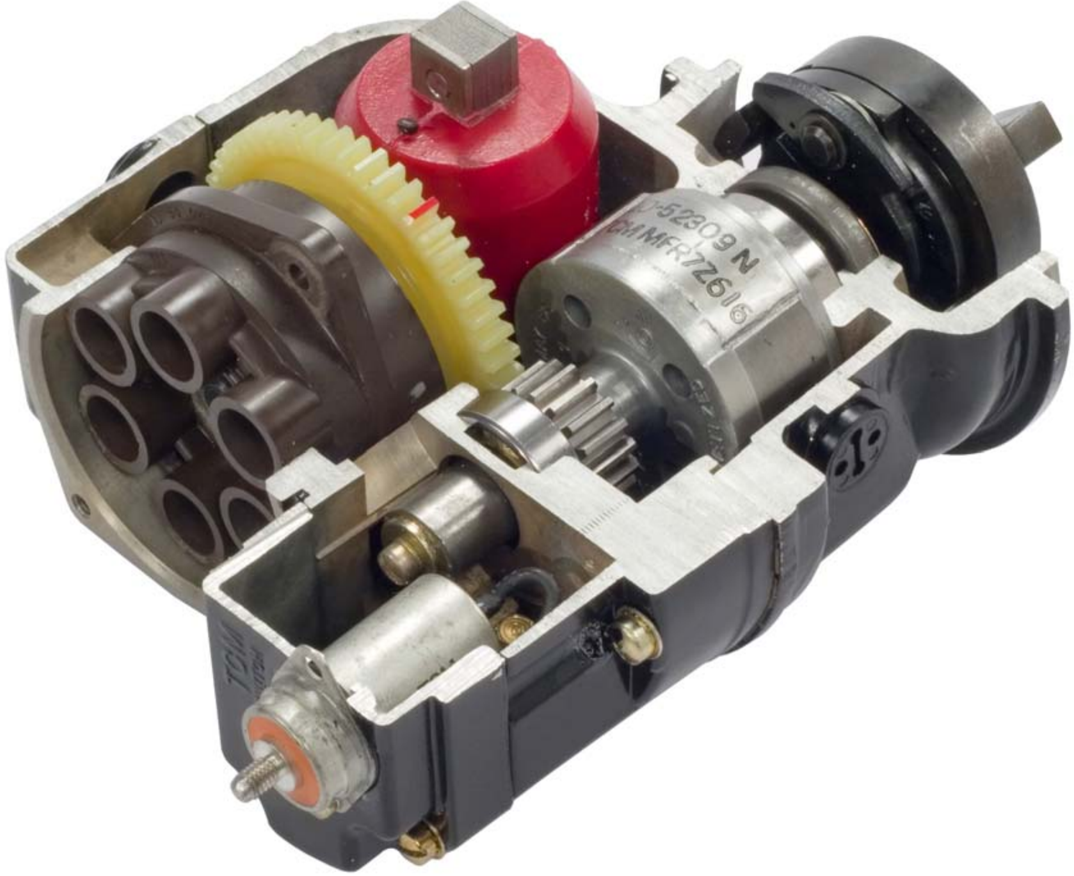
The Aircraft Magneto



CONTINENTAL MOTORS

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The Aircraft Magneto

Ignition Systems Principles

Principles of the Aircraft Magneto

I. Magnets and Flux Lines

The operation of TCM 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.

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 comprise the magnetic field.

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.

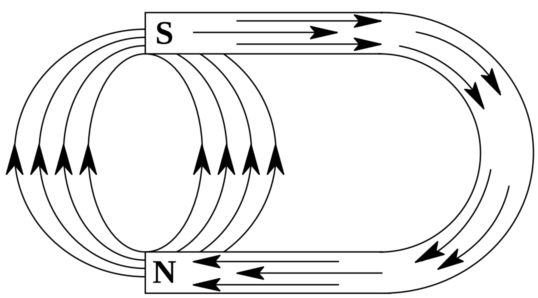

Figure 1

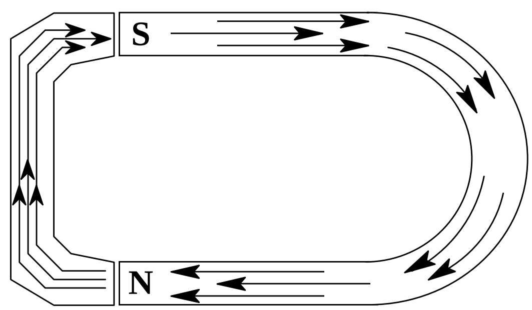

Figure 2.

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.

This can be seen in Figure 2 where the "lines" of flux comprising 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 later in this text.

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. The permanent magnet is made of 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 electromagnet. 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.

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.

II. Generating an Induced Voltage

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.

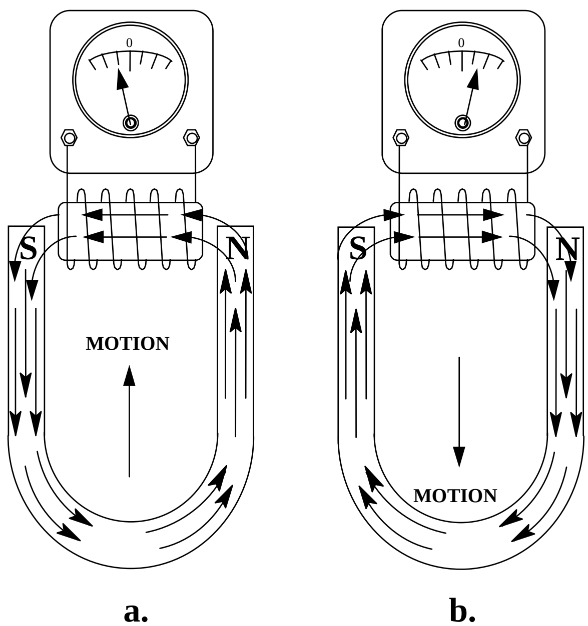

Figure 3. Current Direction

The lines of flux of the magnet, when in 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. Accordingly, if six lines of flux pass through six turns of a coil, there are thirty-six flux linkages, and so on.

If the magnet is brought up from a remote position to the position shown in Figure 3a, 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.

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 removed back away from the coil as shown in Figure 3b, 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.

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.

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.

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 some early makes of magnetos. TCM Aircraft Magnetos, however, still employ their original design of having the magnet rotate to produce the change in flux linkages.

III. The Effect of Current in the Coil of a Generator

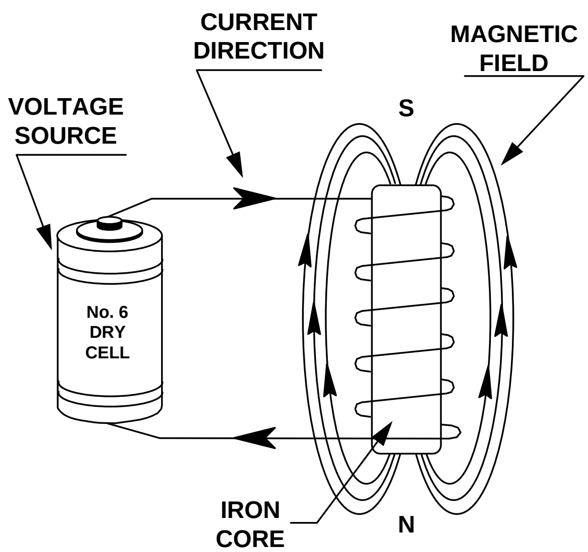

Figure 4. Current Direction

Nearly everyone is familiar with the common electromagnet 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 electromagnet in which the energizing voltage is obtained from a dry cell.

The magnetic field of the electromagnet 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 electromagnet, the field will disappear. We might say 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".

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

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

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 text.

This will be clearer if we refer 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).

If we performed the experiment shown in Figure 3, 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 the picture, we would find 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.

If we applied the "right hand rule"* to this current, we would find that the field which it sets up opposes the field which repels the field of the magnet and tries to push the latter away.

*__NOTE:__ The *"Right Hand Rule"* 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.

While the magnet is being moved up toward the coil as shown in Figure 3a, 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.

When the magnet is moving away as shown in Figure 3b, 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 magnetic 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.

To sum up our understanding of what is happening in these experiments we can 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 ease 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.

IV. The Effect of Interrupting the Current

Suppose we set up the apparatus 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.

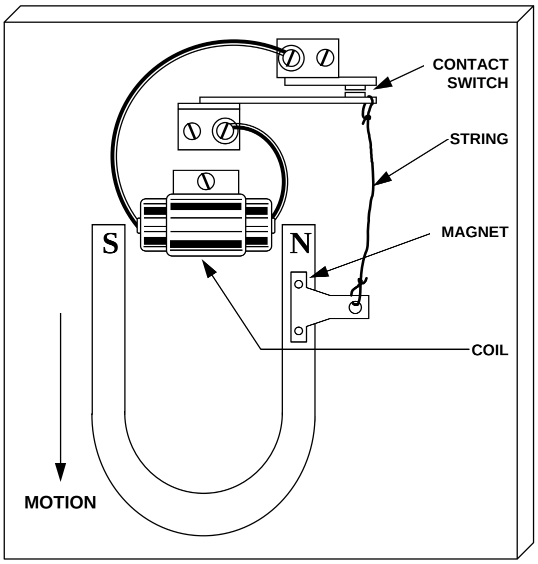

Figure 5

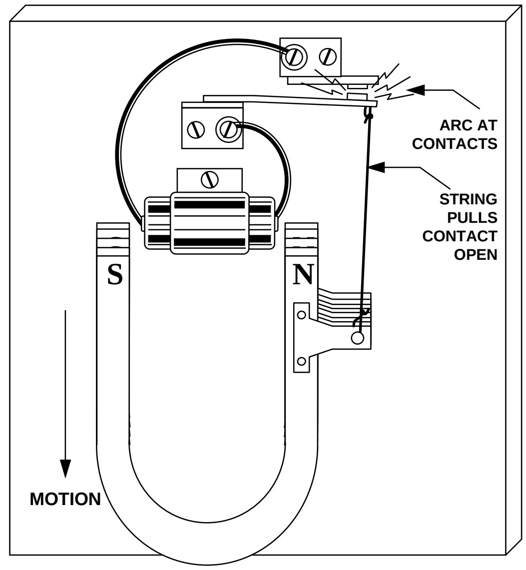

Figure 6

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 electromagnet and try to prevent the flux in the coil core from decreasing. In other words, the coil will, by its electromagnetic action, keep most of the original amount of flux in the coil core even though the magnet has moved away from the core.

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 the coil core, most of the core flux being produced by the electromagnetic action of the current in the coil itself.

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 electromagnet and thus the field of flux which was being held in the coil core by this electromagnetic 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, Figure 6.

Just before the switch opens, the electromagnetic action of the coil is retaining most of the original field in the coil. 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. 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.

V. The Requirements for Aircraft Ignition

Actually the device pictured in Figure 5 is a form of magneto. Some old fashioned stationary gasoline engines employed an ignition system very similar in principle to this simple demonstration apparatus. Such engines had 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. 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 text. 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.

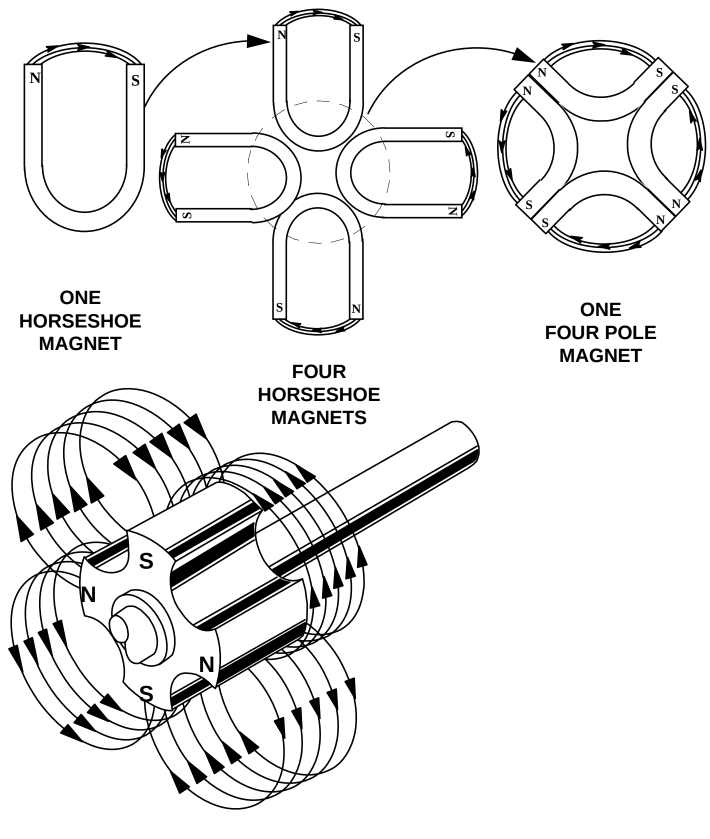

Figure 7. Four Pole Rotating Magnet

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.

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.

Therefore, we must modify this arrangement 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 text.

VI. Application of Fundamental Principles

The properties of the common horseshoe magnet are present in the rotating magnet of TCM Aircraft Magnetos. An illustration of a four-pole rotating magnet is shown in Figure 7. 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.

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

The pole shoes (D) and their extensions (E), together with the coil core (C) as shown in Figure 8, 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 the positions shown in Figure 8. This is known as the "full register" position of the rotating magnet.

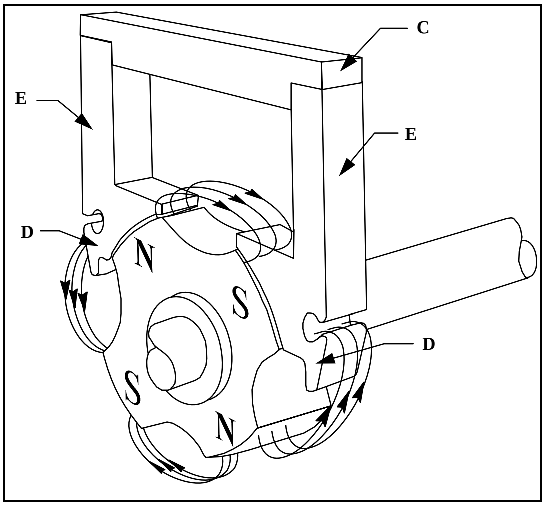

Figure 8. *"Full Register"* Position

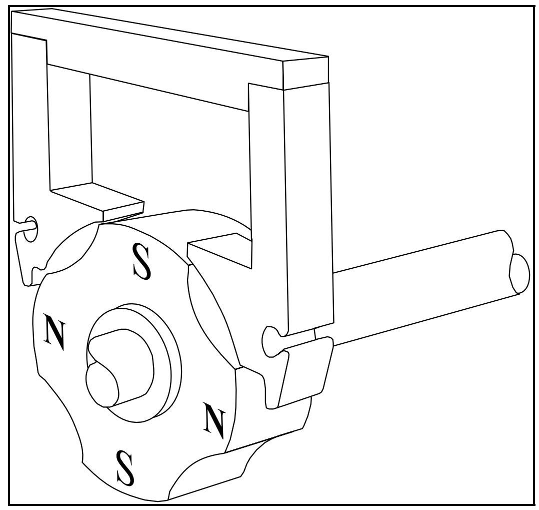

Figure 9. *"Neutral"* Position

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 9), 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.

The reader should note that no primary or secondary windings are shown on the coil core in Figures 6-8 & 9. These have been omitted to permit a clearer description of the magnetic action. By first observing the action without the windings, we can later obtain a better understanding of their function in the magneto.

If the magnet shown in Figures 6-8 and 9 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.

Although the pictures 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 in our discussion. Such a graph, showing number of lines of flux plotted against magnet position in degrees, is shown in Figure 10. 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.

The curve in Figure 10 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.

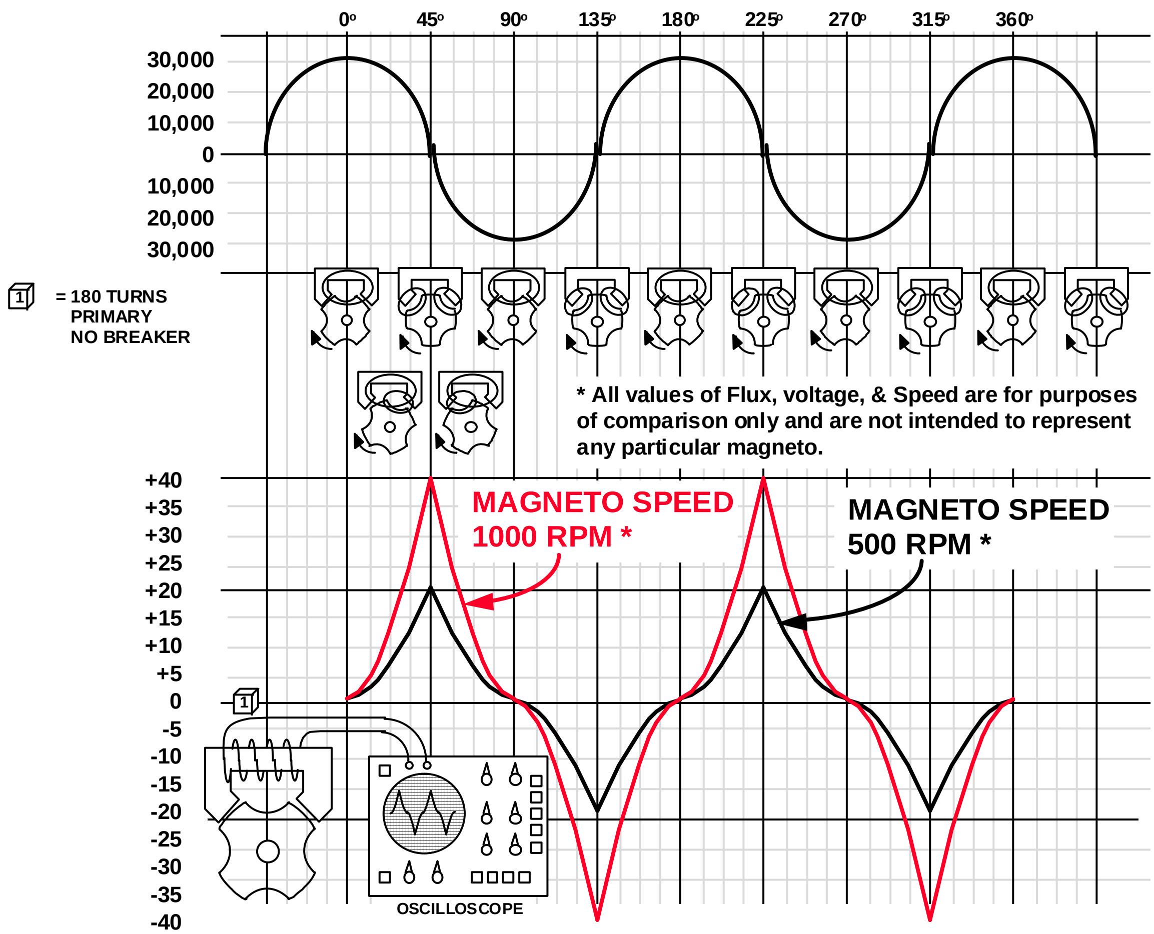

Figure 10. Static Flux Curve and Voltages Generated by Rotating Four Pole Magneto

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.

For example, suppose there are 32,000 lines of *flux* passing through the coil core in a direction from left to right (see Figure 10) when the magnet is in the full register position indicated by "zero degrees" of the graph.

If we turn the magnet clockwise, the *flux* value will decrease along the curve indicated by the graph, until at the 45° position we have zero *flux* in the coil core. Thus in 45° of rotation of the magnet we have produces a *flux* change of 32,000 lines in the coil core.

If we continue to turn the magnet, the *flux* through the coil core will increase again, but 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 we have reached the 90° position of the magnet we find (see graph) that we have 32,000 lines of flux in the coil core again, but this time of the opposite direction,

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.

If we continue to turn the magnet in a clockwise direction, 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.

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

In the same way we have 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.

From the above description it should be clear that the four pole magnet provides four flux changes for each complete revolution thru 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.

Having now obtained an elementary understanding of how the static flux curve (Figure 10) is produced, let us see what the effect is when a primary winding is installed on the coil core. We will not connect the breaker points into the circuit just yet, since we wish first to observe the open-circuit voltage of the primary without the breaker installed.

The primary winding is made up of, let us say, 180 turns of heavy, insulated copper wire, and is wound directly around the coil core. See sketch, Figure 10. 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.

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.

We can prove this by connecting an oscilloscope across the primary winding and measuring its open circuit voltage while the magnet is being rotated. If we turn the magnet at 500 RPM we will obtain a voltage curve something like that shown in the solid line in the lower part of Figure 10. If we drive the magnet at 1000 RPM, we will obtain a curve like the gray line shown in Figure 10, which, since the rate of change of flux linkages has been doubled (speed of magnet doubled) gives us, for all practical purposes, twice as much voltage as we got at 500 RPM.

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.

While the voltage values shown in Figure 10 are not presented as being actual values for the open circuit primary voltage of any particular magneto, they are never-the-less 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!

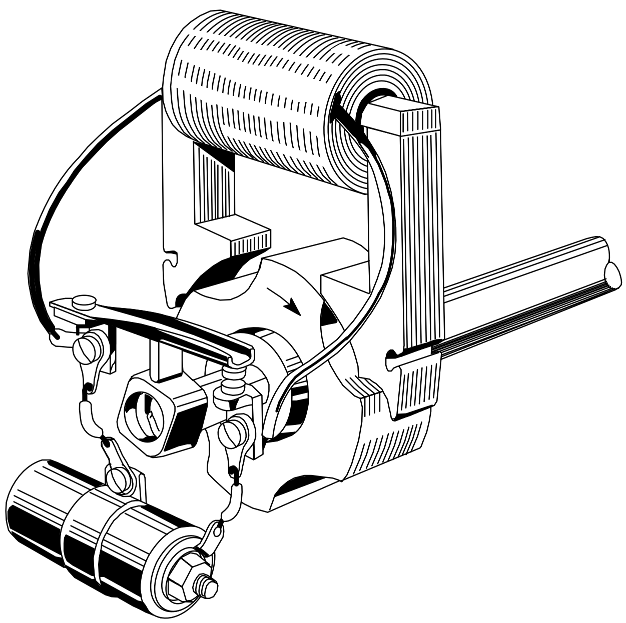

Figure 11. Breaker Points and Condenser to Interrupt Primary Current

Further, even if we could work out the difficulties of getting proper voltage, it would be impossible to time such a unit to an engine. This is because the slope of the voltage curve shown in Figure 10 is quite gradual, and depends on engine speed. As an example, suppose the voltage values shown in Figure 10 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 10. But 12 volts is not reached at the same position of the magnet on the 1000 RPM curve as it is on the 500 RPM curve.

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.

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

However, you will recall 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.

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 attenuated.

This can be done by connecting a condenser across the contact points of the breaker as shown in Figure 11. The condenser prevents arcing of the contacts of the breaker as they arc being opened, by allowing a "by-pass route" for the current 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.

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 11.

With the breaker points, cam and condenser added to the circuit as in Figure 11, the action which takes place when the magnet is turned will be somewhat different from that portrayed by Figure 10 for a magnet and coil with no breaker points.

The action of the device shown in Figure 11 is depicted by the graph curves shown in Figure 12. At the top of the Figure 12 the original static flux curve of the magneto is shown for reference purposes, together with degrees of magnet rotation.

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 position of the magnet. Note also that the point opening and point closing intervals are approximately equal.

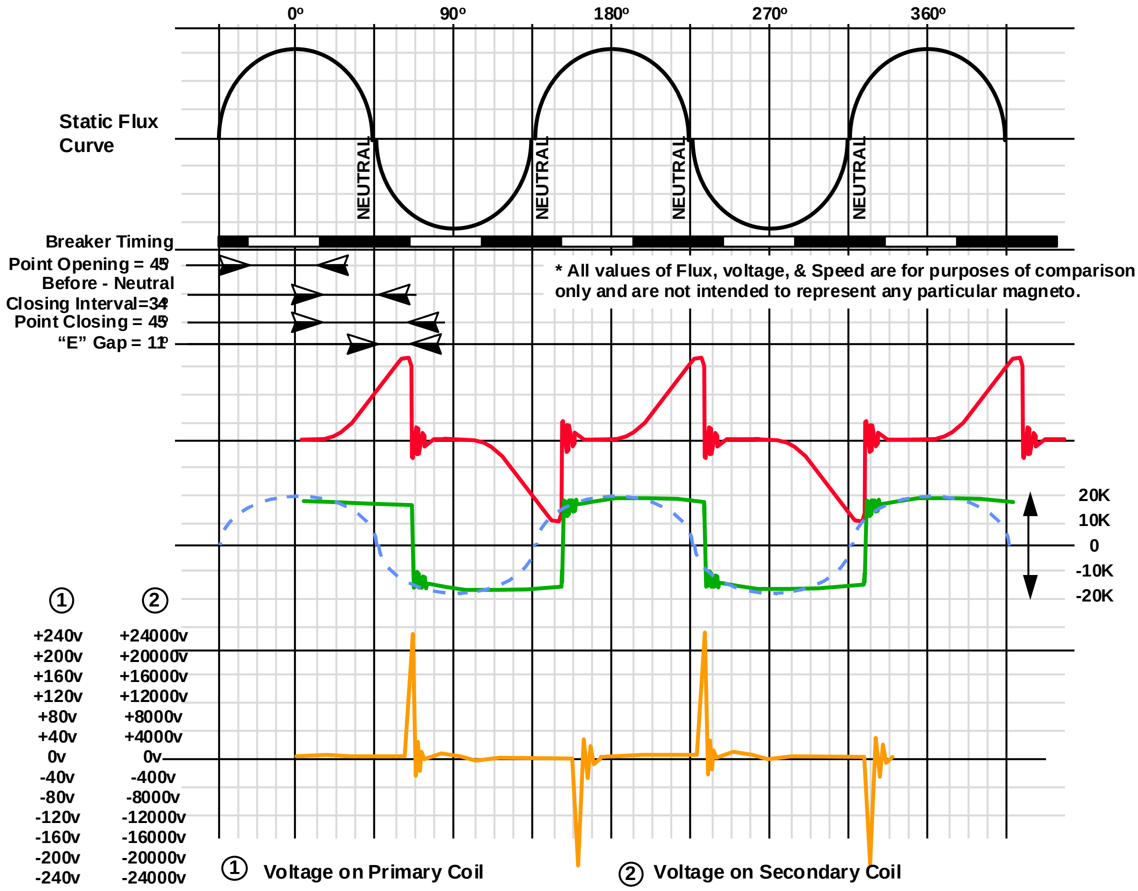

Figure 12. Operating Circuit Waveforms of a Magneto

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

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 12). This decrease or change in flux linkages induces a current in the primary winding, as depicted by the curve marked "Primary Current" in Figure 12.

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.

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 12. 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 direction as represented by the dotted "static flux" curve. However, the electromagnetic 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 solid curve line which is known as the "resultant flux" curve.

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.

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.

The contact points, when opened, function with the condenser as described in connection with Figure 11, 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 12) 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 12. 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 6- 11 and 12), now can produce 12 times this much voltage.

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 12) complies with the requirement for precise timing of the spark in an engine cylinder.

VII. The High Tension Ignition System

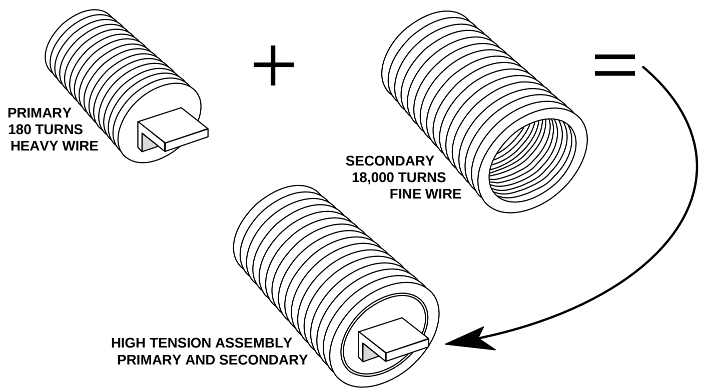

Figure 13. Evolution of Coil for High Tension Magneto

The most common way in which the rapid flux change discussed in connection with Figure 12 can be made to produce the necessary high voltage for firing a spark plug is to remove the coil from the assembly shown in Figure 11 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.

Upon reassembling the unit (see Figure 13) we would find that since the secondary contains 100 times as many turns as the primary, and, since the primary was capable of producing 240 volts (Figure 12) the secondary is capable of producing 24,000 volts. This type of coil is used with minor variations in all conventional high tension magnetos.

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 12, except that the voltage values would be multiplied by 100. (See ② Figure 12.)

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.

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 electromagnetic effect of this current flowing in the secondary coil. As has already been pointed out in connection with Figures 6-5, and 6-6 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.

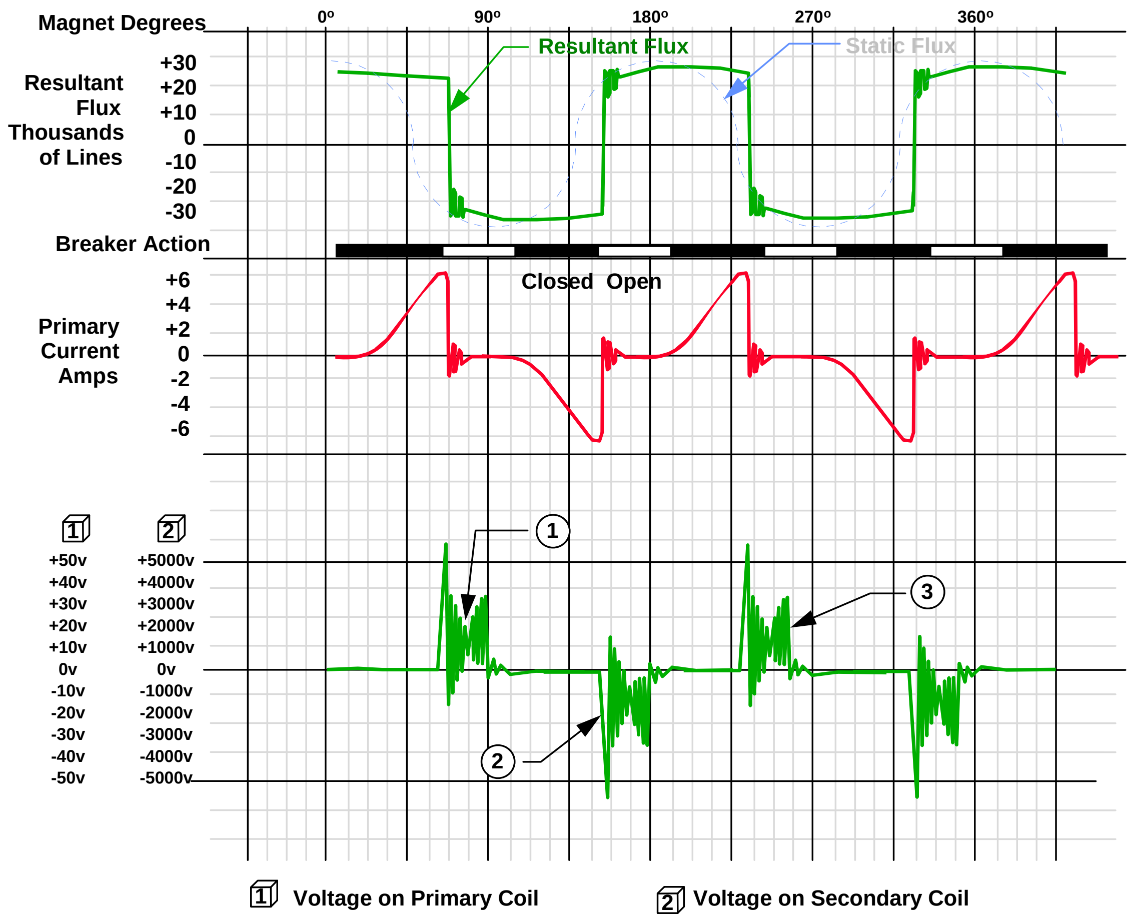

Figure 14. Waveform Representation when Firing a Spark Plug in Engine Cylinder

Figure 14 shows graphically the sequence of events which occurs in the magneto when the latter is running in a normal manner on an engine.

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 12. Also the rise of primary and secondary voltage takes place when the breaker opens in the same manner as previously outlined.

* 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.

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 14, 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.

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 14. During the time it takes for the spark to completely discharge, current is flowing in the secondary winding.

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.

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 14 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 electromagnetic 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.

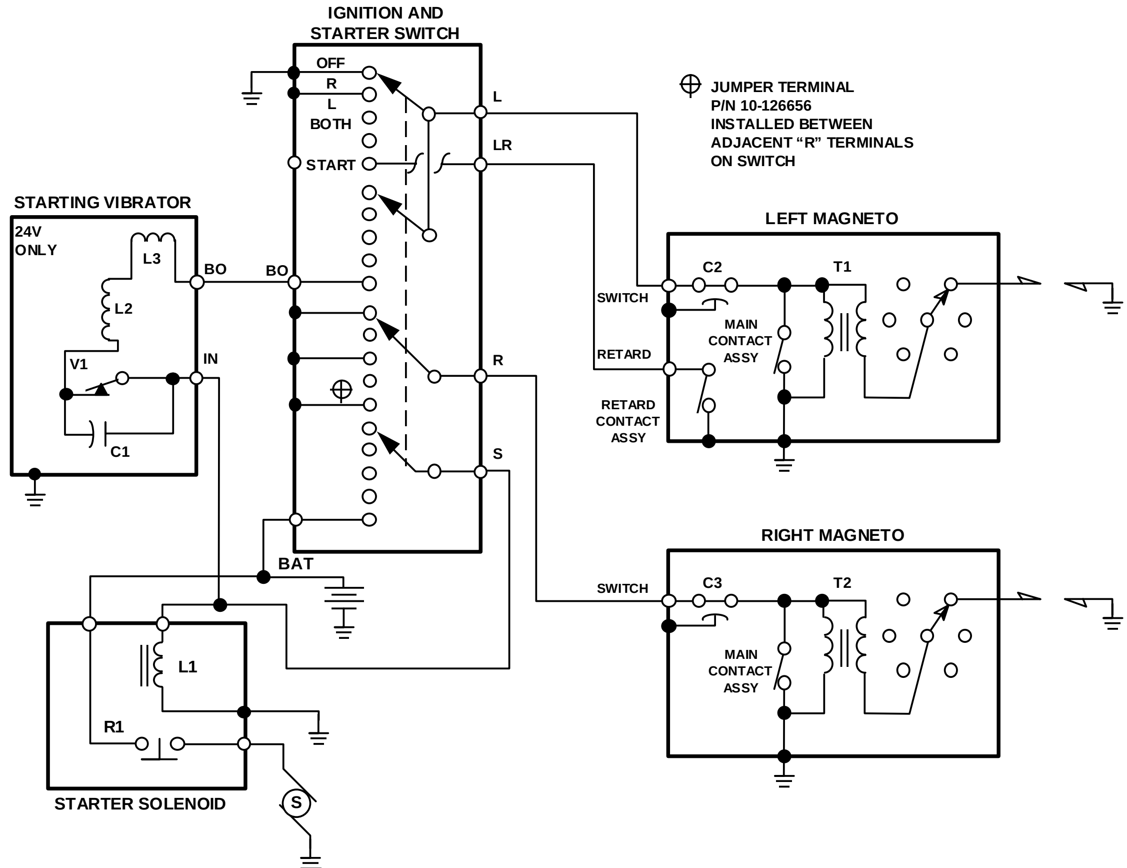

Figure 15. Schematic Diagram of Magneto Circuit and Starting Vibrator

Figure 15 illustrates a complete high tension ignition system consisting of two magnetos, radio shield harness, spark plugs, switch and a starting vibrator.

One end of the 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.

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

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.

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 insures proper distribution of the high tension current to the spark plugs in accordance with the firing order of the particular engine.

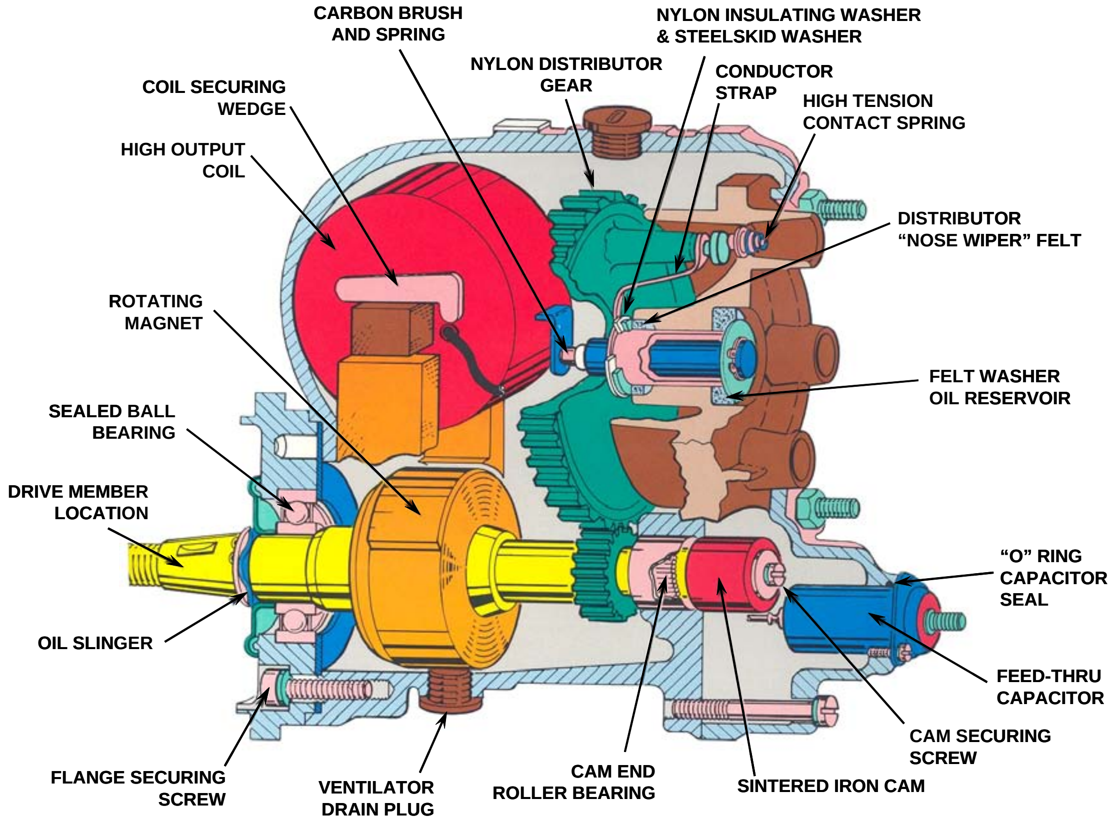

Figure 16. The TCM S-1200 Series Magneto Cutaway Diagram

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 usually half the number of cylinders on the engine divided by the number of poles on the rotating magnet.

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.

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 150 RPM. This is known as the "coming-in" speed of the magneto.

When conditions make it impossible to rotate the engine crankshaft fast enough to produce the "coming-in" speed of the magneto, magneto timing must be altered and input energy boosted for starting purposes. This may be accomplished in the form of an integral impulse coupling or an external battery-powered starting vibrator. In the former, flyweight pawls on a spring-loaded cam catch stop pins until tripped by rotation of the body-thus storing and rapidly releasing mechanical energy and retarding timing. In the latter case, the vibrator points in the starting vibrator serve to supply an interrupted or pulsating current to the primary of the ignition system. Grounded until the retard contacts open, this pulsating current is stepped up by transformer action in the magneto coil to provide the required voltage for firing the spark plug.

In as much as a magneto is a form of high frequency generator, radiation emanating from it during operation will cause interference with radio reception in the airplane 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.

If the high tension cables and switch wire of the magneto are unshielded, they can serve as antenna from which these uncontrolled frequencies are radiated. Since the receiving aerial on the airplane 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 plane.

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 radiation of noise from reaching the receiving aerial.

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