered off to zero and the resultant flux curve has likewise tapered off to exactly coincide with the static flux curve.

111 In Figure 19 "B" however, due to lower resistance of the test bench spark gaps, the spark is not quenched, but is still flowing right up to the instant the breaker closes. Further, this flow of spark current in the secondary prevents the resultant flux curve from tapering off to coincide with the static flux curve.

112 At the instant before the breaker closes, there is still some voltage in the secondary which is maintaining the flow of secondary current. This voltage, say, is 500 volts. Now since there are 1/100 as many turns in the primary as in the secondary, the voltage across the primary is at this instant 1/100 x 500 = 5 volts.

113 When the breaker closes, the resistance

of the primary circuit falls to a very low value, say, about .5 ohm. Since the voltage before closing was 5 volts, the current in the primary will at the instant of closing start to rise toward a value of 10 amperes ($I = E/R = 5/.5 = 10$).

114 But as soon as the primary current starts to rise, its electromagnetic action opposes the change in flux linkages which is producing the original 5 volts. Since the same flux change is producing the secondary voltage, the decreased rate of change of flux caused by the current in the primary, lowers the secondary voltage and the spark in the secondary circuit is extinguished.

115 During the time that the secondary current is coming to a stop, the primary current rises at such a rate that at any instant, the sum of the ampere turns of the primary and that of the secondary remains approximately constant.

116 As a result of this process, it might be said that the current flowing in the secondary at the instant the breaker closes is "transformed into the primary".

117 Now this current, since it is a part of the energy left over from the spark which has just taken place, has the same direction or polarity as the original primary current for that spark. But since the next spark in the firing sequence of the magneto will have the opposite polarity, this residual or "left over" current is of the wrong direction for the build-up of primary current for the second spark. This "wrong way" current is termed a "negative" current because it subtracts from the primary current for the second spark. This makes the second spark weak in comparison to the first spark.

118 Since the second spark is weak it will become completely discharged before the breaker closes, and there will be no negative current. Then a normal primary current will build up for the third spark, and this normal spark, as in the case of the first spark, will not have time to become completely discharged before the breaker closes, again causing a "negative current" for the fourth spark, and so on. From this it can be seen that every other spark will be weak.

119 It is perhaps worth repeating here that the above phenomena take place only in cases where the breaker closes while there is still a considerable amount of energy in the magnetic circuit. It is a fortunate coincidence that the rate of dissipation of spark energy at the spark plug increases with the pressure and turbulence in the engine cylinder. Therefore, the greater the BMEP of the engine, the more favourable are its effects upon the dissipation of the spark energy and the prevention of the "negative current" effect.

120 When a magneto is run on a test bench in the repair shop it may fail to pass a minimum output voltage specification by reason of the weak alternate sparks caused by the "negative current" effect. This is, as previously stated, because the open air test gap on the test stand has a lower "resistance" than the spark plug in the engine cylinder. To eliminate the "negative current" effect during such tests, service literature covering the procedures usually prescribes the use of a secondary condenser connected in series with the magneto output. This condenser, when in an uncharged condition offers no resistance to the flow of current to the spark plug. But the spark current very quickly charges the condenser, which, in the same manner as explained for the primary condenser in Figure 13, brings the secondary current to a stop. Thus the secondary condenser prevents the possibility of a "negative current" by bringing the secondary current to a stop more quickly than would ordinarily be the case.

121 Under some conditions of speed and spark gap length, the secondary condenser may discharge backward through the circuit in the opposite direction after first reaching its fully charged condition as described above. In this case should the breaker close during the reversed-direction flow of condenser discharge current, an effect of aiding the primary

current for the next spark would take place. However this aid is not consistent at all speeds, and the object of attaining this condition is not the purpose of the secondary condenser.

122 When the first eight pole magnetos were produced, the secondary condenser was incorporated within the magneto as a permanent part of the electrical circuit. This was done because of a general conviction that if a magneto without this condenser could not meet minimum voltage specifications in the test laboratory, it would fail to meet proper performance standards on the engine. Since that time it has been proven that such reasoning is not applicable to magneto output voltage standards and while the secondary condenser is retained for test purposes, its omission from the completed magneto has now been approved, and is in fact recommended by all engine manufacturers on whose products such magnetos are used.

THE LOW TENSION IGNITION SYSTEM

123 There are several very serious problems encountered in the production and distribution of the high voltage electricity which is used to fire the spark plugs of an aircraft engine. For this reason high tension magneto ignition systems of the type described in paragraphs 79 to 122 of this EO have always required a certain amount of skilful maintenance while in service, despite the many refinements which have been introduced into their design.

124 In general, the troubles experienced with high tension ignition systems for aircraft use can be blamed on the fact that high voltage electricity is a very perverse and difficult commodity to handle. It corrodes most metals, deteriorates most organic insulation materials, and displays an amazing ability for getting from where it should be, to where it should not be.

125 There are four inherent causes for the trouble experienced in handling high voltage electricity:-

(a) Flashover

(b) Capacitance

(c) Moisture

(d) High Voltage Corona

126 These four causes need no introduction to aircraft operators or to ignition equipment design engineers, since their troublesome effects are well known. It was, in a deliberate effort to overcome these troublesome effects that the Bendix low tension ignition systems were designed. Since their introduction to the aircraft industry in 1940, low tension ignition systems have been proved in regular operation by practically every manufacturer of large radial engines, as well as the armed services and the major airlines.

127 In order to understand the reasoning behind the use of the low tension ignition system, it may be helpful to clarify in greater detail the four troublesome factors of flashover, capacitance, moisture and corona.

128 By flashover is meant an entirely different phenomenon than that which is associated with a wet distributor, or a moisture laden part in the ignition system. The term "flashover" is used to describe what happens inside the distributor of a high tension ignition system when an aircraft ascends to a high altitude.

129 A distributor is a necessary part of the ignition system because it performs the function of switching the magneto output in sequence to the various cylinders which are to be fired. The distributor cannot be eliminated from the system, because to do so would mean that there would have to be a separate magneto for each engine spark plug. Obviously, the distributor cannot be filled with oil, plastic, or other insulating compounds. Therefore, air must be depended upon for a dielectric or insulator between the high voltage conductors.

130 When an aircraft equipped with such a distributor approaches the altitude of 30,000

feet, troubles begin to occur due to the rarefied nature of the air at this altitude. As the air within the distributor housing becomes thinner, its insulating strength becomes lower, until at the critical altitude, electricity finds it easier to jump through the air in the distributor and go to the grounded housing, than it does to travel down the spark plug wire and fire the spark plug.

131 Before the development of low tension, considerable ingenuity had been exercised in overcoming this problem. One solution which was quite successful was to make the distributor of large physical size, so that the length of the flashover path was increased; and to provide a means of pressurizing the oversize distributor with engine-driven air pumps. This system is still giving satisfactory service in several different designs, but it does have the disadvantages of additional weight and power requirements on the engine. It was evident that the best answer to the problem was to eliminate high voltage from the distributor completely.

132 The factor of spark plug lead capacitance is, for commercial operators, of greater importance than flashover, due to its effects upon the economics of line maintenance. This factor is perhaps the least understood of all. While the electrical effects of capacitance are well-known to technical personnel, their effects upon the spark plug discharge are not so well appreciated.

133 To clarify this, compare the output of any magneto (either high or low-tension), to the shock energy of the mechanical blow delivered by a hammer. If the capacity (or the electrical elasticity) of the spark plug wire is sufficiently large, it will absorb the shock of this electrical blow and prevent it from being transmitted to the plug with sufficient force to fire the gap. The mechanical analogy of this condition is that of trying to drive a nail with a block of springy rubber between the hammer and the nail head.

134 From a design standpoint, this means that unless the lead capacitance is eliminated, a considerably larger reserve of energy than is actually required for ignition must be built into the magneto.

135 No particular problem exists in designing a magneto which incorporates the additional reserve of energy to fire through a shielded cable. The real problem lies in the effect this excess energy has on the spark plug. For the energy which is absorbed and stored in the lead capacitance during the rise of voltage across the plug before it fires is dissipated in heat at the plug electrodes after the plug has once become conductive.

136 The discharge of energy stored in the spark plug lead capacitance can be compared to the type of arc that an electric welding operator draws between the electrode and the work. It is a low-voltage, high current discharge, capable of burning and melting the electrodes of the spark plug. The magneto itself is not capable of delivering a current which is detrimental to the spark plugs. But when the energy of the magneto is stored up in the lead capacitance before the plug fires, and then suddenly released after the plug gap has become conductive, a high current results which shortens the life of the plug electrodes.

137 The detrimental effect of spark plug lead capacitance is also related in at least one way with the problems of spark plug fouling. This relation is involved with the effect of lead capacitance in lowering the effective frequency of the voltage applied to the spark plug. To avoid a lengthy discussion on the term "frequency" let it be said that this refers to the sharpness or quickness of the electrical blow delivered by the magneto to the spark plug. The higher the frequency, the more fouling can be tolerated across the plug insulation before the plug will misfire.

138 Since the problems of plug erosion and frequency are both related to the amount of lead capacitance, and since lead capacitance is directly related to lead length, the only complete solution to this problem would be to

eliminate the spark plug lead entirely from the system. This solution however, is not practical for reasons which will be covered in later pages of this EO.

139 The last two factors on the list - moisture and corona - need but little explanation since their effects are pretty well-known. It may be in order to state that by "corona" is meant the electrical stress which surrounds any conductor of high voltage electricity*. When a high voltage is impressed between the conductor of an insulated wire and any metallic mass near the wire, an electrical stress is set up in the insulation. Repeated application of voltage stress to the insulation will eventually cause its failure, in a manner analogous to that in which repeated mechanical stressing of a part will eventually cause fatigue and failure. If air is used as an insulator, its chemical composition soon changes as a result of the voltage stresses, and it becomes less effective as an insulator. If solid insulators are used, their shape and composition must be critically controlled in order to retard the destructive effects of these stresses. It is the action of these stresses which makes necessary the ventilation of high-voltage distributors, and the changing of wires in free-wire type harnesses.

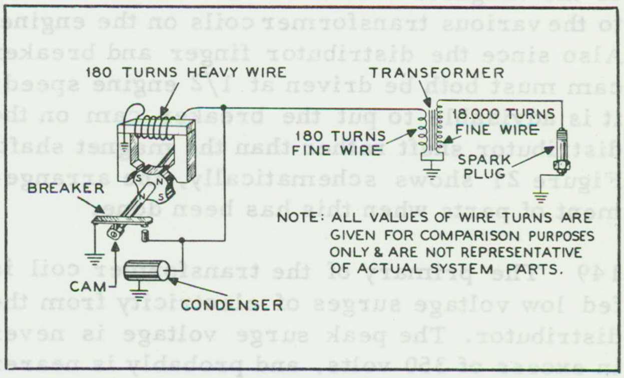
140 Although some ingenious answers have been developed in the form of improved insulation, plastic-filled harness units, and special compounds, the threat of high voltage stress effects can never be completely eliminated so long as high voltage must be handled. The only complete solution is to keep the high voltage confined to as small as possible a part of the total system.

141 Keeping in mind the four factors which have been discussed above, it may be of interest to follow the train of reasoning which was employed to circumvent their destructive effects in the planning of the low tension system.

142 First, refer to Figure 14, in connection with which will be recalled the statement made in the text to the effect that there are two ways in which high voltage may be obtained from the demonstration model shown in the figure.

143 One of these ways has already been discussed in paragraphs 79 to 122. The other way is to take the output voltage from the demonstration model, Figure 14, and feed into a step-up transformer having the required characteristics to provide the necessary voltage for firing the spark plug. Figure 20 shows a simplified circuit of such an assembly.

144 With arrangement shown in Figure 20, the 240 volts (see Voltage Graph Figure 15) obtainable from the apparatus depicted in Figure 14 is stepped up to the required voltage for firing the spark plug of the engine. This is actually the basic circuit of the low tension system. While the electrical operation of this circuit is quite simple, it is not exactly as might appear from the schematic diagram, and will therefore be discussed briefly in later pages of this EO. Before proceeding with this



NOTE: ALL VALUES OF WIRE TURNS ARE GIVEN FOR COMPARISON PURPOSES ONLY & ARE NOT REPRESENTATIVE OF ACTUAL SYSTEM PARTS.

Figure 20 Simplified Circuit of Low Tension System

---

*The use of the word "corona" is, frankly, making a concession to popular usage which is not strictly correct in a technical sense. A better expression would be "insulation stresses".

EO, however, it will be interesting to consider some of the factors governing the use of this principle in designing an aircraft ignition system.

145 In the first place, the spark plug itself employs high voltage. This fact must be faced if standard types of plugs are to be employed with the system.

146 On this basis it becomes impossible to completely eliminate high voltage from the system.

147 The effects of this necessary compromise can be minimized by keeping the high voltage confined to as small as possible a part of the total system. This has been done by keeping the length of the spark plug lead very short, obtaining the high voltage energy for this lead from a small transformer, mounted on some satisfactory supporting part of the engine as close as possible to the plug. In practice the length of the high tension spark plug leads is less than one foot on most installations. A separate transformer is used for each plug.

148 Since a separate transformer is used for each spark plug, a carbon brush type distributor is used to distribute the output voltage of the magneto coil-breaker-condenser team to the various transformer coils on the engine. Also since the distributor finger and breaker cam must both be driven at 1/2 engine speed, it is advisable to put the breaker cam on the distributor shaft rather than the magnet shaft. Figure 21 shows schematically, the arrangement of parts when this has been done.

149 The primary of the transformer coil is fed low voltage surges of electricity from the distributor. The peak surge voltage is never in excess of 350 volts, and probably is nearer 200 on most installations. This means that the magneto, the harness, the distributor, and the leads from the harness to the engine cylinder coils have all been made virtually immune to the troubles associated with high voltage.

150 As a result, a low tension system could fly at 65,000 feet without pressurization or other special treatment of any kind. The system is also practically immune to the effects of moisture, since only the short high tension lead is directly vulnerable on this score. It is true that water in the system may have harmful mechanical effects such as rusting of ferrous materials, and mechanical softening and warping of insulation materials if subjected to prolonged and thorough wetting. Electrical interruption may then occur as a secondary, and greatly delayed consequence. Low tension systems have actually been operated on experimental test completely submerged in water.

151 High voltage troubles are now confined to the short leads at the plugs. Equipped with coupling nuts at each end these leads are easily kept water-tight at the ends, and easily replaced in the event a failure should occur.

152 The effects of capacitance are also minimized by this design. As a comparison: the capacitance of the average low tension spark plug lead is approximately 100 micro-micro-farads, as compared with a nominal capacitance of about 300 micro-micro-farads for a typical high tension system. Since the wires in a high tension system are of different lengths, these figures are approximations. However, the relation of these figures is borne out by practical experience, in which it has been found that a certain type of spark plug, operated on a low tension system, will show about one-third the erosion of an identical plug operated under

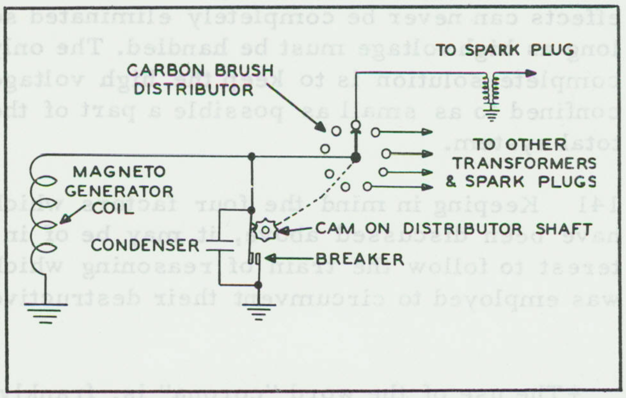


Figure 21 Schematic of Low Tension Ignition System

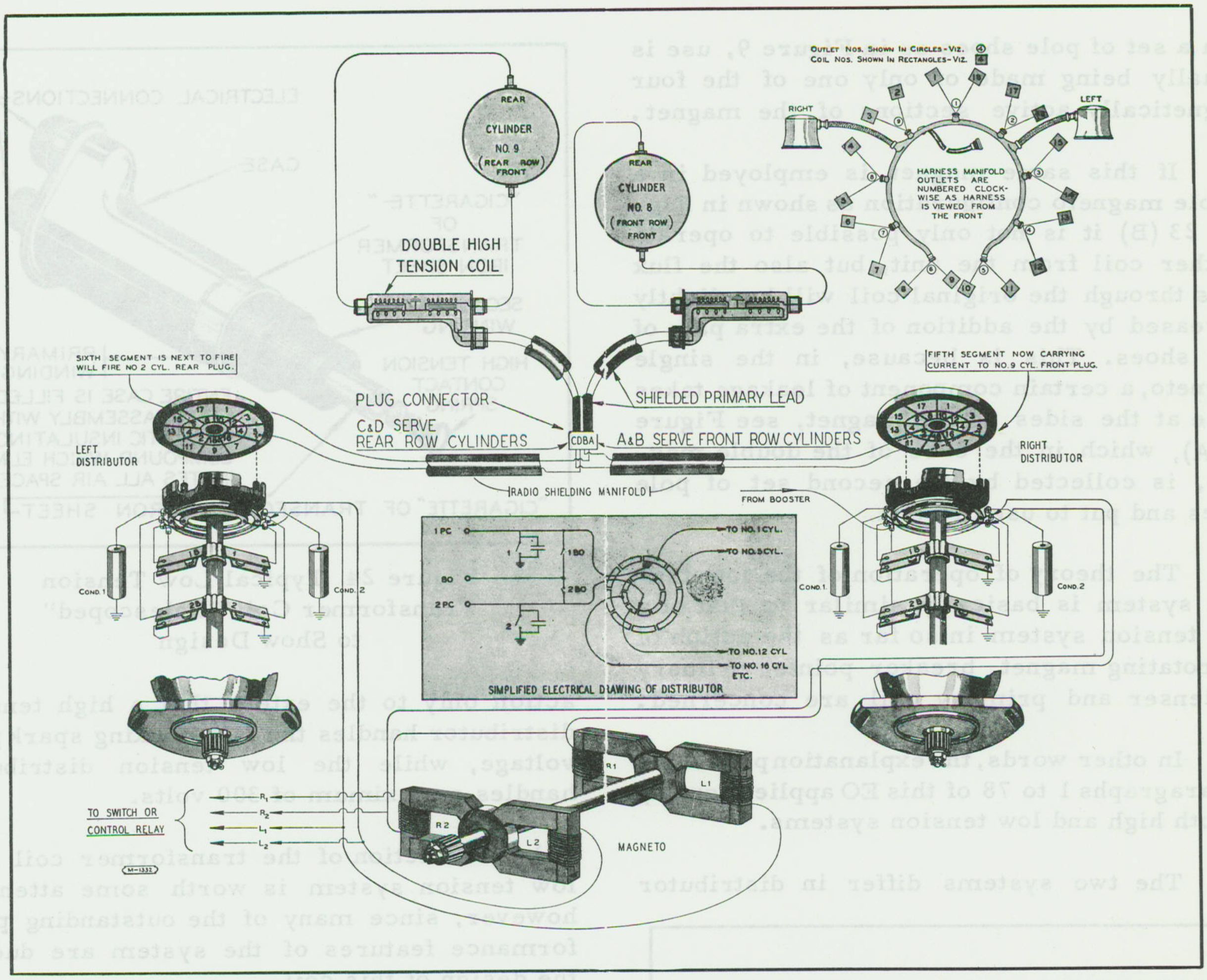


Figure 22 Schematic Diagram of Electrical and Magnetic Circuits

identical conditions with high tension ignition.

153 A schematic drawing of a complete low tension ignition system consisting of one double magneto, two distributors, radio shielded harness, transformer coils and spark plug leads is shown in Figure 22. This system, which is for use on an 18 cylinder engine, employs four separate 9-cylinder circuits of the type described in connection with Figure 21.

154 One of these circuits fires the front spark plugs in the front row of engine cylinders, another the rear plugs in the front row; another the front plugs in the rear row, and the remaining circuit, the rear plugs in the rear row. Each circuit consists of a magneto generator coil, breaker, condenser, breaker cam and distributor. Each spark plug on the engine is provided with a separate transformer coil, but on this particular system the two transformers for each cylinder are placed together in a single case for convenience in installation.

155 The double magneto circuit pictured in Figure 22 is of interest, and is worth commenting upon here, since this design is quite widely used in both low tension and high tension systems. Its operation is based upon the properties of the four pole magnet which was introduced in Figure 8.

156 When a magnet of this design is installed

with a set of pole shoes as in Figure 9, use is actually being made of only one of the four magnetically active sections of the magnet.

157 If this same magnet is employed in a double magneto configuration as shown in Figure 23 (B) it is not only possible to operate another coil from the unit, but also the flux lines through the original coil will be slightly increased by the addition of the extra pair of pole shoes. This is because, in the single magneto, a certain component of leakage takes place at the sides of the magnet, see Figure 23 (A), which in the case of the double magneto, is collected by the second set of pole shoes and put to useful work.

158 The theory of operation of the low tension system is basically similar to that of a high tension system in so far as the action of the rotating magnet, breaker points, primary condenser and primary coil are concerned.

159 In other words, the explanation presented in paragraphs 1 to 78 of this EO applies equally to both high and low tension systems.

160 The two systems differ in distributor action only to the extent that a high tension distributor handles the full working spark plug voltage, while the low tension distributor handles a maximum of 300 volts.

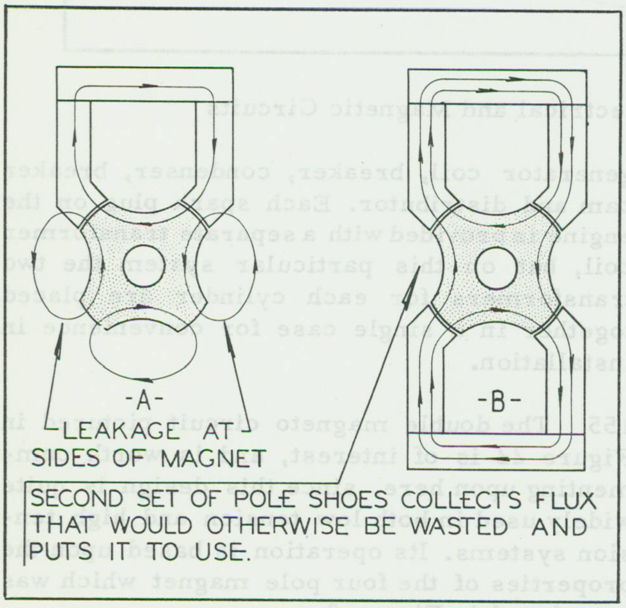


Figure 23 Magnetic Circuit of Double Magneto

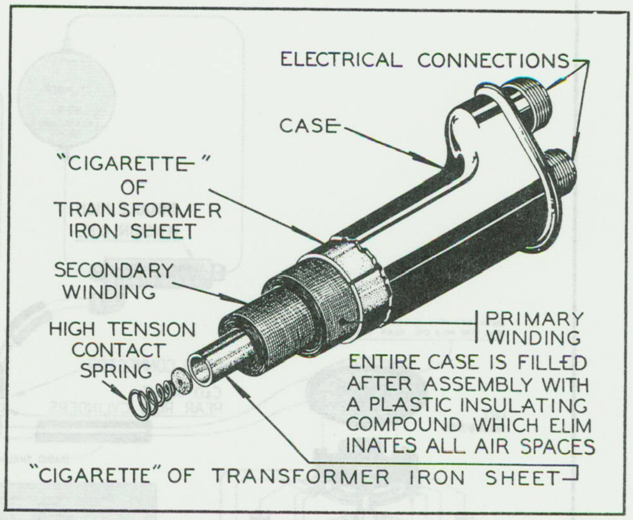


Figure 24 Typical Low Tension Transformer Coil "Telescoped" to Show Design

161 The action of the transformer coil in a low tension system is worth some attention however, since many of the outstanding performance features of the system are due to the design of this coil.

162 Basically the coil is a transformer, consisting of a primary and secondary winding. Figure 24 shows a typical design of low tension transformer coil "telescoped" to clarify this construction.

163 While there are a variety of executions of transformer coils in use on low tension systems, three basic characteristics are common to all designs:-

(a) Small size

(b) Light weight

(c) A primary winding having a resistance several times that of the magneto generator coil winding.

164 The requirements for small size and light weight are dictated primarily by the conditions of the engine installation. However, these physical characteristics of the unit also influence the electrical performance in a favourable manner, enabling the transformer to deliver a "hot", short duration, spark, with an initial rate of rise of voltage which is about four times that of a conventional high tension ignition system.. More will be said concerning the purpose of the rather high resistance primary.

165 While the process by which the transformer coil accomplishes its purpose is not actually a simple one, the following explanation is sufficiently accurate for the purposes of this Engineering Order.

166 At the instant of opening of the breaker contacts which are connected across the magneto generator coil, a rapid flux change takes place in the magneto generator coil core, causing a rapid rise of voltage in this coil. As has already been pointed out, it is the primary condenser which actually brings the current to a stop when the breaker opens.

167 Now the primary condenser and magneto generator coil of a low tension system are connected through the distributor directly across the primary winding of the transformer coil, see Figure 25. Therefore during the time that the voltage across the primary condenser is rising, as the breaker points open, the natural tendency is for current to start flowing out through the distributor and through the primary of the transformer coil.

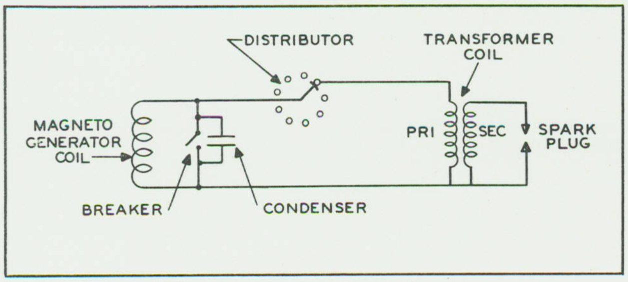


Figure 25 Circuit of Low Tension System at Instant Breaker Opens

168 When this condition has been achieved, the situation exists of a primary condenser charged to nearly 200 volts, connected across the primary of the transformer. The result is a very rapid rise of current in the primary, accompanied by a very rapid change in flux linkages in both coils. The rapid change in flux linkages in the secondary induces the voltage which fires the spark plug. As soon as the spark plug gap has been "broken down", current also starts to flow in the secondary.

169 As previously stated, the transformer of the low tension system is purposely designed to have an appreciable resistance in the primary winding (5 ohms or over). When the secondary current increases, the resistance of the primary prevents a corresponding increase of current in that winding, so that as soon as the voltage originally generated in the secondary has been lowered by the flow of secondary current, the spark is extinguished and no further action takes place. From this it will be clear that the duration of the spark in a high tension system is several times that of a comparable low tension system. After the secondary current has stopped, the energy stored in the form of a charge in the primary condenser continues to drain away at a rather slow rate through the primary of the transformer coil.

170 The rather high primary resistance, (usually five ohms or more) which is characteristic of all low tension transformer coils, helps to bring the primary current to a stop after the spark has been produced. If this were not done, the primary current would continue to flow through the circuit until the distributor finger carbon brush reached the edge of the distributor contact segment, at which time the current would be stopped by the interruption of the contact as the carbon brush moved off the segment. This would cause pitting and burning of the distributor segments.

171 Thus it should be clear that the spark voltage is produced by the growth of a magnetic field in the transformer and not by the collapse of the field as is the case in conventional igni-

tion coils. This fact sometimes raises the question as to why the subsequent collapse or decay of the field in the transformer does not produce a second spark at the spark plug.

172 The reason for this is that the rate of decay of the magnetic field of the transformer is determined by the rate of decay of the primary current. It has already been pointed out that the primary current results from the discharge of the primary condenser and that this current tapers off at a rather slow rate after the secondary current stops. Since the rate of decay of the magnetic field is the same as that of the primary current, it is too slow to produce enough voltage for a second spark at the plug.