ATS | AUTOMOTIVE Test Solutions

Training

IGNITION SYSTEMS

by Bernie Thompson

Did you know that a fourth state of matter powers the spark ignition internal combustion engine and it can be used for engine diagnosis as well? So one may ask, what is this fourth state of matter any way? We commonly think of matter existing in three states; solids, liquids, or gases; but there is another state called plasma. Plasma is the most common state of matter in the universe; however on earth, this matter is much sparser than the vast amounts of intergalactic plasma in the universe.

Creation of plasma on earth requires high levels of naturally occurring or man-made energy and this plasma is the result of heating a gas in which the particles become charged and the molecules or atoms are ionized. An ion is an atom that has lost or gained an electron thus changing it from a neutrally charged particle to a charged particle. When a gas is super heated, large numbers of ions are formed which forms a plasma and because of the large number of charge carriers present, it becomes electrically conductive. Plasma has unique properties that differ from solids, liquids, or gases and therefore, it is considered to be a distinct state of matter.

In the spark ignition internal combustion engine, the plasma becomes a major player in igniting the air/fuel charge within the combustion chamber. It does this not by electric flow through the hydrocarbons, but by the intense heat from the plasma. This heat puts enough thermal pressure on the hydrocarbons that the hydrocarbon chains break, thus igniting the air/ fuel charge. Since plasma can be created naturally or by man, the question at hand is how is plasma produced in the combustion chamber? This plasma is not naturally occurring, but is man-made and it is produced by the step up transformer known in the automotive industry as the ignition coil. The step up transformer uses the principle of electromagnetic induction which occurs when a magnetic field is “changing”- “moving”-“ varying” across a conductor and this change in the magnetic field will create a potential or voltage within the conductor. This potential is caused by the changing magnetic field forcing electrons of the conductor to move from one atom to another atom; thus creating a difference between positively and negatively charged atoms. This difference is potential or voltage.

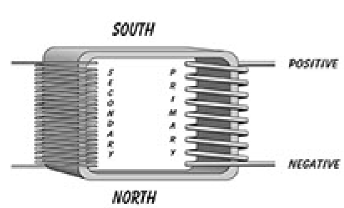

Fig. 1

The step up transformer uses a low voltage, high current pole, to create a high voltage, low current pole. This is done by using two different coils or windings of wire. The first coil is the primary; the second coil is the secondary as shown in Figure 1. The primary is wound around a core for magnetic amplification. In newer transformers, this core will be made of many plates of a ferrous metal, usually a soft iron, layered or laminated together. This gives better amplification than a solid core. The primary winding uses larger diameter wire with fewer windings. This allows the primary to have a very low resistance value. The secondary uses small diameter wire with many more windings which allows the secondary to have a high resistance value. The automotive coil is usually wound approximately 1 to 100, in other words, for every 1 winding of the primary the secondary has 100 windings. The primary winding usually has 1 to 4 ohms of resistance; whereas, the secondary winding usually has 8,000 ohms to 16,000 ohms of resistance.

The waveform that is produced on an oscilloscope from the automotive step up transformer is shown in figures 2 and 3 where the primary and the secondary are electromagnetically coupled so anything that affects either winding is mirrored in the other winding. The automotive step up transformer works by controlling the primary circuit; by either completing the primary circuit or opening the primary circuit. Once this circuit is completed (point C figure 2), current flows through the primary conductor which in turn creates a magnetic field around the conductor and this magnetic field is amplified by the laminated soft iron core. As the current increases, the magnetic field also increases. Since the secondary winding is wound very close to the primary winding, the magnetic field from the primary winding moves or changes through the secondary winding. This changing of the magnetic field through the secondary winding induces voltage in the secondary winding as can been seen as ringing at point B figure 3. The primary winding has ringing as well, but this ringing is dampened by the current flowing through the primary circuit. The primary winding will continue to build the magnetic field around itself until the primary winding is saturated as can be seen at point E. This saturation point is dependent on a combination of the wire diameter, the number of turns, the distance between the turns, and the applied voltage to the circuit.

Fig. 2-3

Once the primary winding is saturated, the current path is broken by the points or ignition module as can be seen at point F. Since the stored magnetic energy in the primary winding is the same as the electric potential and the electric current flow is shut off by opening the circuit, the primary magnetic field now falls back into the primary conductor in order to try to maintain the current flow within the conductor. Since the electric circuit is open due to the points or ignition module, the current path for the collapsing primary magnetic field would not be present. This in turn would slow down the collapsing magnetic field and would not allow very much electromagnetic induction to take place because the faster the magnetic field changes, the more electromagnetic induction takes place. In order to allow a current path to be established for the collapsing primary magnetic field, an alternate circuit through the condenser or capacitor is used. The condenser or capacitor allows the primary circuit to be completed if the electrical field is moving rapidly. The primary magnetic field being allowed to collapse through the condenser or capacitor at a fast rate allows this magnetic field to fall rapidly across the secondary winding which creates electromagnetic induction in the secondary winding. This induced voltage puts electrical pressure on the electrons within the secondary winding which causes the electrons to move. The voltage is amplified since there are a greater number of secondary windings than the primary winding. This allows the vehicle’s 12 volt battery to be amplified and produce 50,000 volts from the step up transformer.
The step up transformer produces a high energy state of greater than 20,000 volts and contains it within the transformer; however this high energy state will want to move to a lower energy state outside of the transformer. A conductor is used such, as an ignition wire, that connects the secondary winding to the spark plug. The high energy pushes the electrons down the ignition wire to the spark plug where there is an open circuit present between the spark plug electrodes. This high voltage produced from the step up transformer will push low energy into the gap of the spark plug electrodes known as a corona discharge. The corona discharge is an electrical path that is not strong enough to form a conductive region and yet is not high enough to cause electrical breakdown or arcing. This corona will allow electrons to start to flow across the spark plug electrodes. This forms early ionization of the spark plug electrodes. As the energy across the spark plug electrodes increases, electrical breakdown occurs as seen at point G. The electrical breakdown is the energy that is required to overcome the overall resistance within the secondary circuit which should be approximately 10k to 20k volts. During breakdown, the electrons are ripped off of the atoms that are within the spark

plug electrodes. These atoms and molecules are accelerated by the electric field and start to hit each other. These molecular hits or collisions create energy exchanges that produce heat. As the areas where the electrons are flowing across the spark plug electrodes have greater numbers of collisions, each collision generates heat so the heat intensifies with a greater current flow. At some point, the gas (nitrogen, oxygen, and hydrocarbons) across the spark plug electrodes is super heated and a plasma channel is produced. Plasma is a super heated ionized gas containing about equal numbers of positive ions and electrons. The plasma is conductive so that when the plasma is created the resistance across the spark plug electrodes is reduced as seen at point H. The creation of the plasma channel is the difference of point G where breakdown occurred, and point H where the breakdown was super heated creating plasma which is conductive and lowers the resistance. It is important to note on an oscilloscope that the voltage changes show resistance changes occurring within a circuit.

When diagnosing the engine using point G of the ignition waveform, it can be very hard to determine whether or not there is a problem, due to point G's normal range moving between 10k and 20k. If the point at G is greater than 20k, this indicates there is a problem with the resistance of the secondary circuit. A much better indicator of a problem than point G is the point of plasma at H. This point will be very steady and should be between 1.5k and 2k depending on the size of the spark plug gap. Since the plasma is created by the number of ion collisions which is proportional to the amount of current flowing, the only thing that will move this point up or down is resistance. If the resistance moves up and the current goes down the resulting smaller plasma channel is less conductive, whereas if the resistance moves down and the current moves up, the larger plasma channel is more conductive.

Ringing will occur after the point of plasma which is where the vertical fire line and the horizontal burn line meet. The ringing is the energy changing between electrical energy and magnetic energy. Just like when a bell is struck, the ringing from the bell is loud when first struck and diminishes. The harder it is to ionize the spark plug electrodes the larger this ringing will be. Point I is the plasma channel (what is referred to in the automotive industry as burn time) that was established during breakdown. Remember that the gases that were contained within the combustion chamber are what results in the plasma. In other words, the plasma will contain atmospheric gas which is approximately 79% nitrogen, 21% oxygen: and other gases which can be present including; hydrocarbons (gasoline), exhaust gases (EGR), and positive crankcase ventilation (PCV) gases. The conductivity of the plasma will change depending on what gases are contained within the plasma channel. This means that the voltage shown on the oscilloscope of the burn line will be proportional to the resistance of the plasma channel.
The point at J is where the plasma is breaking down. Since the plasma is composed of an equal number of positive ions and electrons, when the electron flow starts to decrease due to a limited reservoir contained in the step up transformer, the positive ions and electrons become unbalanced allowing the plasma channel to break down. This break down changes the conductivity within the plasma and creates more resistance which in turn causes an increase in voltage.

The point at K indicates the amount of energy that is still remaining in the step up transformer. The first negative oscillation is the most important one and this point should be about -1k volts to   -2k volts. At the point the electron flow ends across the spark plug electrodes, the energy that did not leave the transformer must be dissipated. The step up transformer accomplishes this by ringing the energy. This ringing or oscillation is caused by the change in energy between electrical and magnetic which the step up transformer is very good at creating. The larger the voltage change and the more oscillations within the ringing, the more energy is left in the ignition coil. If there are no rings, the energy of the ignition coil was totally dissipated. This ringing can be used to see how much energy was used or not used during the ignition coil discharge.

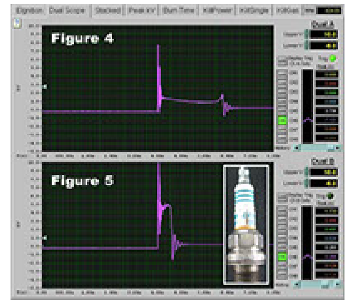

Fig. 4-5

Now let us analyze the ignition waveforms that are seen in figures 4 and 5. This engine ran with an intermittent misfire and figure 4 shows where there was not a misfire present and figure 5 shows where a misfire occurred. In figure 4, the ignition waveform is normal. The breakdown voltage is at 8k volts, the point of plasma is at 1.5k volts, the burn time is over 2ms, and the energy left in the coil is -1k volts. Now let us analyze the waveform in figure 5, which indicates that the breakdown voltage is over 10k volts, the point of plasma is at 4.5k volts, the burn time is about .6ms, and the energy left in the coil is -1.5k volts. When analyzing ignition waveforms it is very important to check the “Time to Tail”.

The “Time to Tail” shows the time the transformer had to discharge the energy and how much energy was still remaining in the transformer. In this case the burn time is only .6ms and the energy remaining in the transformer is only -1.5k volts. With only .6ms of time to discharge the energy that was contain in the transformer, it would not have enough time to dissipate the energy to -1.5k volts. If the spark had ionized across the spark plug electrodes with only .6ms of burn time, the energy that would be left within the transformer would be over -5k volts. There are physical conditions that determine how much energy can travel through the plasma channel created across the sparkplug electrodes. If the time that the transformer has to ionize the spark plug electrodes is limited, then the amount of energy dissipated in this time is limited, so a large amount of the energy will remain in the transformer. This energy will have to be dissipated with the ringing of the transformer.

If the burn time is limited and the energy that is still remaining in the transformer is low, then the spark did not go across the spark plug electrodes but went elsewhere. It is necessary to check the point of plasma in order to determine where the spark went. Since the plasma is at 4.5k volts, this indicates that the spark did not ionize, but took a carbon path. Carbon is a conductor that changes the resistance. This is why the point of plasma is so high, and the energy contained within the transformer is totally drained. How the burn voltage is formed will show what type of material the carbon trace is on. As can be seen in figure 5, the carbon trace is down the side of the spark plug between the D and the E. When a carbon trace has been made on the spark plug, the spark plug boot will have a carbon path has well. The carbon trace in the spark plug boot will look like a squiggly light gray line which indicates that the spark plug and spark plug boot will need to be replaced.

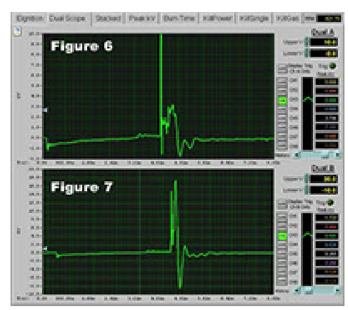

Fig. 6-7

Now let us analyze the ignition waveforms in figures 6 and 7. This engine ran with an intermittent misfire. Figure 6 shows where there was not a misfire present and figure 7 shows where a misfire occurred. In figures 6 and 7, the throttle is snapped to about 50% in order to load the ignition system. With more air volume in the combustion chamber, more pressure can be produced and it is far harder to ionize a gas that is under pressure. This loads the ignition discharge in order to locate problem areas. In figure 6, the ignition waveform is normal with a snapped throttle opening. The breakdown voltage is at 10k volts, the point of plasma is at 1.5k volts, the burn time is 1.2ms, and the energy left in the coil is -1.7k volts. Now let us analyze the waveform in figure 7 which shows the breakdown voltage over 14k volts, the point of plasma is at 1.8k volts, the burn time is about .5ms, and the energy left in the coil is -8.5k volts. The “Time to Tail” is .5ms of burn time and the energy left in the transformer is -8.5k volts. The point of plasma is 1.8k volts. This shows that the spark did ionize across the spark plug electrodes; however, the burn time voltage increases rapidly to 17k volts. Since the plasma channel sets this voltage, a high resistance is indicated. This resistance is created by what the composition of the plasma gas is. In this case, it shows a lack of hydrocarbons contained within the plasma channel. This lean air/ fuel charge changes the plasma composition, which with the lack of carbon creates low conductance within the plasma channel, thus creating a high burn voltage. With this additional resistance, the transformer could not discharge the energy contained within it and therefore, the energy had to be dissipated by the transformer. This is indicated by the negative going tail which is quite high at -8.5k volts. This intermittent misfire was diagnosed as caused by dirty fuel injectors which resulted in low levels of fuel in the air/gas mixture.

The vast amounts of intergalactic plasma in the universe are not very important to you when repairing a vehicle in your bay; however, the fourth state of matter within the combustion chamber is. As you can see with an understanding of the fourth state of matter, very fast, accurate diagnoses can be made in your service bay.