Rambling on about Ignition - Low Voltage for Model Engine Ignition

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Low voltage or low tension ignition was not the first electric ignition used in engines but it is the basis for understanding all the others. It is a simple circuit, just a battery, a coil and some electrical contacts in the cylinder. The primary focus here is how this system works electrically.

We need to start with an even simpler DC circuit, a battery, a resistor and a switch. We need to go to the imaginary world of physics and mathematics where everything is ideal. Initially in our circuit, there is a 6 volt battery and since the switch is open, no current is flowing, the voltage across the resistor is 0 volts and the voltage across the switch is 6 volts. Instantly, as the mechanical switch is closed the voltage from the battery is no longer across the switch, it is now across the resistor and causes current to flow at a rate that Ohms Law predicts.

$$Current(Amps) = \frac{Voltage(volts)}{Resistance(Ohms)}$$

For example, if we have a 6 volt battery and a 1 ohm resistor we will get 6 amps flowing in the circuit. When we open the switch the current stops immediately, the voltage again appears across the open switch and there is no voltage across the resistor when the switch contacts separate. If we do this in a vacuum that's the whole story, no sparks, no arcs.

If we do the same experiment in air or a mixture of gasses (like fuel and air) we have one change, gases ionize and can arc or spark. For air, the Ionizing voltage is about 3,000,000 volts per meter, which works out to be about 0.000,05 inches for 6 volts. That means that when the 2 parts of the switch are 0.000,05 inches apart, the air will ionize and arc. That's not a very large arc and probably not capable of starting the combustion process. If the voltage could be 600 volts, for example, the switch would ionize the air and arc at 0.005 inch gap and that is big enough for ignition.

In 1832, Joseph Henry demonstrated sparks and shocks from the induction affects of a single coil. In about 1886 the mathematics were finally developed to explain exactly what was happening. A coil of wire stores energy in the magnetic field it creates when DC current flows through it and can release that energy when the current is interrupted.

If we replace the 1 ohm resistor with a coil of wire with an iron core like an ignition coil, and we will do it all again, starting with an open switch in air or a mixture of gasses, and no current is flowing, initially the voltage across the coil is 0 volts and the voltage across the switch is 6 volts as before. When the 2 parts of the switch are 0.000,05 inches apart, the air will ionize, arc, and start current flowing. Once again, that's not a large enough arc to start the combustion process. However, this time the current does not instantly jump to 6 amps as the resistor did. The first instant as the switch closes, and the 6 volts from the battery appears across the coil, the current does not flow. The current increases and the magnetic field builds. The current approaches the level of 6 amps as expected from ohms law if the coil has a resistance of 1 ohm and is left on for a short time.

Coils have a time constant that comes from the equations of how the voltage and current interact. The time constant is the time that it takes the current to increase from where it is now to 63% of the change to the maximum value set by the resistance. After 3 time constants, the current is at over 95% and is close enough to the maximum for most applications. This time needed for the magnetic field to build is what actually sets the dwell time for the ignition system. The coil should be on for this time, at maximum speed for a full power spark. From this time, a dwell angle can be calculated for the engines highest speed and used for cam design. It's not very important for a low speed hit and miss engine but as speeds and the number of cylinders increase, it becomes critical. The coil we are discussing here has a time constant of about 0.005 seconds so the dwell needs to be over 0.015 seconds. This will come up again in later articles.

A popular analogy for all this is a water system. The water flow relates to current, pressure relates to the voltage, the coil would be a turbine (ideal mathematical turbine) connected to a flywheel. When the water flow is first started, no water flows until the turbine begins to rotate and let the water through. As the turbine speed increases so does the flow of water, energy is being stored in the flywheel as it speeds up. At some point the maximum flow will be reached based on the pipe and turbine size. At no point in this water system is the pressure any higher than the original water source. Looking at the flow over time, we see the flow smoothly increasing to a maximum rate.

If we suddenly block the water exiting the turbine, there is no place for the water to go. The turbine starts acting like a pump powered by the flywheel. Suddenly the pressure increases at the turbine output with the system trying to maintain the previous flow rate. Depending on how good the parts are the increasing pressure may just slowly leak away or it may cause the pipe to burst. The arc we are looking for is the electrical equivalent of the pipe bursting.

Switching back to our electrical coil that has had current flowing for a period of time has developed the maximum magnetic field around itself, the current through the coil like the water through the turbine has reached its maximum value. The coil has stored energy in the magnetic field. A typical ignition coil is about 0.005 to 0.010 Henrys, there are 6 volts across the coil and 6 amps maximum flowing through it.

$$Energy(watt - seconds) = \frac{1}{2}\ X\ Inductance(Henrys)\ X\ Current(Amps)^2$$

Using this equation we can calculate our example would have 0.09 watt-seconds of energy for a 0.005 Henry coil.

If we open the points or switch, the voltage across the coil changes instantly to maintain that same current flow. The increasing voltage appears as soon as the contacts separate and starts an arc by ionizing the surrounding gas. As the contacts continue to separate, the voltage keeps increasing for the widening gap and maintains the arc. The energy going into the arc is the energy stored in the coils magnetic field, because it is being dissipated as a high energy spark it is consumed quickly. As the energy is dissipated, the current is reduced as time passes.

$$W\text{atts} = \text{Voltage}\ \ \text{X}\ \ \text{Current(Amps)}$$

If we assume the arc can be maintained with 200 volts average and the average current is 3 amps the calculations indicate 600 watts. We only have 0.09 watt seconds of energy so we can calculate the arc will last about 0.0002 seconds by dividing the energy by the power to get time. This is fast, but it is a lot of energy in a little space and it will ignite a proper fuel air mixture.

This is a good ignition system form the electrical standpoint, simple and minimal parts. The problem is to make it work the points need to be inside the combustion chamber. There are all kinds of mechanisms that slide and rotate points in the combustion chambers of old engines. The problem they are in the combustion chamber. There are all types of spring loaded and wiping designs intended to protect or self clean the interrupting points in the cylinder. There is fuel, oil, smoke and carbon always in the cylinder, it is a poor place for an electrical switch. If the interrupting points get contaminated with fuel, oil, or carbon there resistance goes up and reduces or stops the current which can flow in the circuit, reducing the spark energy. As we know from above less current leads to less spark energy and a weaker spark which leads to engines that won't start.

Like so many things, low tension ignition works great for a while, but in the long run, it needs too much attention for a workhorse system.
Next time I will continue with High Voltage ignition.

Reference: Sparks & Flames by J.C.B. MacKaend, Published by Tyndar Press © 1997.