8

IGNITION THEORY

INTRODUCTION

If you hold a ball in front of you, and drop it, it will fall to the floor. Every time. Although you can calculate the speed at which it will fall, and the force with which it will hit the floor, and you know that it falls because of gravity, no one really knows why. Gravity is one of the fundamental forces of nature. We know it's there, we can calculates its effects on objects, so we just accept it

If you hold a magnet in one hand and a coil of wire in the other, and wave the magnet close to the wire, electrical current will flow through the wire. If you hold the magnet still, and don't move it with respect to the wire, no current flow will be induced. No one knows why. This is another of the fundamental properties of nature.

If you run a current through a coil of wire, it will create a magnetic field around the wire. No one knows why, it just does. If you increase the current, the magnetic field will increase. If you decrease the current, the magnetic field will decrease. If you alternately increase and decrease the current, the magnetic field will also alternately increase and decrease.

A magnetic field that alternately increases and decreases looks pretty much like the magnetic field surrounding a permanent magnet that is moving back and forth. If you place a second coil of wire (secondary) near the coil of wire with the fluctuating magnetic field (primary), the second coil of wire sees the fluctuating magnetic field as if it were seeing a moving magnet, and current will be induced into it.

This, then, in a nutshell, is how a transformer works. In **figure 1** below, I show a simple transformer circuit. By applying a varying current to the primary winding, a varying magnetic field is produced, which is coupled over to the secondary windings. This in turn produces a varying current in the secondary, which will be fed to the load.

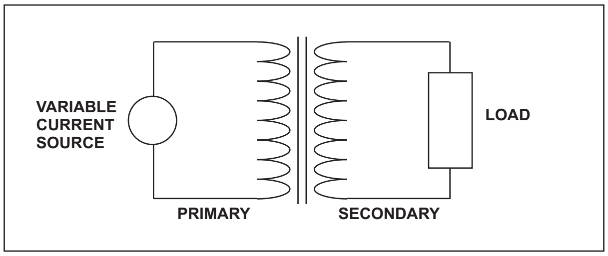

FIGURE 1

A variable current source is of interest, for the most part, only to laboratory technicians. For the rest of us, we are used to thinking in terms of a voltage source - 120 VAC from the wall mains, or 12 volts DC from a battery. So, instead of a varying current source, lets redraw **figure 1** as shown below in **figure 2**.

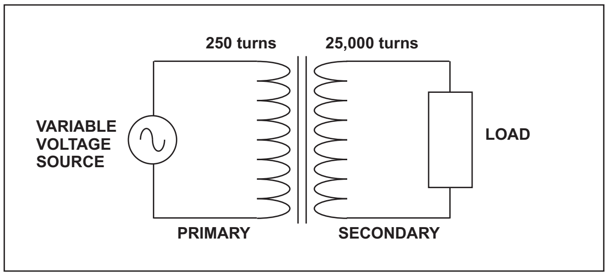

FIGURE 2

Notice that I have added the number of turns of wire in each of the transformer windings. 250 turns in the primary, and 25,000 turns in the secondary, i.e., the transformer has a turns ratio of 100:1. This illustrates another property of transformers, in that the voltage out of the secondary will be a multiple of the voltage applied to the primary, in this case, 100 times as much. In **figure 2**, if we apply 12 volts to the primary, we will get 1200 volts out of the secondary. Of course, as with anything else in life, you don't get something for nothing. You do multiply the voltage, but the current is divided by the same ratio. 12 volts @ 5 amps on the primary will give 1200 volts @ 0.005 amps from the secondary.

Suppose, though, that instead of using a varying voltage source, I connected the primary to a steady voltage source, such as an automobile battery? In this instance, no current would be delivered to the secondary, as a moving magnetic field is required, and a constant current does not provide a moving magnetic field. With that in mind, it may be surprising to learn that the ignition coil in your car is nothing more than a simple transformer. How can that be, if we just said that a transformer won't work with a steady current source, and the battery in a car is a steady current source? To answer that, look at **figure 3** below.

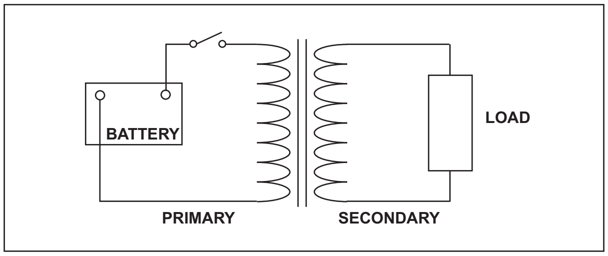

FIGURE 3

In this figure, the varying current source has been replaced with a battery and a switch. With the switch open, there is no current flowing in the primary. When the switch is first closed, primary current goes from zero to a maximum value very rapidly, (rapid, but not instantaneous), producing a very rapidly rising magnetic field. This “spike” of current in the primary produces a corresponding spike of current in the secondary. Likewise, when the switch is opened again, the maximum current primary current flow once again returns to zero, in a rapidly changing manner, and a corresponding current change takes place in the secondary.

With the exception of the condenser, **figure 3** is the diagram of the ignition system in a car, the switch being the points, and the transformer being the coil. The turns ratio of 100:1 is also typical of an automotive ignition coil, which means that the most voltage available from the secondary would be 1200 volts, not nearly enough to produce a spark at the plugs, and certainly less than the 20,000 - 30,000 volts we expect. So, where does the extra voltage come from? To understand that, we have to dig a little deeper into theory, and examine inductors.

INDUCTORS

What is an inductor? An inductor is nothing more than a coil of wire. The wire may be wrapped around an iron core, wrapped around an air core, or wrapped around another coil of wire. In our ignition coils, it is the latter. The primary coil is wrapped around the secondary coil (the primary coil, carrying the most current, gets the hottest, so by placing it on the outside of the secondary, near the surface of the case, heat dissipation is maximized for the primary).

An inductor has an interesting property, in that it tends to resist a change in current. If you apply voltage to an inductor that has no current flowing - by closing a switch, for example - the inductor presents a very high impedance to the current flow (impedance is just a fancy word for resistance, and is used mostly when talking about inductive or condenser circuits). After a period of time, the inductor presents no more impedance to current flow than the resistance of the wire in the coil. Coincident with the buildup of current in the coil, there is also a build up of a magnetic field around the coil.

What happens now if the switch is opened? As stated above, an inductor tends to resist a change in current, so it will try to maintain the same current as it had before the switch was opened. It does this by means of the magnetic field collapsing. As the field collapses, it cuts through winding of the inductor, and creates its own current flow. Initially, the current flow is just the same as before the switch was opened, decreasing to zero as the field decays.

Figure 4, top right, shows the current in the inductor when the switch is closed and when it is opened. You can see the rise and fall of the current is not instantaneous.

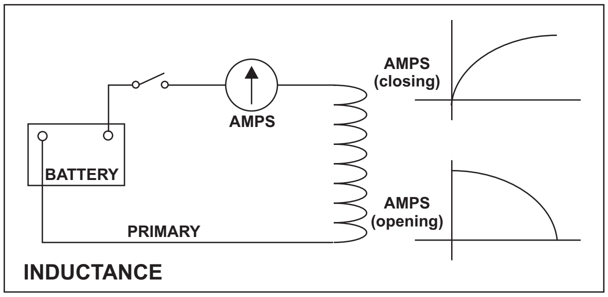

FIGURE 4

This, though, raises an interesting question: where does the current go if the switch is open? Answer: the current will arc across the switch contacts. Which brings another question: how does the arc form, if there is only 12 volts on the coil terminals? Answer: if there is no good path for the current, the voltage on the coil will rise to a quite high value, as it attempts to maintain the current flow. On an automobile coil, the voltage on the coil primary will reach 250 volts or more as it tries to establish an arc. This is not good for the points, but this phenomenon is quite good on the secondary side.

I stated earlier that an inductor resisted a change in current. That is true only if the current change is imposed by a current source (or voltage source). If the coil is exposed to an external magnetic field, the current change is instantaneous. When the field in the primary of the ignition coil collapses because the switch (points) has been opened, there is an instant increase in current in the secondary. Or there would be if the current had anyplace to go. Until an arc is established across the spark plug, no current flow can take place. Just like the primary, however, the output voltage of the secondary will rise to a quite high value as it tries to establish current flow. As much as 20,000 - 30,000 volts - just the right amount to fire the plugs!

The secondary won’t produce that much voltage though, unless the decay of the primary field is very rapid. A slow decay will not produce a high voltage. To ensure a rapid decay, a condenser is used. The condenser also has another valuable purpose, in that it also protects the points from burning as a result of the primary arcing. The condenser basically prevents an arc from forming. So, what is a condenser?

CONDENSERS

A condenser (often called a capacitor, and almost always called a capacitor in any application other than the ignition circuit in an automobile) is nothing more than two conductive plates separated from each other by an insulating material. Usually, the two plate are long, thin, strips of foil, separated by long, thin strips of a paper-like insulating material, and all three strips are then rolled up like a roll of toilet paper, and packaged in some sort of protective material. See **photo 1** for a view of a disassembled ignition condenser.

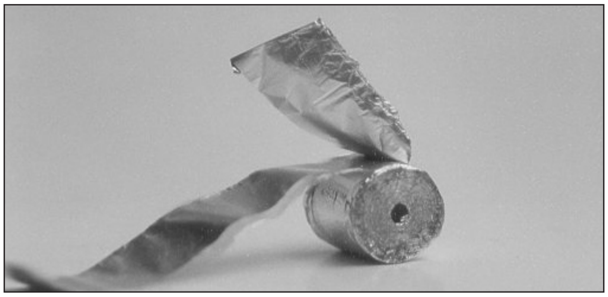

PHOTO 1

In operation, a condenser operates much like a battery. If you apply a voltage to it, it will charge up to the applied voltage, and hold that charge after the voltage is removed. The charge will remain on the condenser until a discharge current path is provided, either by placing a load on the condenser, or by leakage current through the atmosphere.

Whereas an inductor tends to resist a change in current, a capacitor tends to resist a change in voltage. If a voltage is applied to a discharged condenser, the condenser will initially look like a short circuit to the voltage source. The voltage across the condenser terminals prior to placement of the voltage source was zero; the condenser will try to maintain the zero voltage by absorbing as much of the current as it can. In time, the voltage across the terminals will equalize to the applied voltage, the condenser will be fully charged, and no more current will flow.

If a load is applied to a fully charged condenser, the full voltage of the condenser charge will be applied to the load, and the maximum current will flow through the load as the condenser tries to maintain its charged voltage. In time, the charge will be dissipated, and the voltage will drop to zero

The operation of a condenser circuit is shown in **figure 5** below. When the switch is placed in position A, voltage is applied to the condenser, electrons pile up on the negative side of the condenser, positive charges (holes) pile up on the positive side, and the voltage rises on the condenser terminals as shown in the top right of **figure 5**. If the switch is then placed in position B, the condenser will discharge, the electrons and holes will equalize on both sides of the condenser, and the voltage curve shown in the bottom right of **figure 5** is produced. Flip the switch back to "A" and the process stars all over again.

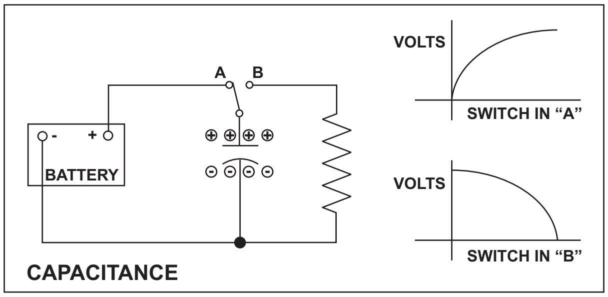

FIGURE 5

Now, it's time to put these components together into an ignition circuit, and see it works. **Figure 6** below illustrates a typical ignition set up.

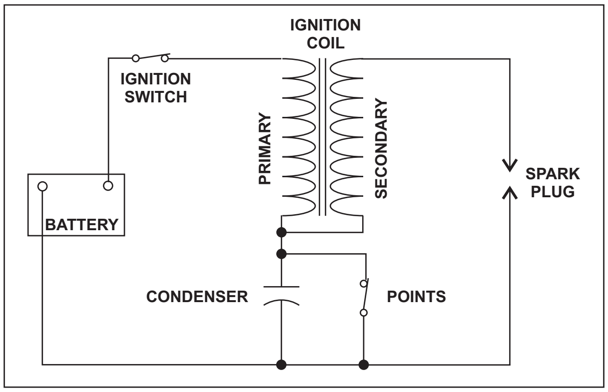

FIGURE 6

To start our analysis, assume the ignition key is on, and the points are closed. Current will flow through the inductor (the coil primary), rising slowly as shown previously. As the current builds up, so does the magnetic field surrounding the primary. As the engine rotates, the points will open, interrupting the current path through the primary. The primary, being an inductor, will try to maintain the current flow as the magnetic field collapses.

Without the condenser, the only path for the current is through the points, by means of an arc. This path is not a very good path, though, and the decay of the inductor current will be rather slow. Enter the condenser. While the points were closed, the condenser was shorted out, and had zero volts across its terminals. Being a condenser, it will try to maintain zero volts across its terminals after the points are open. It does this by acting as a short circuit to the current from the primary. If the coil primary and the condenser are sized properly, the primary current, and the associated magnetic field, will collapse much, much quicker than they would if they had only the arc through the points as a discharge path. The current through the primary will look pretty much like that shown in **figure 7** below.

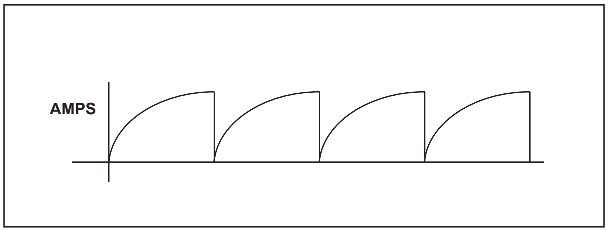

FIGURE 7

It was stated earlier, and illustrated in **figure 4**, that the current rise and fall in an inductor occurs over a period of time, yet the current *fall* in **figure 7** appears to be instantaneous. Actually, it's not. If the horizontal scale were stretched, the fall time would look a lot like the inverse of the rise time. With the condenser out of the circuit, the fall time would be about the same as the rise time. The condenser dramatically shortens the current and - most importantly - the magnetic field decay time.

There are a couple of interesting items of note in **figure 7**. First of all, as stated above, is the rapid current decay when the points open. Only a rapid current decay in the primary will produce a sufficiently rapid field decay to produce the required output voltage from the secondary. Secondly, with a rather slowly rising current when the points close, the rise time of the current, and the magnetic field, is not quick enough to generate a spark from the secondary.

I must admit, now, that I have taken a lot of liberties with all of the above, and I have simplified the theory a great deal. An electrical engineer reading this will probably cringe, but then an electrical engineer already knows all of this, and has no reason to read it. I have tried to take a very complicated subject and simplify it enough that some one who is not well versed in electrical theory can have a fair understanding of what is involve in generating a spark.