Capacitive Discharge Ignition *vs* Magnetic Discharge Ignition: Ignition System Options for the TR4A.

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UPDATED 2015: RELUCTOR DRIVEN HEI FOR THE TR4. Page 29 & see pg 65.

WARNING: Car ignition circuits contain devices which can produce very high voltages in excess of 10kV that could be hazardous to your health especially if you have an implantable electronic device such as a pacemaker or defibrillator. Only trained & qualified individuals should work on high voltage systems such as these. Any use of my freely given designs is at an individual's own discretion & own risk.

INTRODUCTION:

All standard TR cars and in fact nearly all cars from the early 1900's to the late 1970's were fitted with the Kettering ignition system (magnetic discharge ignition or MDI). This system was incredibly simple in design and also had excellent reliability on the whole, except for a problem. It is the same problem shared by any mechanical contact that is switching an inductive load. Contact arcing and contact burn occurs. This degrades the quality of the electrical connection and promotes unreliability. Due to this disadvantageous feature the car owner and or service mechanics would find themselves having to clean and adjust the distributor contacts at regular intervals and also replace them at regular intervals.

Since the mid 1960's various improvements or "attempts at improvements" have been made to the Kettering system. These include many types of add on electronic modules claiming to improve spark energy, lengthen spark plug life, improve miles per gallon and decrease service intervals. The claims didn't stop there, smoother engine running, higher horsepower, easier starting and better performance in cold weather were other claims and that is not an exhaustive list.

This paper looks at the Science & Physics of ignition system designs and with the aid of an especially built **Spark Energy Test Machine** seeks to determine what is true, what is not and to break down the myths & legends in this field as there are many.

1) MDI: Magnetic Discharge Ignition & Ignition coil theory:

The basic operation of a Kettering system shown in figure 1 is that when the contact breaker closes at time = 0, the ignition coil's primary current climbs with time as indicated in figure 2. As the current climbs then so does the *magnetic field* in the iron core of the coil.

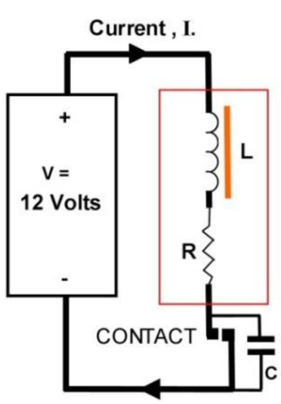


FIGURE 1.

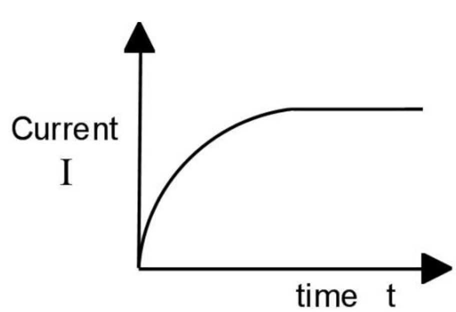


FIGURE 2.

The coil has a DC resistance of R Ohms and an Inductance of L Henries. The general shape of this climb in current I is an inverted exponential waveform. This conforms to the general equation one below where I(t) is a function of current with time and V is the applied voltage:

$$I(t) = \frac{V}{R}(1 - \mathbf{e}^{-t.R/L}) \qquad \textit{equ. 1}$$

As time progresses the value in the brackets approaches 1, so the current in Amps simply settles on the supply voltage V divided by the coil's resistance R. At this point the coil is said to be saturated in that neither the stored energy or the magnetic field or the current is changing with time.

The coil depicted in figure 1 could equally well be the primary of an ignition coil. The resistance R is that of the copper wire that makes up the primary turns of the coil, although there may be a small amount of resistance in the hookup wiring too. It should be noted that the resistance of copper wire increases with temperature. The orange line in figure 1 represents the coil's iron core. The capacitor C is shorted out by the contacts during the climb in current and at this stage performs no function.

At any point in time when the current value has climbed to some amount then the energy in Joules E_L, that is stored in the magnetic field of the inductance is equal to the value of the coil's primary inductance L times the square of the current value divided by 2. This can be represented by the equation 2 below where E_L is the energy stored in Joules in the magnetic field of the inductance:

$$E_L = L.\frac{I^2}{2} \qquad \textit{equ.2}$$

One disadvantage of the Kettering ignition system is that the time to reach some primary coil current after the points close and hence develop some amount of stored magnetic field energy is shortened at higher RPMs. This is because the contact breaker or points are closed for a shorter period of time and so a lower magnetic field has developed in this time. The spark energy therefore falls off at higher engine RPMs in the Kettering or MDI system.

Contact Breaker opening:

The stored magnetic field energy cited in equation 2 is released to supply the spark shortly after the contacts open. When the distributor contact opens, the magnetic field in the coil's core begins to collapse and back emf (or voltage) is induced across the ignition coils terminals. The voltage induced across the terminals of an inductor is proportional to the *rate of change* of magnetic flux with time. So if a magnetic field collapses rapidly the induced voltage can be very high.

On the primary winding side of the ignition coil this induced voltage has the reverse polarity to the originally applied voltage. The negative side of the primary winding, which was previously held at ground level (battery negative) by the contact breaker, now swings to a higher positive voltage than the battery voltage and a higher voltage than positive ignition coil terminal which is connected to the battery positive terminal. Depending on the coil and the size (capacitance value) of the contact breaker capacitor, the peak voltage can be in the order of 200v to 500v.

On the secondary (high voltage side of the coil) there is a large negative voltage peak as the polarity of the secondary coil is wired with this polarity and the primary voltage is transformed up by the turns ratio (Tr) of the coil by about 50 to 100 times depending on the particular coil.

This generated voltage from the collapsing magnetic field charges up the capacitance of both the primary winding's tuning capacitor (contact breaker capacitor) and the secondary's (high voltage winding's) self capacitance.

This exchange of energy between that of the coil's magnetic field and the capacitor's electric field effectively converts the stored magnetic field energy into electric field energy of the capacitances. All of the magnetic field, less energy losses in this process, is converted to an electric field or voltage field at the point where the coil primary current is zero and the capacitor's voltage has peaked.

This electric field energy, if not dissipated another way, then returns to become magnetic field energy again in an alternating or oscillating way because the capacitances and inductance form an oscillatory or resonant circuit.

This oscillatory process is exactly analogous to a mass oscillating on a spring, where the kinetic energy of the mass is alternately exchanged with potential or elastic energy of the spring. In this physical system example there are times when the mass is not moving (as it changes direction and all the energy is stored at that moment is in the spring). This occurs in the electrical example when all the energy is being stored at one moment is in the capacitor and the inductor or coil current is zero and the magnetic field is zero at that moment.

The equation for energy stored in a capacitor's electric field Ec, in terms of the capacitor's terminal voltage **V** and the capacitor value C in Farads is:

$$E_c = C.\frac{\mathbf{V}^2}{2} \qquad \textit{equ.3}$$

Equation 2 and 3 will come in handy later in calculating the expected peak voltage on the primary or secondary winding of the coil when the magnetic field has collapsed and given all of its stored energy to the electric field of the ignition coil's capacitances. This peak occurs ¼ of a cycle into the oscillation.

What is the Spark?

The spark itself can be regarded as a conductor that dissipates energy and it comes into existence only when the coil's secondary voltage is high enough to cause the gap in the distributor and spark plug contacts to flash over. This condition usually occurs when the peak voltage is high enough to ionize a stream of gas between the spark plugs electrodes. The spark is composed of ionized gases and can be referred to as "plasma". The plasma has the physical properties of a gas but the electrical properties of a conductor like a metal. This is because gas's electrons have been mobilized by the very high voltage electric field. We see a plasma or ignition spark as a sharp blue/white line with an accompanying cracking sound and a smell of ozone.

Given the spark voltage drop is relatively stable during the spark's existence then increased spark current corresponds to either multiple fine sparks in parallel side by side or a thicker spark with a wider cross sectional area.

The voltage measured across a spark plug is fairly stable during the spark time and is in the order of 1000V. An artificial spark plug can be made with 1000V Zener diodes.

An article on www.worldphaco.net describes a **Spark Energy Test Machine** capable of measuring spark energies in automotive ignition systems during the process of spark formation by MDI or CDI systems. This machine, along with an oscilloscope, allows thorough investigation of spark generating systems, including the total energies and spark time profiles. The spark energy test machine measures the spark's energy in milli-Joules per spark time and is a very useful tool to study and compare the performance of a number of possible ignition system options.

IGINITION COIL PARAMETERS:

Some of the voltage and current waveforms seen on recordings of working ignition coils show multiple features including various resonances (Oscillations). Firstly to understand these recordings it is necessary to look at the electrical parameters of an ignition coil. The ignition coil is a transformer with a large step up ratio. There are typically 50 to 100 times more winding turns on its secondary than its primary winding. Each winding, measured alone, has a certain Inductance and a certain DC resistance (of the copper wire). Then there is the important property of Leakage Reactance which comes about due to lines of magnetic flux (leakage flux) which do not link the two windings, figure 3 below shows this feature:

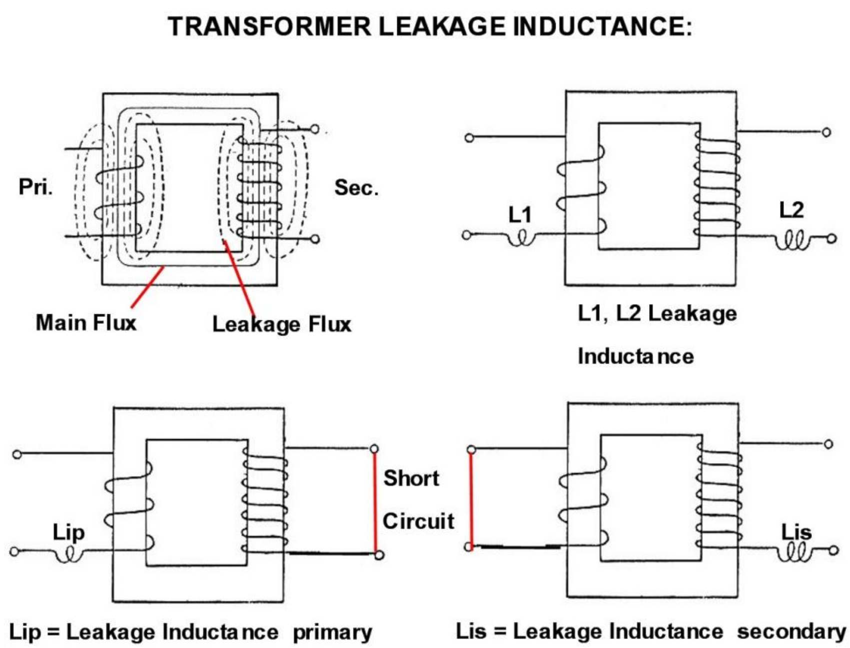


FIGURE 3.

As indicated in figure 3 the leakage flux results in a leakage inductance L1 and L2 which appear in series with the primary and secondary windings. When one winding is shorted out or very heavily loaded the leakage inductance can be measured wholly in the other winding. So when the secondary winding is shorted out the leakage inductance can be measured with the inductance meter in the primary winding as a total amount Lip and likewise when the primary is shorted out the leakage inductance Lis appears in series with the secondary winding.

With the ignition coil in use in the MDI system the primary winding is shorted out (to AC currents) when the contact breaker closes and the fixed DC battery voltage is applied to the primary winding. Therefore Lis appears in series with the secondary winding. In addition at other times when there is a spark loading the coil's secondary winding and due to the fact that the spark plug voltage is fairly stable at 1000V and the spark in the distributor fairly stable with about a 500V drop, the fixed 1500v load on the secondary effectively shorts out the secondary coil (HV) winding since the coil is attempting to supply 20Kv or more, so during this time the leakage reactance appears as Lip in series with the primary winding.

In the case of the standard ignition coil, the magnetic circuit is not closed and the coils are simply wound on top of each other on an iron bar shaped core and the ground return for the high voltage winding is connected to the coil positive to avoid having to have an extra coil terminal. This also allows the primary peak voltage (usually about 400v) to be added to the total secondary high voltage (HV) output, see Figure 4 below:

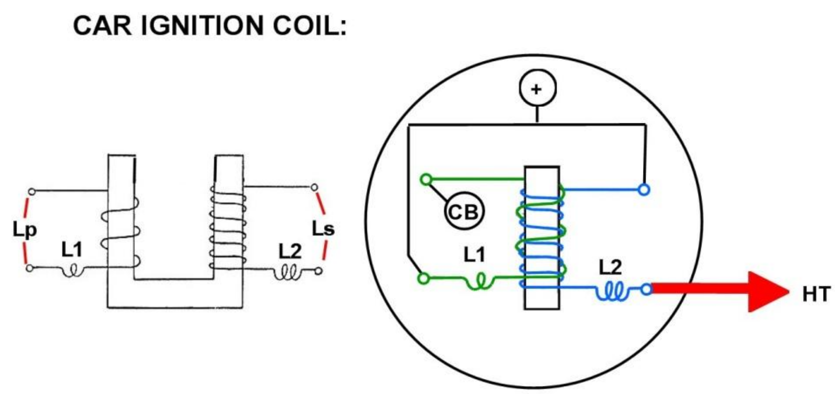


FIGURE 4.

Standard oil filled coils wound on an iron bar have higher overall leakage inductances than transformer coils (where the magnetic pathway is a closed ring) making them quite unsuitable for CDI use. Despite this they have still been used in CDI systems were an aftermarket device is added to the car. (see section on CDI Physics)

With no load on the fellow winding, the primary and secondary windings have a total inductance Lp for the primary and Ls for the secondary and this is easily measured on the primary winding with the inductance meter. Because the secondary inductance is so high often in excess of 50 Henrys most inductance meters are unable to measure it. However it is readily calculated by multiplying the primary inductance by the square of the coil's turns ratio.

The relationship of the total leakage inductance either appearing wholly in the primary or wholly in the secondary is very simple. If there are N1 turns on the primary and N2 turns on the secondary the turns ratio Tr is N2/N1 which is typically 50 to 100 for ignition coils.

$$Lip = (L1 + 'L2) = L1 + L2\left(\frac{N1}{N2}\right)^2 \quad \textit{equ 4.}$$

$$Lis = (L2 + 'L1) = L2 + L1\left(\frac{N2}{N1}\right)^2 \quad \textit{equ 5.}$$

The notation ‘L2 indicating it’s a *transposed* value of L2 from the secondary into the primary winding. This relationship also holds true for the primary and secondary DC resistances which can be imagined to be transposed into either the primary of secondary windings where Rp is the DC resistance of the primary and Rs the DC resistance of the secondary and ‘Rp and ‘Rs are the transposed values. This is shown in the equations 6 and 7 & figure 5:

$$R(\text{primary})\ \text{total} = (Rp + 'Rs) = Rp + Rs\left(\frac{N1}{N2}\right)^2 \quad \textit{equ 6.}$$

$$R(\text{secondary total}) = (Rs + 'Rp) = Rs + Rp\left(\frac{N2}{N1}\right)^2 \quad \textit{equ 7.}$$

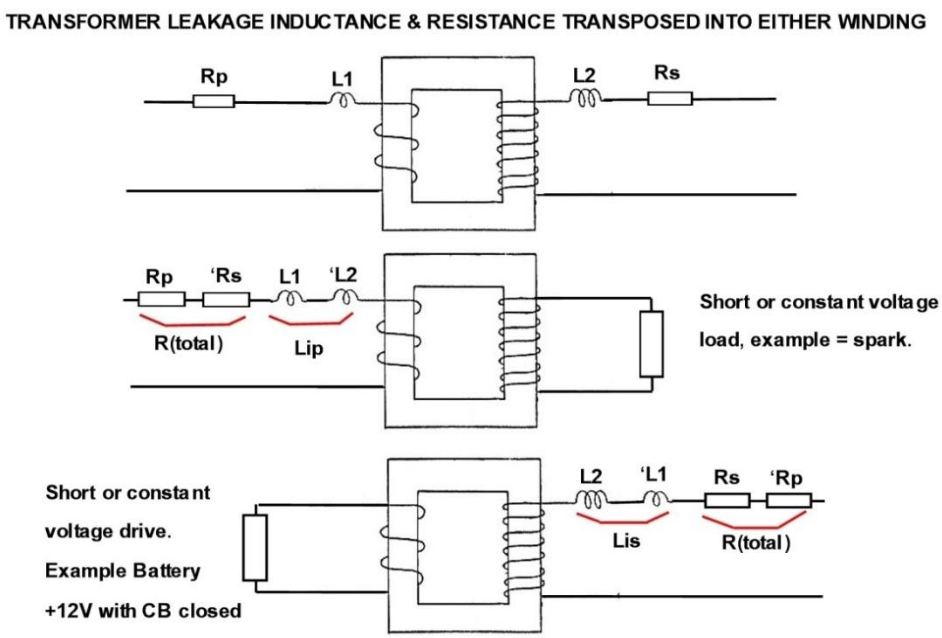


FIGURE 5.

In addition there are capacitances of the coil windings themselves (due to the proximity of the winding turns and the layers of turns) especially in the very long secondary winding. There is also the capacitance, typically around 0.22uF of the contact breaker capacitor which "tunes" the coil primary winding. Therefore a comprehensive *model of the ignition coil* must take all of these factors into account, as in figure 6:

BOSCH SU12 COIL DATA:

Rp = 3 Ohms (m) **Rs = 14K Ohms (m)**

Cp = 0.22uF (m)

Csp= 0.003uF(c) **Cs = 50.6pF (c)**

Lp = 9.5mH **Ls = 68.6H (c)**

Lip = 1.6mH (m) **Lis = 10.2H (m)**

fp = 2.36 KHz (m) **fs = 2.7 KHz (m)** **fsc = 2.1 Khz (m)**

fpl = 8.4Khz (c) **fsl = 7.0KHz. (c)** **fps = 29.9Khz (m)**

Tr (turns ratio N2/N1) = 85 (m)

(c) = Calculated value

(m) = Measured value.

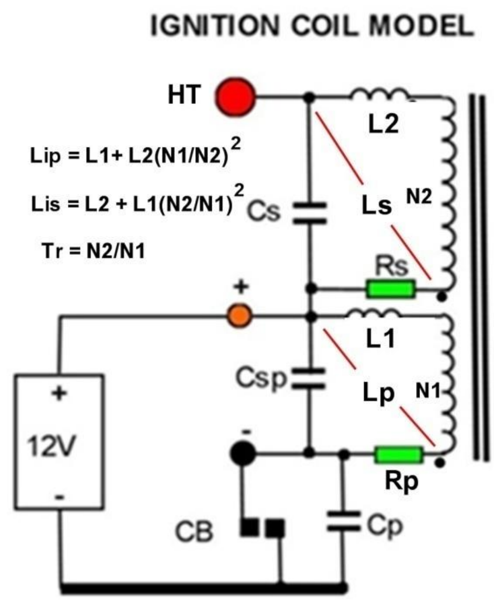


FIGURE 6.

Deriving the calculated values:

Some parameters are easily measured with meters. Some must be calculated using various tests such as the coil's resonant frequencies. These tests are done with a sine wave signal generator and an oscilloscope.

Cs is the inter-winding capacitance of the secondary coil. Csp is the inter-winding capacitance of the primary coil. Cp is the contact breaker capacitor value. Lip and Lis are the total leakage inductances of the primary or secondary winding referred to that winding alone with the other winding shorted. Lp is the primary winding inductance (secondary winding unloaded) and Ls the secondary inductance (primary winding unloaded).

fp, fs, fpl, fsc, fps, and fsl are resonant frequencies that result from the capacitances tuning the inductances.

fpl is the frequency of the resonant circuit created when the total primary capacitance (Cp + Csp) tunes the primary leakage reactance Lip. Likewise fsl is the frequency when Lis is tuned by the secondary winding's self capacitance Cs. These will be discussed below in some sample recordings.

Equation 4 is used to find the relation between inductance L, capacitance C and resonant frequency f:

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \textit{equ 4.}$$

The secondary winding's tuning capacitance Cs can be estimated using equation 4. This capacitance results from the proximity of the many hundreds of winding turns and the layers of the windings.

On testing the coil with a sine wave signal generator the self resonant frequency fs of the secondary winding is 2.7 KHz (open circuit primary) and the inductance of the secondary is 68.6H. Therefore Cs (the secondary self capacity) using equation 4 is approximately 50.6 $x10^{-12}$ Farads or 50.6pF.

The primary self resonant frequency fps is 29.9 KHz with no tuning capacitor and an open circuit secondary. Again using equation 4 the winding self capacitance of the primary; Csp = 0.003uF. This makes the total primary tuning capacity about 0.223uF.

However if we use equation 4 to *calculate* the resonant frequency of the primary (inductance 9.5mH and capacitance 0.223uF) we get a frequency of about 3.4 KHz, which doesn't match up with the *measured* primary resonance fp of 2.36 KHz. This is because of the tight coupling of the primary tuned circuit to the secondary tuned circuit.

On the other hand when we measured the secondary coil's resonant frequency fs of 2.7 KHz I was able to disconnect the primary coil's tuning capacitor (which is the bulk of the tuning capacitance for the primary) and the primary winding's self capacitance Csp of 0.003uF is not significant. When I measured the primary's resonant frequency I was unable to remove the secondary coil's self capacitance because it is the physical inter-winding capacitance of the secondary coil and not a discrete capacitor that can be disconnected for an experiment.

There is however a way to estimate what the effect of the secondary coil and self capacitance resonant system might be expected to have on the primary resonant system. This can be done with an equivalent circuit concept to explain the point, figure 7 below, without any complex mathematics:

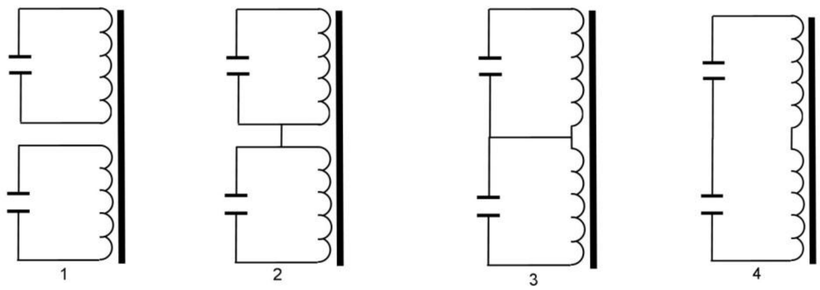


FIGURE 7.

Shown in figure 7 (1) above are two identical resonant circuits of the same L and C values in this example wound on one magnetic core and tightly magnetically coupled. They can be linked together as shown in (2) with no alteration to the function. They can be re-drawn as in (3). Then it is also noticed that there is no current in the link connecting the centre tap of the now longer coil with the junction of the two capacitors as the voltage on both these points is always identical. Therefore this link can be disconnected as in (4) and the circuit is still electrically the same.

Looking at (4) we now have a circuit with half the capacitance value (two capacitors in series) but twice the number of turns and therefore 4 times the inductance value. The resonant frequency of the system is one over root 2 (or 0.707) times lower than if there were just one LC resonant system on the core rather than two. This is an interesting and useful finding and is what one would expect if the capacitance on one winding was simply doubled.

If we multiply the *calculated* value of the primary resonant system of the ignition coil of 3.4KHz by 0.707 it yields 2.4KHz which is close to the fp of 2.36 KHz found with practical measurement when measuring the primary resonance.

In addition fsc is the measured value of secondary resonance when the primary coil is tuned by the 0.22uF contact breaker capacitor and it is also lower at 2.1KKz due to the influence of the tuned primary winding on the tuned secondary winding.

Summary of ignition coil properties and “expected resonances”

We have in essence an ignition coil where the unloaded primary and secondary coils resonate with the associated system capacitances at about 2.1 KHz. So we could expect to see this resonance during recordings or oscillograph traces of a working ignition system.

We also have a situation also where if the primary is loaded the secondary leakage inductance of 10.2 H would be expected to resonate with the secondary capacitance of 50.6pF and produce a frequency fsl around 7.0 KHz. The primary is heavily loaded when it is switched across the 12V to 14V DC supply by the contact breaker.

We also have a situation with a loaded secondary (for example when the spark occurs) where the primary leakage inductance of 1.6mH would be in resonance with the 0.223uF total primary capacitance so we could expect to see a frequency fpl of around 8.4KHz during the period that the spark was present. Also with any resonances (oscillations) seen we would expect that they would decline exponentially with time due to energy losses in the resistances of the coils.

The ignition coil in action:

The coil diagram of figure 6 shows the important features of the leakage inductances and tuning capacitances. From the alternating current perspective the contact breaker capacitor Cp is effectively directly in parallel with the small self capacitance of the primary winding Csp because the battery voltage is a constant. Therefore the capacitor Cp can be thought of as connected directly across the positive and negative terminals of the coil like Csp. The only difference is that when the contact opens the capacitor Cp over time also becomes charged to 12V which it would not be if connected directly across the coil primary.

When the ignition coil's magnetic field collapses after the contacts open, for a brief time, all of the stored magnetic energy is converted to electric field energy of the primary capacitances (self capacity and tuning capacitor) and the secondary (self) capacitance. But how is this energy distributed between the electric field energies of the primary and secondary capacitances? Is it equal or some ratio?

We know that the voltage ratio or turns ratio of the coil is 1:85 from primary to secondary. If for example the primary peak AC voltage is one volt, then at that moment the energy, from equation 3, stored in the primary's capacitance is $(0.223 \text{ x } 10^{-6})/2$ Joules. The peak secondary voltage is 85V.The energy in the secondary's capacitance is $(85^2 \text{ x } 50.6 \text{ x } 10^{-12})/2$ Joules. These can be added to find the total energy. The percentage of the total stored energy in the primary capacitance is 38% of the total amount and that stored in the secondary capacitance is about 62% of the total amount.

If the contact breaker switches on the coil for 5mS then the current, according to equation 1 climbs to about 77% maximum value or 3.3 Amps. The magnetic field energy stored, from equation 2 is 0.052 Joules. When this is released and at its peak then 38% (0.0197 J) of this is stored in the primary capacitance. Using equation 3 to solve for the voltage across the total primary capacitance (0.223uF) this yields 421 volts peak on the primary and about 36Kv peak on the secondary.

With resistive power loss (damping) then for each full cycle of oscillation about 40% of the amplitude is lost over the 460uS period. With each cycle the amplitude drops to *about* 60% of its previous value. This is due to energy dissipation in the resistance of the primary and secondary windings and is a fine example exponential decay and damping. Practical measurement shows that the initial *primary voltage* peak under these conditions where 12V is applied for 5mS and the contact opens is in the order of 360V. See figure 8 below, y axis 100v/large division. This reduced amount, below the calculated 421V, is explained by the resistive damping**. *No spark is allowed to occur for this test (coil HV output wire is disconnected).***

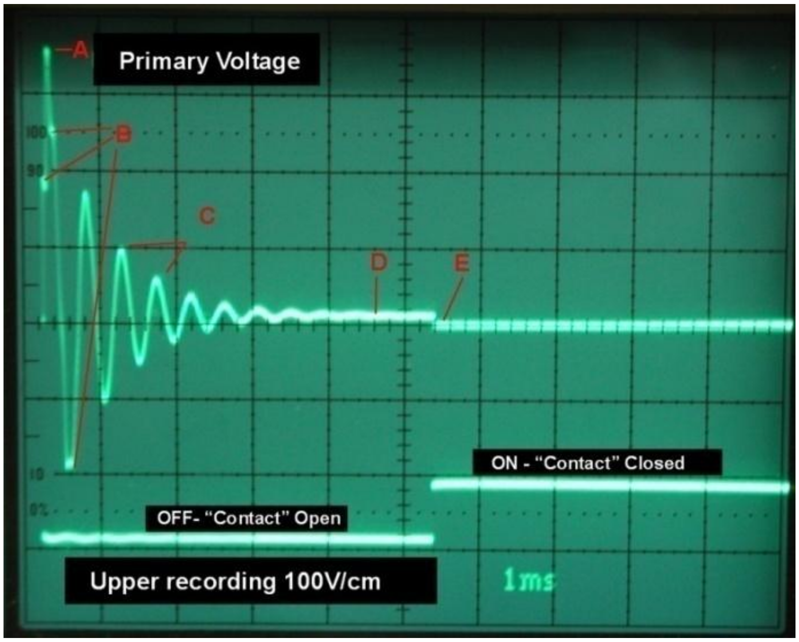


FIGURE 8.

In this instance a transistor is being used to switch the coil on & off achieving the same effect as a mechanical contact. The lower waveform is the *drive* to the transistor. When this drive voltage is high the transistor is switched on, when low it is switched off. A shows the initial voltage peaking after the transistor switches off (same as contacts opening) peaking to 360 volts. Some small higher frequency resonances are seen at B most likely relating to the leakage inductance. The decaying 2.1 KHz oscillations are seen C and the amplitude drops to about 60% of what it was with each cycle. By D the oscillations have decayed away and the coil negative terminal voltage settles on 12 volts and the coil current is zero. The contacts close again at E (transistor switches on) and the primary voltage on the coil's negative terminal gets pulled close to ground (zero volts). This impresses 12V again on the primary coil and the current and magnetic field builds up again.

We can now refine our calculation of the initial expected primary voltage amplitude. With each 460uS the voltage level drops exponentially by 60% therefore just using the exponential function that describes decay with time:

$$e^{-\alpha.t} = 0.6$$

t is 460 uS, so we can solve for the damping constant α,

$$-\alpha.t = \ln(0.6)$$

$$-\alpha = \frac{\ln(0.6)}{460 \text{ x } 10^{-6}}$$

$$\alpha = 1110$$

A quarter of a cycle into the waveform (after 115uS) then the amplitude would be expected to be:

$$e^{-1110(115 \text{ x } 10^{-6})} = 0.88$$

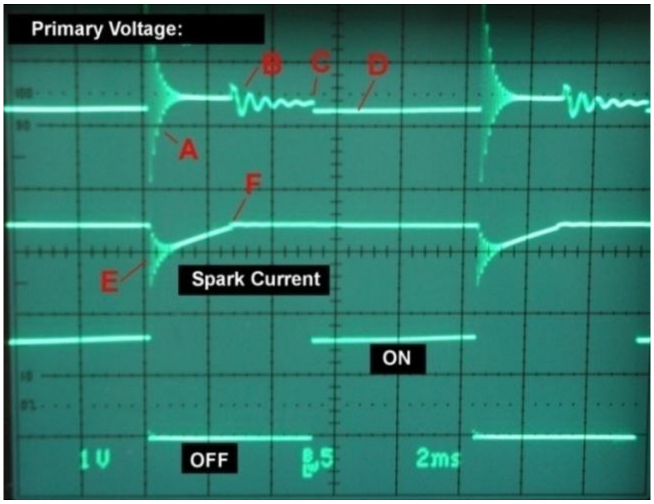
Therefore we would expect that due to resistive damping, that the actual peak voltage we should get ¼ of a cycle into the oscillation will be *88% of that calculated with no losses* (which was 421 volts):

$$0.88 \text{ x } 421\text{V} = 370\text{V}$$

This is close to the *measured* 360 volts on the practical measurement of figure 8.

The next series of ignition coil tests involved using 100 Hz square wave drive (equivalent to 3000 RPM in a 4 cylinder car and 45 degree dwell angle) giving an ON time (contact effectively closed) of 5 mS and an OFF time (contact open) of 5 ms . This also enabled the on-off switching events to be recorded and photographed one after the other by setting the scope's time-base to 2mS/div. Also a spark was allowed to occur by fitting the spark plug and current sense resistor in series with a real spark plug (in air) to negative. Figure 9 below shows the result:

FIGURE 9.



There is a lot of detail in the recording of figure 9. This is where we need to take full advantage of out coil model of figure 6 to explain it. For the spark current recording 1 cm on the Y axis corresponds to 50mA /cm

When the contact breaker opens (Transistor turns off) the voltage on the secondary (high voltage winding) peaks which is off the visible top of the recording in figure 9. A spark is generated shown by the current recording at E. The spark current value (a negative voltage developed across the 100 ohm resistor) is zero until the spark is generated. Initially there are oscillations in the spark current, but the oscillations do not stop the spark as the value during the spark time is never zero. The spark stops suddenly at F when the secondary voltage falls too low to maintain it about 2.3mS after the spark begins. The top recording shows the voltage on the primary measured with respect to earth and is 100 volts per cm and the initial large positive peak if off the top of the recording.

The lower trace is the switching voltage controlling the transistor switch. With a spark plug in a combustion chamber, the spark voltage is higher (about 1000v vs 600V for one in air) so the spark time in the car is less than the 2.4mS shown in figure 9)

When the spark occurs the ignition coil's secondary is loaded and the primary leakage inductance Lip resonates with the primary capacitance. Examining the trace indicated about 3 &1/2 peaks of oscillation are seen in about 400uS. This corresponds to a frequency about 8.7KHz. The value calculated for fpl was 8.4KHz. These oscillations are seen both in the primary voltage at A and in the spark current at E and they die away before the end of the spark. The spark current then keeps the coil damped until the spark is extinguished. The moment the spark extinguishes the ignition coil is undamped again and the approximately 2.1KHz oscillation of this condition emerges because the residual magnetic field energy that wasn't used up generating the spark supplies this oscillation with energy and then again it begins to decay in amplitude, these are seen a B.

The primary voltage on the coil's negative terminal at C settles on the battery voltage (12V) so there is no voltage across the coil at this time. The transistor conducts (contact breaker closes) shortly after point C, taking the negative terminal of the coil to near to zero volts. This impresses the 12V across the coil. This again damps out the 2.1KHz oscillation although it had nearly decayed away completely by then anyway. Then for the next 5 milliseconds the current is building in the coil and no oscillations are seen due to the heavy damping. When the transistor switches off (equivalent to the contact opening) the cycle repeats. The transistor is turned off for about 5mS and turned on for 5mS to create this repeating pattern seen in figure 9.

Summary of coil testing:

As shown by way of measurement & calculation the ignition coil tested has a fundamental resonance of around 2.1 KHz. With the points capacitor of the correct value the resonant frequency of both the primary and secondary windings (which influence each other) have a similar resonance around this value. This resonance is easily seen in recordings. When the spark is being generated the secondary winding is heavily loaded and this causes the primary winding's leakage inductance Lip to resonate with the primary capacitance to generate 8.7 KHz oscillations that are easily seen in the primary circuit voltage and also in the spark current itself.

In theory there should also be higher frequency oscillations around 7KHz seen in the secondary circuit if the primary circuit is heavily loaded. Therefore a test to monitor the coil's high voltage winding might show this. To avoid damaging the oscilloscope the probe was simply placed on the insulation of the HT wire to lightly couple the signal, figure10:

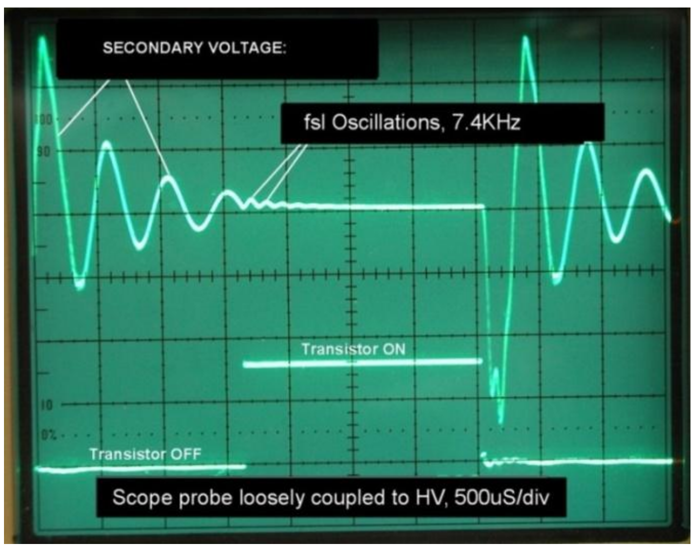


FIGURE 10.

Referring to figure 10, when the transistor conducts the primary and secondary oscillations are damped out and vanish and high frequency fsl oscillations are in fact visible and these represent the leakage inductance of the secondary Lis resonating with the secondary winding's self capacitance Cs. The calculated value for this resonance fsl suggested the value would be about 7KHz. They appear to be around about 7.4 KHz on the recording.

2) STANDARD *vs* TRANSFORMER IGNITION COILS:

The types of coils suited to magnetic discharge systems are not well suited to CDI use. Standard Kettering coils have a significant leakage inductance. This is caused by magnetic lines of force linking one winding such as the primary winding and not the secondary winding and visa versa. This is due to the windings being wound on what amounts to an iron rod, rather than a closed magnetic ring of iron such as that used in a “Transformer Coil”.

In a transformer coil the magnetic circuit is closed by an iron core formed into a rectangle and the magnetic circuit is closed. Most magnetic lines of force therefore link both the primary and secondary coil windings improving the coupling between the windings and improving the performance when the coil is used as a transformer.

A comparison between two similar Bosch coil types, one a standard design oil coil the other a transformer coil is shown below in figure 11:

PARAMETER	GT40T	GT40(oil)
Rp	3 Ohms	3 Ohms
Rs	8.56k	17.5k
Lp	13.5mH	8.16 mH
Ls	38H	73.6H
Lip	1.4mH	0.86mH
Lis	3.53H	7.92H
TR	53	95

FIGURE 11.

(TR in the table is the coil’s turns ratio)The GT40T is a Transformer Coil. The transformer coil by virtue of its higher primary inductance Lp stores more energy as per equation two, although the higher inductance slows down the build up of current. The improvement for an MDI system using a transformer coil is only realized at low RPM’s where there is plenty of dwell time to saturate the coil, see figure 12 below (note this is actual measured spark energy, not coil stored energy which is higher).

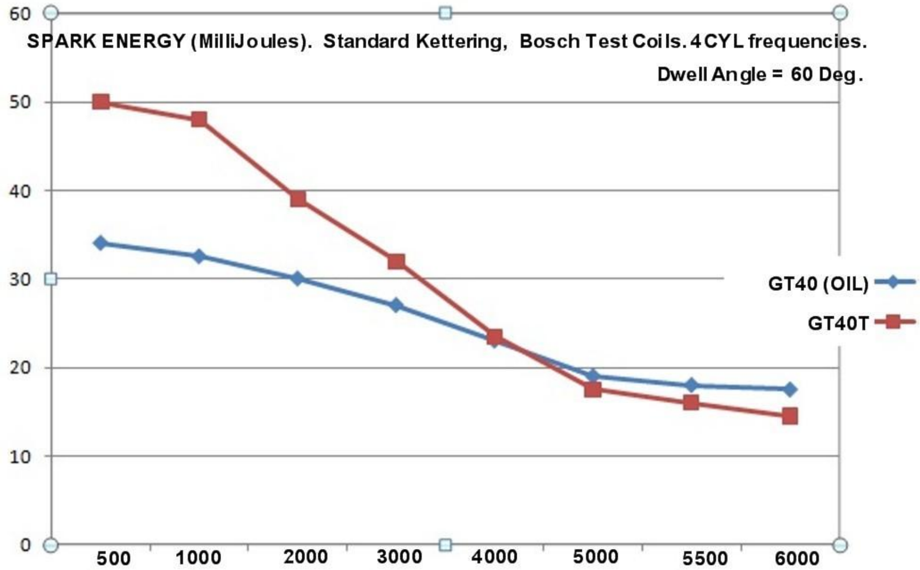


FIGURE 12.

One interesting feature is the lower turns ratio and lower secondary resistance in the transformer coil. Any coil resistance is disadvantageous as resistance dissipates heat and wastes energy.

Notice the much lower leakage inductance Lis of the transformer coil *vs* the standard oil coil. This is another way of saying that the primary and secondary windings in a transformer coil are much more tightly magnetically coupled than in a standard oil coil.

The reason the energy is higher in the low rpm range for the transformer coil, is that it has a larger primary inductance than the oil coil, about 13.5 mH for the transformer coil vs about 8.2 mH for the oil coil, while their primary resistance value is the same.

So while the transformer coil is a gain to an MDI system in the low rpm area only, the gain that is really required to improve the MDI system is in the high rpm area.

The utility of changing from an oil filled coil to a transformer coil is limited in a MDI system. Although dwell extension is helpful for both types of coils in the higher RPM ranges.

(This is not the case for CDI systems, see below)

In MDI systems the energy is stored by primary winding current on the "charge" period and released later by secondary winding current on the "discharge" or spark period. The inductive relationship, specifically *leakage inductance* which is high in the oil filled coil, is not a critical factor. The energy is not passing through the coil at the one time as it is in CDI use.

The following figure 13 shows the superior Bosch GT40T coil with an optimized dwell HEI style interface (see later) with recordings of the spark energy and peak spark current. The reason for the latter is that spark currents are substantially higher in CDI than MDI. So the recording here is a good reference for the optimal MDI system to compare with the CDI system later:

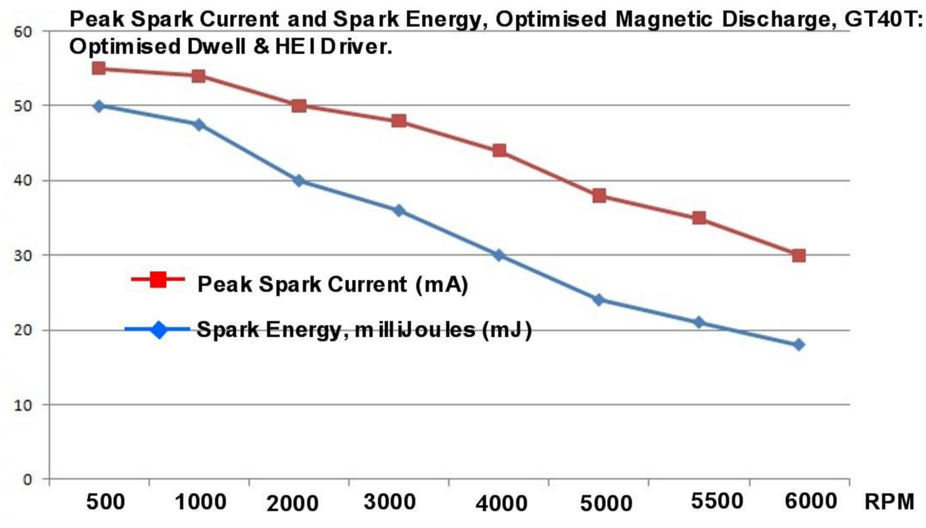


FIGURE 13.

However figure 13 above is an energy recording of an HEI style system where a contact breaker is the source of the drive signal and a standard resistance coil is used and the dwell optimised electronically. Higher spark energies can be attained where the drive source is a reluctor voltage and the ignition coil is a low resistance primary type (1.5 Ohms or less) where the peak coil current is limited by the HEI module and the HEI module optimises the dwell also, see below.

3) COIL VOLTAGES vs COIL and SPARK CURRENTS:

Understanding the pattern of ignition coil *voltages* is one issue explained above. Unfortunately there is an obsession with higher turns ratio and higher output *voltage* coils in the perception of the many in the auto electrical industry and coil manufacturers who boast of high voltages in excess of 40Kv.

The peak secondary voltage only has to be over about 10Kv to 15Kv to reliably strike the spark via the distributor and spark plug. 20Kv to 30Kv is perfectly adequate for this task and allows for lower battery voltages with cranking. Once the spark is struck the coil secondary is effectively loaded down to a low voltage of less than 2Kv.Unfortunately there has been a tendency for people to pull off the spark plug cap and assess the spark by how far it can "jump" when in fact it is a meaningless test. The situation exists where a higher open circuit voltage test produces lower spark energy than another coil with a lower open circuit voltage test. For example the low turns ratio of a GT40T coil compared to the GT40 is a good case in point where the GT40T generates a lower secondary voltage but produces a *higher energy spark* in both MDI and CDI use than the higher output voltage GT40.

A certain amount of current and voltage is required to maintain a spark. The current versus time profile of the spark for an MDI system (ignoring the resonances) shows it to decrease fairly linearly with time after it strikes, corresponding to energy loss from the collapsing magnetic field. When the spark current and coil secondary voltage fall low enough the spark extinguishes.

Attaining higher coil voltage, for the same physical sized coil, means a higher DC resistance secondary winding which wastes more energy as heat losses. In addition the coil has higher leakage reactance and this elevates the impedance of the coil output. This decreases the *transfer efficiency* of stored energy to actual spark energy.(see section on CDI Physics also)

One parameter we are interested in is *coil current* prior to the contact breaker opening and the actual spark energy in Joules which results. This is because we can then know the stored energy from equation 2 and we can measure actual spark energy with the machine or from and oscilloscope recording of the spark's current. Therefore we can calculate the *transfer efficiency* from the stored energy to real spark energy. The test machine can calculate the spark energy and the example results shown below come with the aid of the test machine. Figure 14 below shows how the primary coil current climbs with time after the contact breaker closes in the standard Kettering system with a standard Bosch GT40 oil coil. At 2000 RPM the coil current is close to saturating:

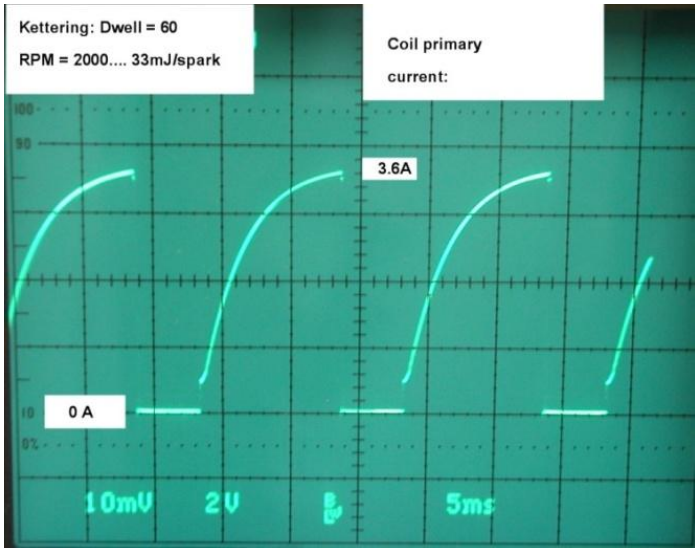


FIGURE 14.

4000 RPM is shown in figure 15:

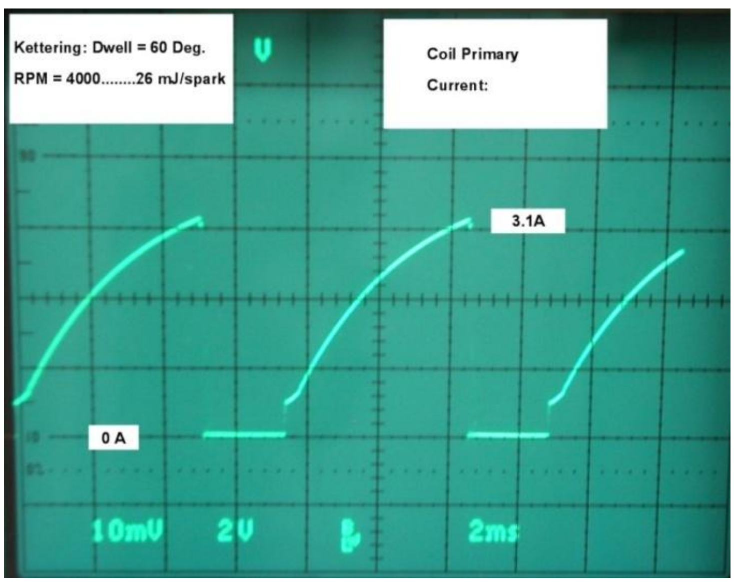


FIGURE 15.

Figure 16 demonstrates saturation of the coil current. No additional spark energy is gained by this situation, only additional heat dissipation in the coil.

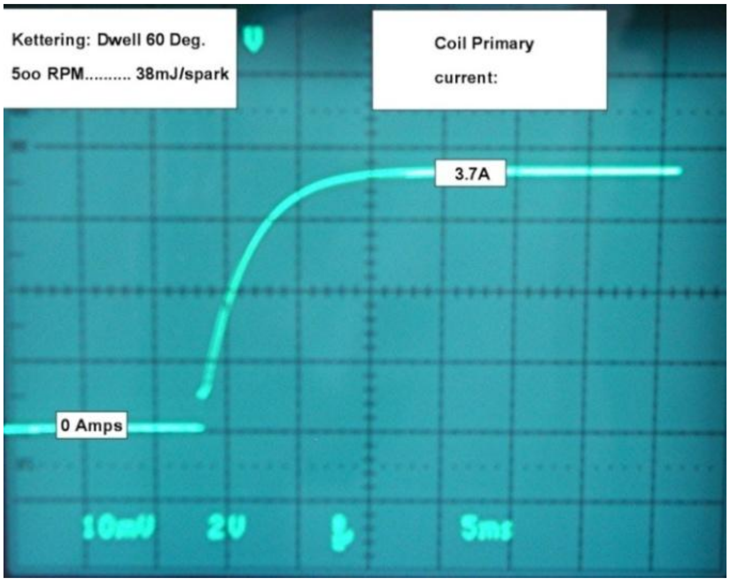
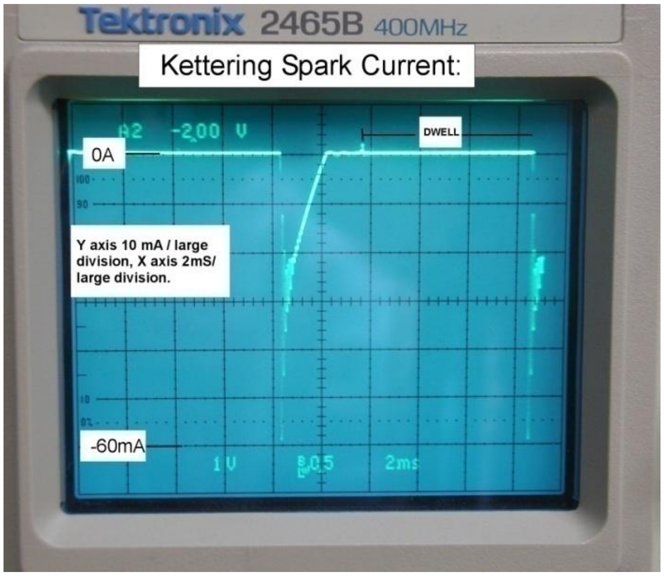


FIGURE 16.

The energy stored is easily calculated by equation two. For example using the data from figure 11 the GT 40, primary inductance around 8.2mH peak primary coil current at 2000 RPM (4cyl) with a 60 degree dwell angle is 3.6 Amps and the stored energy in the coil's magnetic field prior to the spark is 53mJ and the measured spark energy is 33mJ per spark so the *transfer efficiency* from stored to spark energy is about 62%. (This ignores the energy loss of the distributor's component of the spark energy and lumps spark plug energy and distributor spark energy as one item)

The following scope trace of figure 17 shows a typical recording from a Kettering ignition coil system of the spark current at 3000 RPM with a 60 degree dwell angle, in this a case a Bosch GT40 coil in the test machine. The peak spark current reaches – 60 mA:

FIGURE 17.



The test machine simulates an actual contact breaker and associated capacitor so it allows the coil negative terminal to oscillate below ground (negative) as it does with a real contact breaker. When the device driving the ignition coil primary, typically a transistor, has the customary collector-emitter diode, this diode significantly damps the oscillation in the first part of the spark time and while the spark energy remains the same the peak spark current is reduced to around 30 to 40 mA and the spark current waveform adopts a nearly perfect inverted right angle triangle shape with minimal oscillations on its leading edge.

The transfer loss in the magnetic discharge system (in the transfer of stored energy to spark energy) is largely due to the resistance of the ignition coil ***secondary*** winding. Ohmic resistance by definition dissipates energy as heat

Heating of the primary winding increases its DC resistance, so all other things being equal a hot coil stores and therefore discharges less energy than a cold (ambient temperate) coil.

Another feature of MDI is that the energy increases at lower range RPM's. For example at 500 RPM the energy per spark with a 60 degree dwell has climbed to 42 mJ/spark (cold) and 34.5 mJ/spark hot coil with the GT40 coil or 60mJ/spark (cold) and 50 mJ/spark hot with a GT40T coil. Cooling the coil would in fact be beneficial for MDI.

Dwell extension can help a little in the higher rpm ranges > 2200 RPM (4 cyl) Extending the dwell angle or dwell time will result in more stored energy and hence more spark energy. However in the upper rpm range (4 cylinder; 2200 RPM and above) this can only be done to about a 67 degrees dwell otherwise by 5500 RPM the dwell time encroaches on the spark time shortening the spark. When the spark is shortened below about 1.25 mS duration, its energy begins to fall away.

The maximum energy attainable from a (Kettering) MDI style system occurs when the dwell is elongated to the period of the ignition coil firing, less about 1.25mS to allow a spark time. However this is not efficient at mid range to lower RPM's as the coil spends more time in saturation than it needs too, heating it up more and lowering its efficiency due to increase in the electrical resistance of its copper wire windings.

It is worth noting that dwell extension systems are only necessary because the dwell time for a contact breaker (or a reluctor drive in and HEI system) is shorter than ideal, especially in the high rpm ranges.

The way to attain maximum energy from the MDI system is with a simple timer triggered by contact breaker opening which keeps the coil in the switched on state except for a brief period of about 1.25mS to generate the spark. Some use a figure of 1.0 mS. Below about 2200 RPM (4 cylinder frequencies & 60 degrees dwell) the coil is near saturated in that the coil current is not climbing with time to any appreciable amount and has reached a stable value. Therefore increasing the dwell time below 1500 to 2000 RPM doesn't alter the spark energy significantly.

Instead reducing the dwell time reduces unnecessary heat evolution in the coil and that is helpful for the life of the coil.

Therefore, if the ignition coil driver system fixes the spark time at 1.25mS, the system works well and is efficient over about 2200 RPM in a 4 cylinder system, however below that there is significant and unnecessary coil heating without adding any additional spark energy. This RPM threshold or transition point cited is different for 6 & 8 cylinder vehicles and also depends on the inductance and resistance of the particular coil in question. A circuit which executes a “dwell switch over” at the appropriate transition RPM rpm for a GT40T coil in a 4cyl 60 degree dwell system is shown below in the section on HEI ignition. This is one option for the TR4 for electronic ignition. As is the use of a reluctor distributor and an HEI module in conjunction with a lower primary resistance coil, 1.5 Ohm primary such as the GT40RT.

4) ASSISTED MDI (Kettering)

- Contact Buffer Amplifiers & the Boyer unit:

If the contact breaker switches a small resistive load with a low current, say 50mA to 150mA, it will not burn and it will stay clean for years. It is thought that a small current helps keep the contacts of a switch operational, presumably by breaking down surface oxides. Also in switching a resistive load rather than an inductive load there is no sparking or arcing when the contact opens as there is no energy source for this to occur. A suitable *basic* circuit could be that shown in figure 18 below:

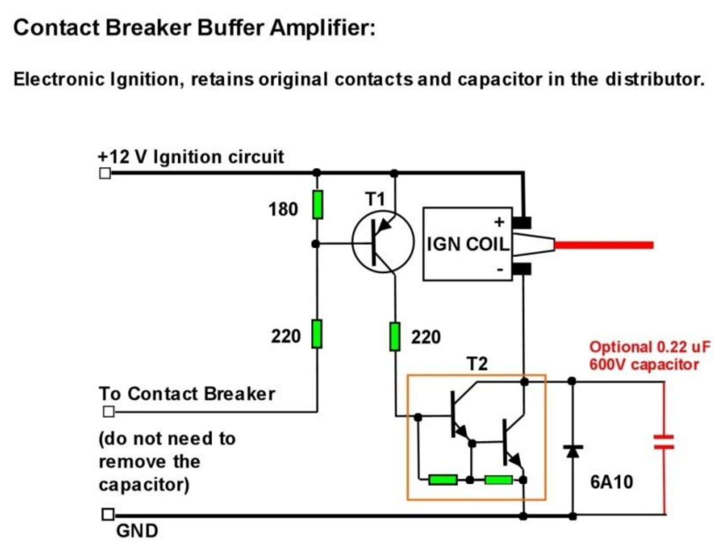


FIGURE 18.

T1 could be a BC640 and T2 a high voltage power Darlington, such as a BU941. These devices also have the collector emitter diode internally so the 6A10 diode can be omitted. The input resistor, 220 ohms, should be 2 watt resistors, the 180 a ½ watt. The base drive resistor for the BU941 may need to be as low as 100 Ohms. Due to the 220 Ohm input resistor value in practice about 0.05 amps will run via the contact breaker (points) when they are closed which is a good value. Arcing at the points is eliminated. The distributor capacitor can be left in situ because the time constant of its value combined with the 220 ohm resistor is only around 50 micro seconds, so the timing is not greatly affected. However the contacts do short out a charged capacitor, if it is left in situ in the distributor, but in practice this is not problematic.

The output capacitor drawn in red is optional however it does reduce the peak collector voltage to around 200V which keeps the BU941's collector voltage at a civilised value. Without this it is advisable to have zener diode protection on the BU941 to prevent the collector voltage rising over 300 to 350 volts. Four 75V 5w zener diodes in series across the collector to negative circuit work. Or 1 watt zeners can be placed from the BU941's collector to its base, turning the BU941 itself into an active 300V voltage clamp.

Clearly the advantage of such a system is that it leaves the car's electrical system original and it is simply a plug in add on module. This has the advantage of keeping the original contact breaker behaviour which not only is important in the timing but defines the dwell angle as well. Internal electronic modules (Hall or optical sensors) placed inside the distributor are more difficult to set up and the dwell angle is often not specified. The "add on" electric buffer amplifier keeps the contact gap and factory timing & dwell specifications intact.

There is a commercial unit made by Boyer- Bransden is not widely known of to other TR owners I have spoken with, possibly because Boyer mainly specialise in motorcycle ignition systems. I have also never seen them advertised in Triumph car related marketing.

This 7 x 5.5 x 2cm thick resin potted module also has two very useful LED's, one green power LED which confirms the ignition is on and a red LED which only goes out when the contacts close and comes on when they open. This is very useful to see that the contacts are working and it is very helpful setting the timing. These are available for around $75 AUD from the Boyer Bransden agents in Brisbane: PPMP (precision Performance Motorcycle Parts). Boyer Bransden Electronics is in Maidstone, Kent in the UK.

The input current of the Boyer unit is around 0.06A which is a good value.

I performed some tests on this unit, again using a transistor to behave as an electronic contact to drive the unit the 5mS on and 5ms off time and with the spark plug & spark present. See figure 19 below.

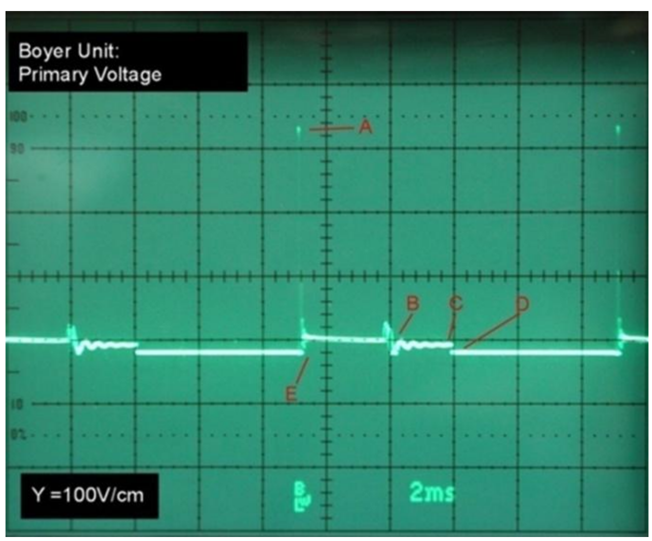


FIGURE 19.

When the “contact” opens the voltage peaks up to about 350V as measured on the coil negative wire with respect to ground. This peak is shown at A in figure 16. At this point the spark has flashed over and begun.

Looking at E there is no negative undershoot in the voltage because the diode in the Boyer unit across the collector & emitter of the output transistor conducts. Some secondary oscillations related to the primary leakage inductance are seen around point E.

However there is no primary 0.22uF tuning capacitor on the output of the Boyer unit so the primary coil leakage reactance resonates at a much higher frequency with the small primary winding self capacitance.

It should be noted that the spark energy is not significantly altered with a buffer amplifier. The gain is in longer lasting contacts in the contact breaker.

The spark is occurring from around point E to just before point B. When the spark extinguishes the secondary alone resonates at around 2.7 KHz shown at B. The voltage on the negative coil terminal again settles near to the 12V battery voltage at C. The “contact” closes again just afterwards taking the coil negative terminal to near zero volts, the voltage level at D. (in this case it is actually about 0.8 to 1 volt above ground due to the collector-emitter saturation voltage drop of the presumed Darlington output transistor in the Boyer unit).

As an experiment I added a 0.22uF output capacitor from the coil negative to ground to observe the effect. This is sown in figure 20 below:

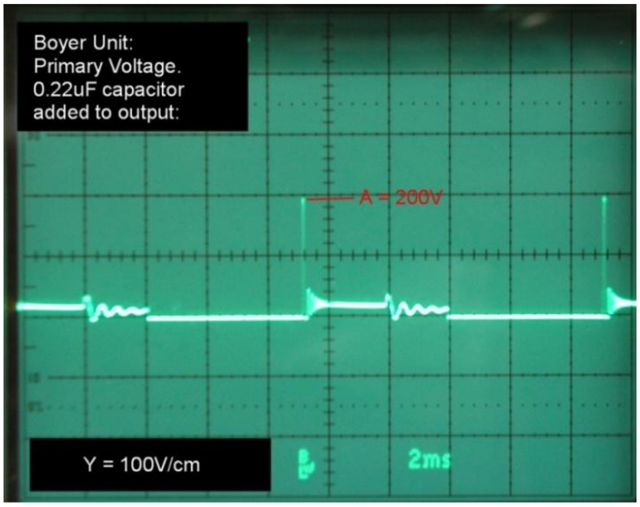


FIGURE 20.

The capacitor has the three expected effects; firstly is has the effect of lowering the primary leakage reactance related oscillation frequency which broadens the width of the high voltage spike and lowers its amplitude. Also the usual 8.7KHz oscillations reappear in the primary voltage. In addition the undamped self resonance drops from around 2.7KHz to around 2.1 KHz as expected. One possible benefit of the 0.22uF capacitor, which could equally well be added across the coil primary as across the points, would be to help protect the output transistor from high voltage breakdown. The photo below, figure 21, shows the Boyer unit:

FIGURE 21.

The photo below, figure 22, shows the unit mounted under the bonnet of a TR4A. The mounting system for the unit as supplied is “double sided tape” This is clearly not a form of adequate mounting in a hot engine compartment. So I made a small metal bracket to clamp it and mount it to one of the ignition coil bolts.

FIGURE 22.

HIGH ENERGY IGNITIONS AND THE HEI MODULE:

Many cars post 1970 were fitted with a reluctor inside the distributor, rather than a contact breaker. The reluctor produces an AC spike like waveform with a sloping profile in between.

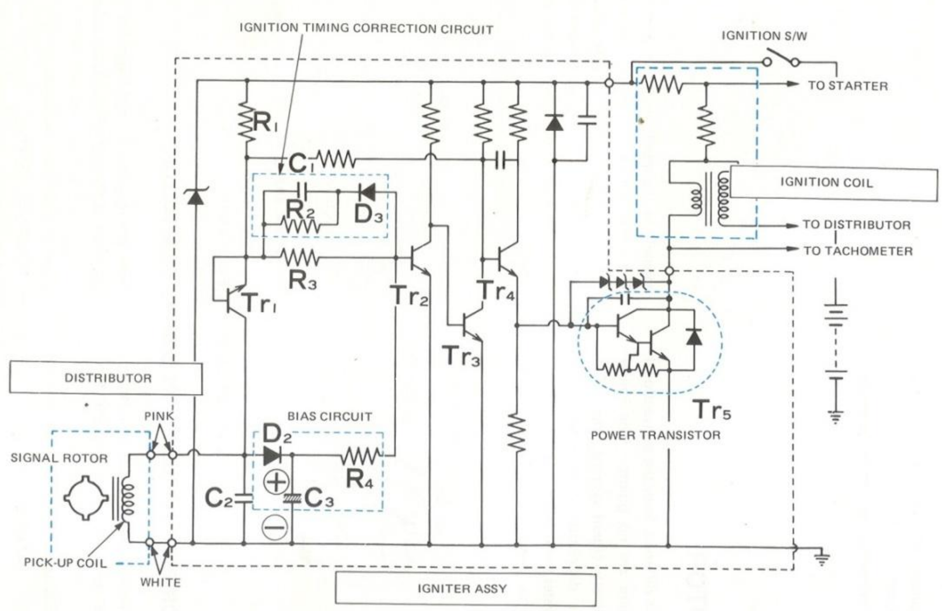
Like any AC generator the reluctor's output voltage is proportional to the rate of change of magnetic flux that the coil experiences. When the tooth like pole pieces in the reluctor are in alignment the rate of change of magnetic flux is zero so the waveform crosses zero volts.

This wave shape caused the designers of the HEI system some headaches. One of the properties of an AC generator is that *both the output voltage and amplitude* are proportional to the RPM. This meant at low rpm and cranking speed they were dealing with a low voltage signal and later at high RPM's a signal potentially 20 to 40 times higher.

If, as was done in early transistor ignition amplifiers driven by reluctors, the reluctor voltage is processed so as to trigger at some threshold voltage, say 200 mV, then the dwell (the time that the reluctor signal is above 200mV and switches on the coil) for the 45DM4 distributor, measured on my distributor test machine is around 26 degrees at low rpm and 44 degrees at high rpm. This is not enough dwell to attain high energy output from the ignition coil at high rpm's.

Toyota had solved this basic problem by 1982. They produced a switching amplifier that modified the dwell by storing energy in a "dwell capacitor" C3 in the diagram below to increase the dwell in proportion to the rpm. The circuit shown fig 22b is from a vintage Toyota training manual of the time. They also noticed that manipulation of the dwell with this method resulted in a timing error as there was a small amount of retard induced in the high rpm ranges, so they added a correction network for this D3,R2 and C1:

Fig 22b



Toyota 1982.

The circuit allowed the maximum possible dwell in the high rpm range. The maximum dwell that can be accommodated leaves at least 1 mS available for spark time over the switching cycle.

It was also realized that in the low rpm ranges it could be useful to shorten the dwell and current limit the drive to the ignition coil. This in conjunction with using a lower primary resistance coil which could attain more than 5 or 6 amps peak current from the 12V supply. This would allow the Darlington output transistor driving the coil primary to go into current limiting mode (reducing the drive voltage to the coil and leveling the peak current).

GM produced the HEI module. It required a special comparator as part of a dedicated IC at the input of the module. The diagram below shows the typical Motorola MC3334 IC used in the HEI module and the type of reluctor waveform that drives the module, Figure 23:

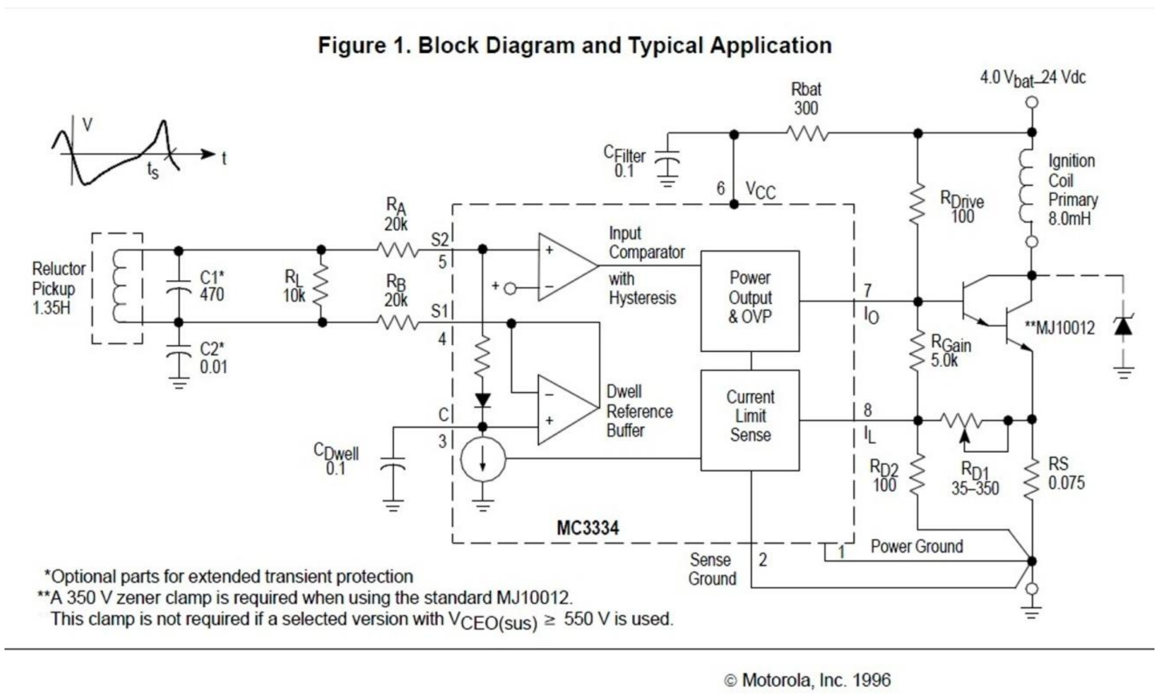


FIGURE 23.

For the sloped and peak like drive waveform from the reluctor, the period of time its voltage is above the comparator's threshold level switches on the coil. To allow for the large variation in signal voltage the lower end of the reluctor is connected to a voltage on pin 4 which represents the charge stored on the dwell capacitor.

The dwell capacitor is charged by the reluctor's peak voltage so that the dwell is lengthened with increasing rpm.

At low rpm when the coil current attempts to climb over 5.5A, the output stage current limiter deploys due to the voltage being detected across the 0.075R emitter resistor RS. This also causes the dwell capacitor to discharge, lowering the dwell time. These two effects tend to keep the ignition coil's maximum current in check at low rpm and this prevents unnecessary overheating of the coil.

This system is arranged so that the maximum dwell that can be achieved in the high rpm range is such that the spark time remains fixed at about 1mS. One other useful feature of the HEI module is that the ignition coil is in the OFF state with no reluctor rotation. So that if the car's ignition switch is left on the coil doesn't sit there overheating.

In the low rpm range the ignition coil primary voltage shows an additional feature not seen in standard MDI systems. The point where the Darlington output transistor comes out of saturation and reduces the coil primary voltage and limits the peak coil current. This is shown on the recording below figure 23b:

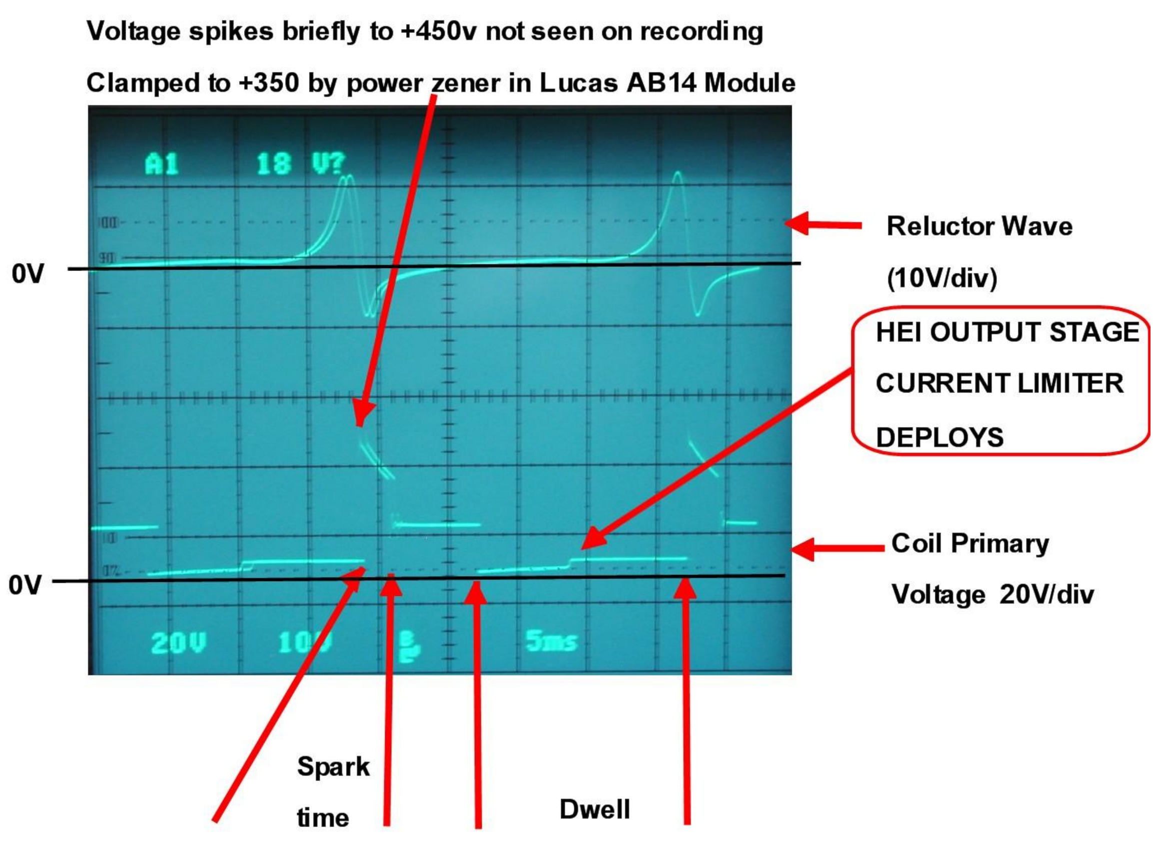


FIG. 23b.

In addition the maximum coil current was limited to 5.5A in most cases and the current limit circuit starts taking the MJ10012 output transistor out of conduction at that level. In terms of any dwell manipulation, for MDI systems as noted above, the maximum dwell that can be accommodated is with a fixed 1mS spark length, with the remainder of the cycle being dwell.

The only quirk of the GM HEI system is that the shift in the DC axis of the reluctor signal results in the actual spark timing becoming increasingly delayed(retarded) at high rpms as the coil switch off point(with respect to the distributor's shaft angle) is shifted further down the reluctor waveform with this system. The effect is probably minor, though Toyota did correct for it. In addition at very low or cranking rpms it is possible that the dwell time is shorter than ideal resulting in a weak spark, especially if there is low output from the reluctor.

The results of the reluctor HEI system are impressive. The data below bears this out. The spark energy at the high RPM range with the 1.5R transformer ignition coil is about double that of the low RPM range with standard Kettering and a standard 3R oil coil, figure 23c:

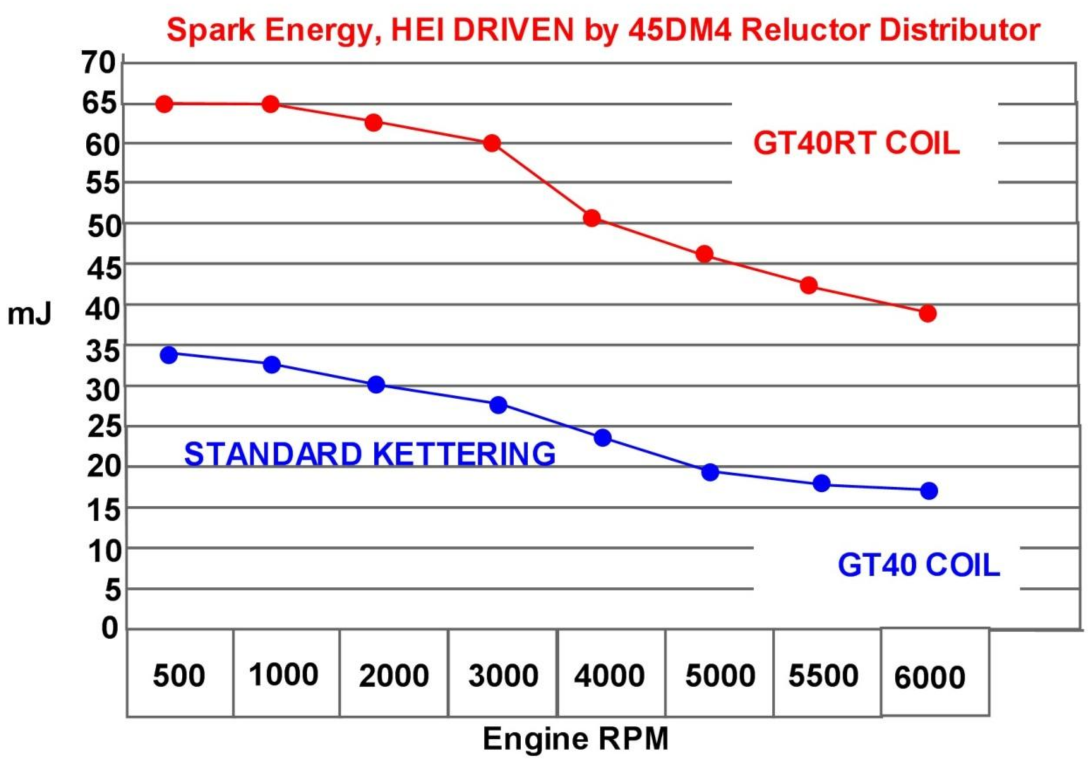


FIG. 23c.

Obviously this makes the HEI system very hard to out-class for its elegance and simplicity. CDI cannot readily produce this spark energy and has shorter duration sparks, although the CDI peak spark currents are much higher than MDI and the voltage rise time of a CDI spark is a little higher.

Beware that not all 45DM4 reluctor distributors have the same reluctors. Lucas had probably designed their own reluctor distributor prior to using GM's HEI module (which is what is inside the Lucas AB14 ignition amplifier) for use with the 45DM4 distributor used in MG's in the early 1980's. There is a lower inductance and lower resistance reluctor version, which is not suited to drive the HEI module in the AB14 unit. This reluctor is not faulty and does not have shorted turns, it was wound with 1/3 the turns of thicker gauge wire, figure 23d:

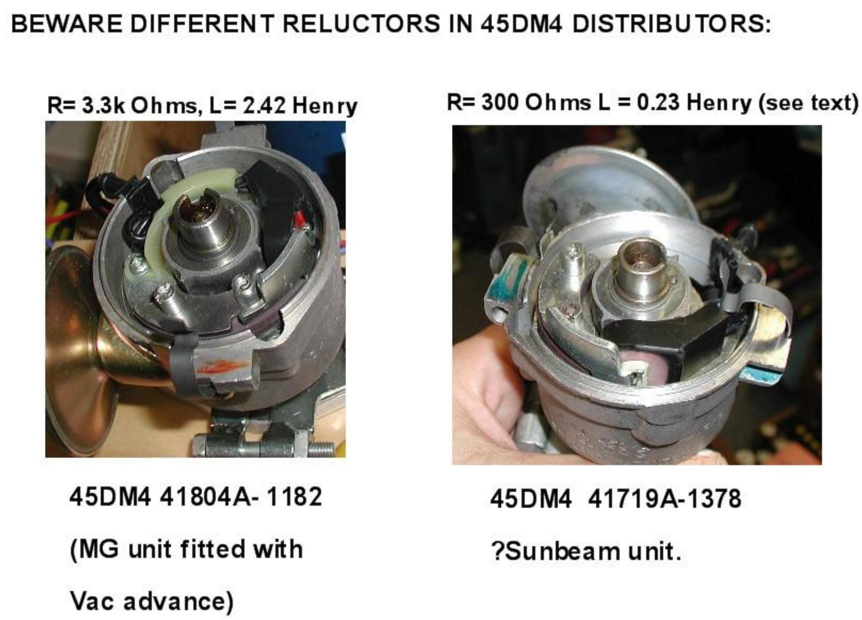


FIG 23d.

The low R and Low L reluctor has about 1/5 the peak output voltage of the one designed for use with the HEI module in the LUCAS AB14 amplifier unit, and as a result gives very low dwell time in the low rpm ranges and low spark energy in this range when used with the HEI module.

Other ways to use the HEI module aside from the usual reluctor driver:

The following circuit of figure 24 shows a simple interface from a contact breaker to an HEI module. The dwell simply follows the contact breaker in the usual way, just like the Boyer unit.

With this system there are some advantages over the Boyer. Firstly the output stage that drives the coil in the HEI unit is current limited to 5.5A, so it makes the unit short circuit protected.

Also the HEI modules are cheap and readily available and are designed to be over voltage and high voltage protected and with this "AC coupled" interface, if the engine is not rotating and the distributor contacts happen to be closed, the HEI switches off the coil so it doesn't overheat, unlike the Boyer unit. Again, as per the Boyer unit, with the same ignition coil there is no spark energy gain of note, only longer contact life. The ground for the HEI module is its metal base which should be screwed to a metal surface or metal case with heat conducting compound to take heat away from the unit.

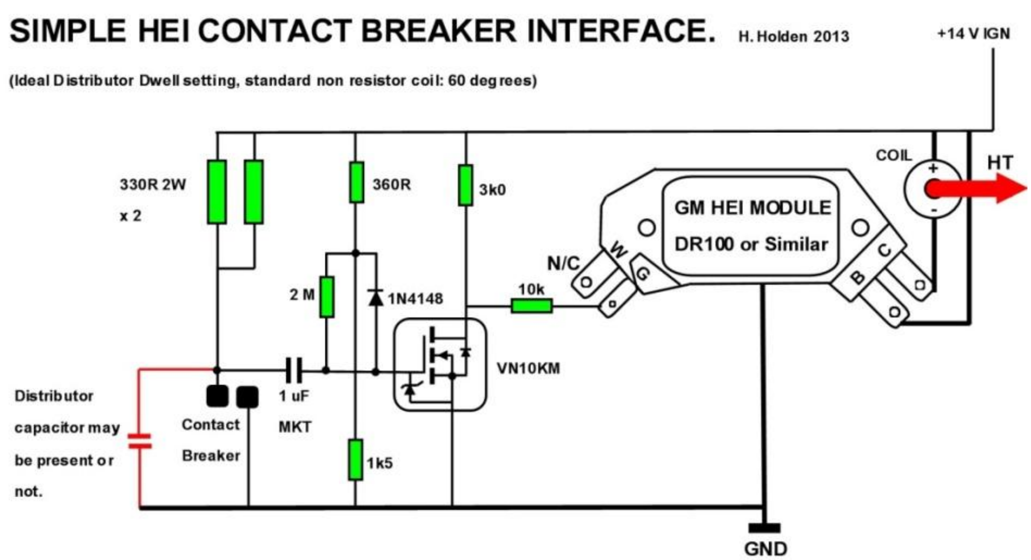


FIGURE 24.

DWELL MOFIFIED MDI SYSTEMS :

It is possible to gain spark energy in the high RPM ranges by manipulating the dwell time as the HEI does. The following more complex HEI interface gains 8mJ/spark at 5000 rpm, by using a “dwell switch over”. Maximum spark energy is attained by fixing the spark time at 1.25mS and therefore having the maximum dwell time. However no additional spark energy is gained below 2200 RPM as the coil is starting to saturate, so at this point the system automatically switches back to standard distributor controlled dwell. This is done without any glitches in the spark timing, figure 25:

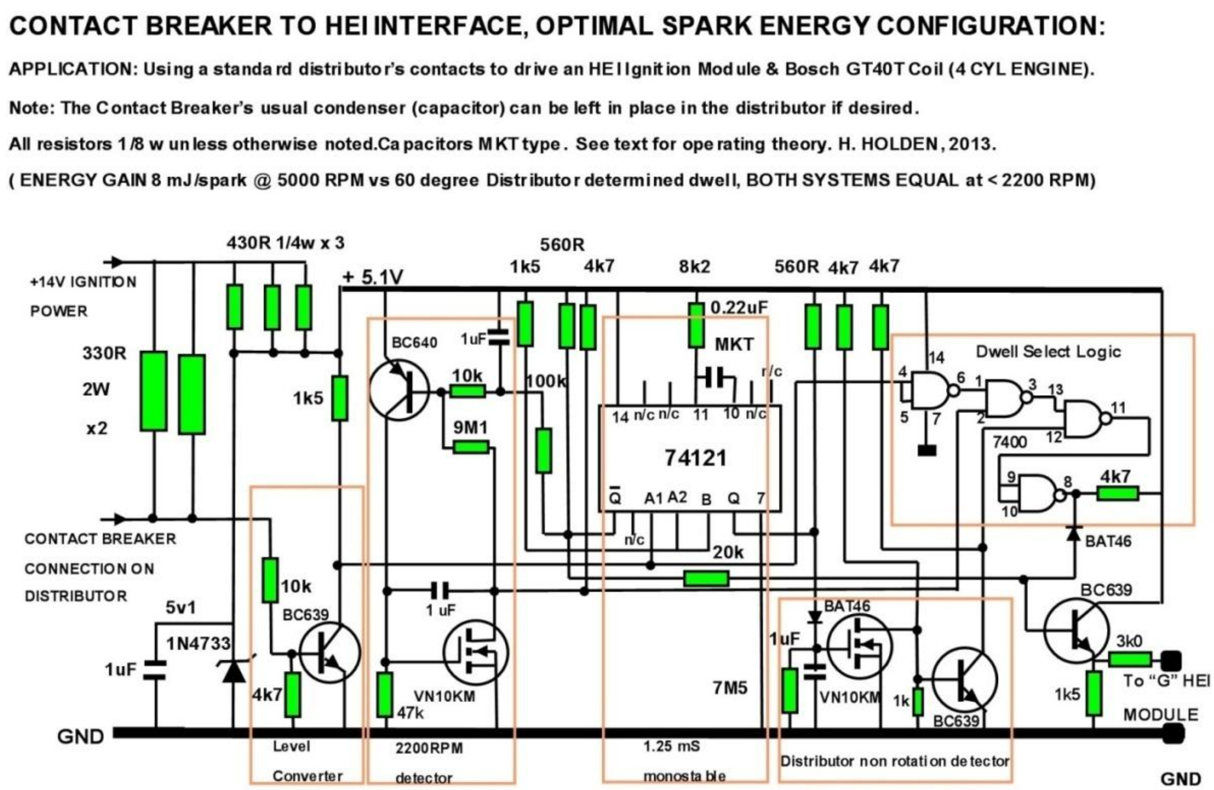


FIGURE 25.

The circuit allows for the fact that in this case there is no reluctor driving the HEI unit, so the dwell control is achieved differently. Again the circuit is such that the HEI switches off the ignition 3 to 4 seconds after the distributor stops rotating. The electronic devices were selected to be hardy & robust in the hot engine compartment environment. Notice the absence of electrolytic capacitors. Use of high current rated semiconductors and robust TTL IC's increases reliability. The best IC's to use are the mil spec ceramic package 54 series versions.

Silicon Chip High Energy Ignition Kit:

Silicon Chip produced a kit which is microprocessor controlled part K4030 from Altronics Australia. The dwell time is set for the specific coil for a "healthy spark" and is remembered by the unit. So the coil is only ever taken to near saturation and not for an unnecessarily long time. The spark length is also set in the high rpm range to 1mS to maximize the dwell time and therefore spark energy.

However the greatest amount of possible energy gain at 5000 rpm, over the standard 60 degree dwell in the TR4 is only about 6mJ to 8mJ/spark for a 4 cylinder system (see below) without also going to a low resistance ignition coil.

Again the unit turns off the coil if there is no distributor signal/rotation which is a handy feature and it has a contact breaker de-bounce function. It also has other features such as boosting the dwell at low battery voltages (not really a feature as this happens automatically with distributor determined dwell as the coil is always very heavily saturated by the usual 60 degree dwell at engine cranking speeds).

The electrical environment is a car is hostile. There are extremes of temperature, vibration and significant voltage spikes. These come about due to inductive devices, such as starter motors, ignition coils, electric motors, alternators etc.

The car battery has a very low internal resistance in the tens of milli-Ohms range. So the battery itself tends to act like a large transient voltage suppressor (TVS) that is directly across its terminals. Further away from the battery's terminals in the car's wiring in the ignition system or charging systems there can be very high voltage transients. As mentioned in the article on electronic dynamo regulators, these transients can be very high especially if there is a bad connection to the battery. The load dump phenomenon from an alternator or dynamo is not an uncommon problem.

In the ignition circuit, a flash over from the ignition coil's output or from poor HT cabling can occur placing large voltage transients not only on to power supply rails of any electronics but also on to the inputs & other outputs of any electronic module connected to any engine bay wiring. Very special precautions have to be taken if fragile devices such as microprocessor IC's are to be used without failure. These consist of TVS devices on the power supply rails and on any inputs and output connections to the module. In addition the module should be able to withstand reverse polarity in case the owner inadvertently reverses the battery polarity on a battery change over. Also the use of electrolytic capacitors (unless specially rated to 120 deg C, see below on the CDI unit) are ill advised inside the engine compartment. These are some of the reasons why most manufacturers put the car's ECU in the passenger's cabin. Some more details about this are explained later.

It is now worth looking at some high energy MDI myths:

MDI High Energy Myth Busters:

Firstly, adding a contact breaker buffer amplifier, and using a standard coil does not change the spark energy or power at any rpm to any *great significance* it merely results in longer lasting contacts in the contact breaker. Although most transistorized ignition modules of the 1960's to 1970's provided a special lower primary resistance coil as part of the kit, as well as the switching amplifiers, so they did produce higher spark energies in those cases.

The following results were obtained on the spark energy test machine. Variables such as coil temperature were controlled for. In addition the diode voltage drop in the artificial contact breaker was also allowed for, but not the actual transistor's voltage drop of the Darlington's Collector - Emitter, which would not be there for a real mechanical contact. So the standard system would produce just a little more or identical spark energy than the electronic module, but in any event they can be regarded as identical for practical purposes. The advantage of the Boyer unit or electronic module is not about increasing spark energy, it is about making the contacts last a lot longer, figure 26:

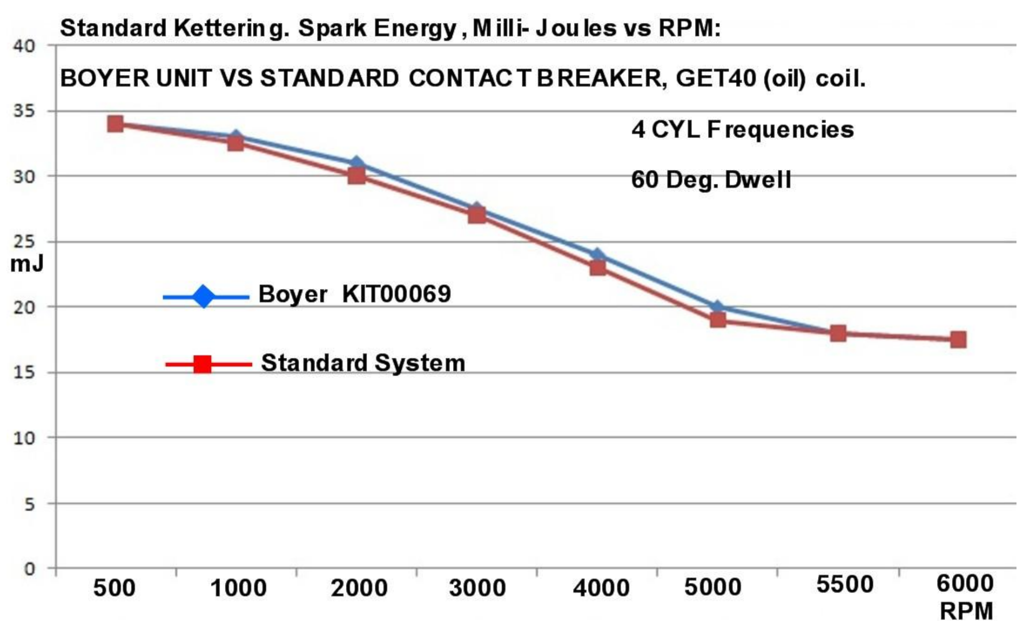


FIGURE 26.

Other “electronic modules” for magnetic discharge systems claiming “high energy” manipulate the dwell time to gain more energy in the high rpm range, but just how much of an improvement is this in terms of real spark energy, with the standard 3 Ohm coil?

Comparing a fixed spark time system with maximum dwell, to a contact breaker controlled system with distributor determined 60 degree dwell, on the spark energy test machine, running 4 CYL switching frequencies, demonstrates that below 2200 RPM (for a Bosch GT40T coil 3R primary) there is no gain in spark energy merely increased coil heating by increasing the dwell time. So below this rpm value the dwell angle is better reduced and the dwell time stabilized to the point where the coil is beginning to saturate. Above this RPM value, the fixed spark length system with maximum dwell is superior, however only a little, see figure 27 below:

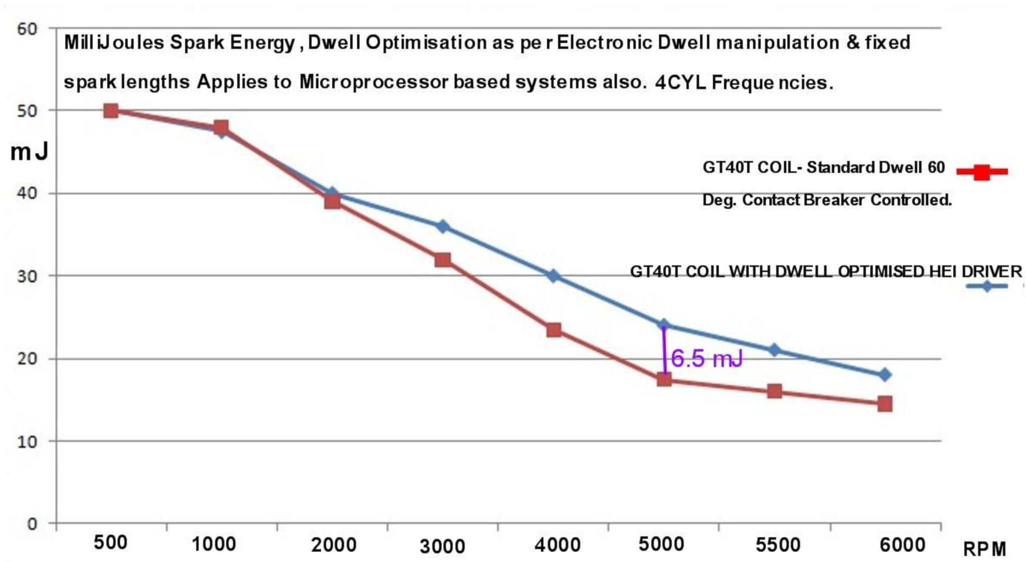


FIGURE 27

For any given ignition coil attempting to gain more spark energy correlates with higher average coil currents. In the low RPM range (<2000 rpm 4cylinder system) the standard Kettering system has more than adequate dwell time if set for the usual 60 degrees. The efficiency (not spark energy) can be improved by shortening the dwell time in that lower RPM region so that the coil doesn’t spend unnecessary time in saturation.

Above a certain threshold RPM, for any given coil, at some specific switching frequency, some spark energy increase can be had by increasing the dwell time. This can be done by fixing the spark time to around 1mS and therefore lengthening the dwell time in between. The gains are not as high as most people believe. For example in a 4clyinder motor and 60 degree dwell system by doing this the maximum increased energy at 5000 rpm that is available is only about an additional 6.5 mJ per spark, falling to zero spark energy gains at 2200 RPM *with the standard coil.*

So most of the time in the *driving RPM range* around the 1000 to 4000 rpm the spark energy gain is only averaging about 3mJ milli-Joules per spark by any electronic manipulation of the dwell time to its maximum possible value (while still allowing 1mS for the actual spark time when compared to a distributor set at a 60 degree dwell angle) with the standard coil and contact breaker or optical or switched Hall magnetic sensor system. This is a hard pill to swallow for enthusiasts of drop "high energy ignition modules based on dwell extension" without changing the ignition coil or type of distributor sensor, but it is true. However, with the HEI system as shown above driven by a reluctor system with dwell control and a 1.5R coil there is a substantial improvement across the full RPM range.

Although at the 5000 rpm area and above and at lower RPM ranges in 6 and 8 cylinder cars where the operating frequencies are higher, there could be a more reasonable gain for racing cars with drop in dwell extension system, but not for a 4 cylinder engine with a max rpm of 5500.

Having said the above, one advantage of a microprocessor based controller for a MDI system is that the dwell can be readily calculated from the length of the previous spark cycle. While again for this 4 cylinder application this technique would only gain a few milli Joules per spark in the driving rpm ranges and only about 6.5mJ at 5000 rpm, it is more efficient in terms of energy consumption and reduced coil heating as the dwell time in the low rpm range is not longer than it needs to be to keep the coil close to saturation.

As mentioned above, an issue with automotive electronics is voltage spike protection. This is critical for any under the bonnet electronic module, especially in the ignition system where it may be confronted by a spark discharge to one of its input or output terminals. Even a small static discharge from the capacitance of the HT wiring, say 10pF, charged to 30Kv stores 4.5mJ and this is enough to completely destroy the delicate input devices inside a PIC micro IC unless ample TVS devices or zener diodes are fitted to all wires leading to the IC from outside the module. A direct full spark discharge to one of the module's terminals could deliver 10 times this energy. The HEI interface above was specifically designed with hardy zener regulated TTL IC's and tough transistors to help prevent these sorts of failures which are more likely with modern fragile microprocessor IC's and Cmos devices vs robust TTL.

(It is hard to get a feel for how much energy a milli- Joule is. However here is an example: A 1mJ to 3mJ burst of Yag laser energy can produce a 1mm diameter hole in a membrane, similar to kitchen style cling wrap plastic in its thickness and strength. This is a common procedure used to clear a hazy membrane behind a lens implant in a person who has had cataract surgery in the past. A 30 to 50mJ energy bolus is equivalent to the spark you see when you remove the spark plug cap to have a look at it arcing to the engine body or ground connection)

For automotive work, regardless of manufacturers saying their regulator IC's are "Automotive Rated" the fact is that a simple zener diode shunt regulator is more reliable & superior compared to the complex LM series voltage regulator modules. The zener is immune to static discharge failures and voltage spikes by nature of their series current limiting resistor and their stable terminal voltage. In addition they conduct like a diode with reverse polarity clamping the reverse voltage to 0.7v and that is helpful to protect the electronics if someone inadvertently fits the car battery in reverse.

So if precision voltage regulation is not needed a zener regulator is the better choice.

With regards to squeezing more spark energy out of an MDI system, of course significant energy increases per spark can be attained by running a coil at higher primary currents, but more stress & heating is placed on the coil. They ideal way to improve the spark energy situation for a magnetic discharge system would be with a physically larger ignition coil with lower resistive losses. However this sort of thing is not practical for home construction. Certainly the Bosch GT40T transformer coil is substantially more efficient that its oil filled GT40 counterpart. Unfortunately Bosch Australia stopped manufacturing the GT40T in 2010.

The HEI system gets around these problems with coil current limiting, reducing the coil stress & heating. But in the low rpm ranges the HEI module heats because its output Darlington transistor is not saturated and it is in current limiting mode.

It should also be noted that decreasing the spark time, below 1mS to gain more dwell time is counter-productive because the shorter spark time has less energy and the energy gain of the increased dwell is lost. In fact on the spark energy test machine with most coils tested this loss occurs with a forced spark time of any less than 1.25 mS not 1.0 mS.

When considering claims of "High Energy Ignition Systems" one must consider the system efficiency (wasted power) heating effects and other factors that can occur with increasing the coil's primary current and therefore spark energy beyond what the manufacturers designed the particular coil for. For example with the standard Kettering system heating effects are very significant:

At 500 RPM, at room temperature, the initial spark energy with the GT40T coil is 60mJ/spark. Due to the fact the coil is running fully saturated for a time at this rpm the heating effects are moderate. 20 minutes later the energy drops down to 50mJ/spark. This is due to the increased resistance of the coil's primary winding with heat and lowering the saturation current.

Pushing a coil harder with higher currents, by using lower resistance primary winding coils or electronic drivers without the standard value of ballast resistor for resistor coils does have a function of diminishing returns with coil heating and shorter coil life.

As will be shown below that the rules are completely different for CDI systems where the ignition coil runs very cool and the spark energy is fairly uniform across the full rpm range as the capacitor in the CDI is always fully charged prior to the next spark. However, generally CDI spark energies are significantly lower than what can be attained especially by reluctor driven HEI systems.

CAPACITIVE DISCHARGE IGNITION:

Basic Principles:

The CDI system stores the energy for creating the spark in the electric field of a capacitor rather than the magnetic field of an inductor as in the magnetic discharge or Kettering system.

One advantage of CDI is that the capacitor can be charged up relatively quickly by a DC/DC converter circuit (known as an Inverter). Typically the capacitor value in a CDI unit is in the order of 1.0uF to 3.0 uF and it is charge to around 350V DC by the inverter. This means that the delivered energy at high RPM's does not fall off as it does in most MDI systems at high RPM's. For example a 1.5uF capacitor charged to 350V has stored 92 milli- Joules of energy in its electric field. The capacitor's energy is transferred to the ignition coil primary winding by a silicon controlled rectifier (SCR or Thyristor) which is triggered to conduct when the contact breaker in the distributor opens or when the sensor device, be it optical or magnetic in the distributor activates.

The diagram below figure 28 is a basic functional diagram of the CDI system:

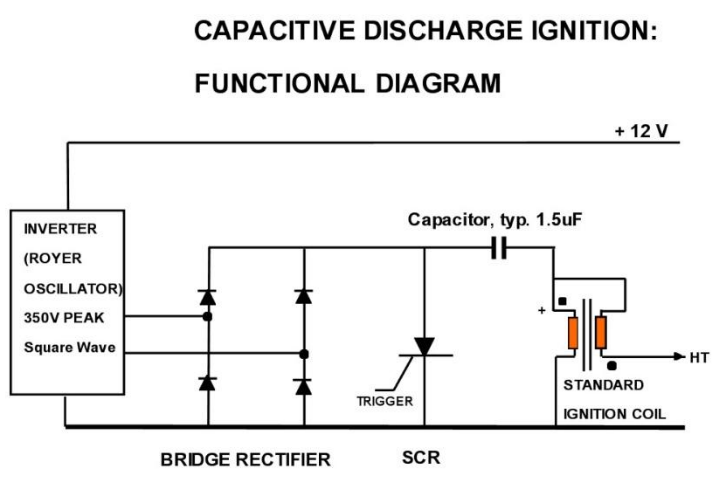


FIGURE 28.

The Inverter charges the capacitor between sparks. When the contacts open the SCR is triggered into a conducting state by a pulse on its trigger input. This shorts out the output of the inverter, but the type of inverter, a Royer Oscillator, doesn't mind this as it automatically deactivates if shorted out. The SCR effectively connects the charged 1.5uF capacitor across the coil primary. The sequence of events is shown in the three trace Oscilloscope recording below in figure 29. The actual spark energy displayed on the Spark Energy Test Machine related to this recording is 15mJ. (This 15mJ is the integrated current- time and spark voltage product from both the positive + negative components of the spark current added together).

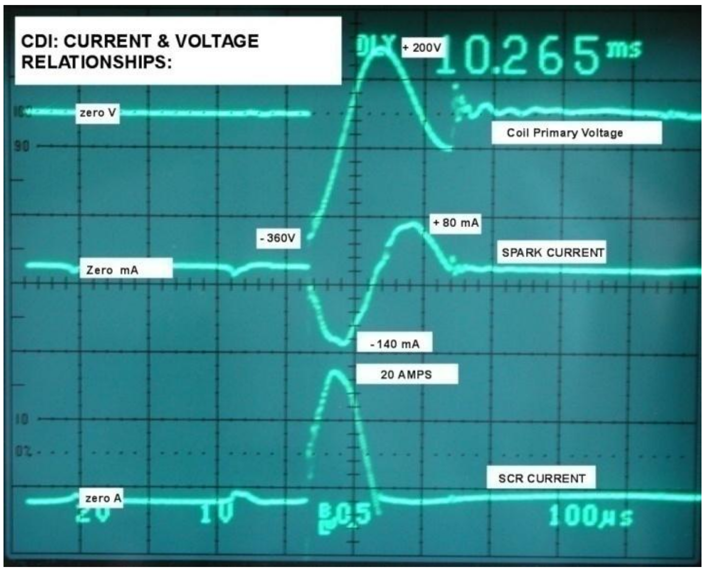


FIGURE 29.

(NOTE: Even without a spark energy test machine, the spark energy can be *roughly estimated* from looking at the recording. The negative peak spark current is nearly sinusoidal and it peaks at -140mA and a duration of about 100*u*S, the charge in Coulombs transferred is the average current x time which is 0.64 x 0.14 x 100*u*S = 8.96 *u*C, and multiplying that by the spark voltage (1000v) yields 8.96 mJ. Likewise for the positive going spark the energy is 0.08A x 0.64 x 100*u*S x 1000 = 5.12 mJ, the total energy being 5.12 + 8.96 = 14mJ, close to the 15mJ measured exactly by the machine with an accurate electronic integration).

The 1.5uF capacitor in the CDI was charged to +360V (measured at the inverter's rectifier output with respect to ground) and had stored 97 mJ prior to the spark discharge. The energy *transfer efficiency* being 15mJ/97mJ x 100 = 15.5% which is the typical poor value when a CDI unit is combined with a conventional oil filled ignition coil which has a very high leakage inductance and makes for a poor transformer.

At the moment the SCR conducts the capacitor's voltage of -360 volts appears within less than a few microseconds on the coil's + or positive connection (the capacitor's voltage here in figure 29 is measured on the coil's + terminal side) because the SCR effectively grounds the positive side of the capacitor.

The SCR's current (which is the current in the resonant circuit comprising the inductance of the coil and the capacitor) in the lower trace of the scope display progressively rises to a high peak value of 20 Amps and over this time the negative spark, or negative spark current is generated. By the time this process is complete the capacitor's voltage (measured on the ignition coil's + terminal) has now charged in reverse to +200V. On the apex of this positive peak, the rate of change of voltage with time is zero, so the capacitor's current and therefore the SCR current is zero and the SCR switches off. When the SCR turns off, as its current has returned to zero, the spark current is also zero at this time . In a spark plug the spark has briefly extinguished at that moment. Over the time that the SCR was conducting, the bridge rectifier output and the inverter were zero volts as they were effectively shorted out.

Now that the capacitor has acquired a + 200V voltage and the SCR has stopped conducting the capacitor now discharges via the coil primary and the bridge rectifier diodes which become forward biased and the capacitor voltage progresses again below zero to about -100V. At this point the inverter re-starts and the capacitor again charges, so its coil + terminal side is zero volts and the SCR side is +360V.The capacitor then awaits the next SCR trigger event.

Notice how the *positive component of the spark current* is generated after the SCR has turned off. It is derived from magnetic storage of energy. The coil acquired this from the charged capacitor. CDI circuit versions/variations which do not use a bridge rectifier and/or do not provide a low impedance capacitor charging pathway to negative will not produce a good positive going spark component. The closely timed spaced double polarity spark is advantageous as its equivalent to a rapid dual fire spark system possibly even superior to multi-spark CDI because in that system the spark sequence my be too late to improve the combustion in any practical way.

One point to note from figure 29, the resonant frequency of the CDI 1.5 uF capacitor in conjunction with the loaded coil (the coil is loaded by spark current) is the capacitor resonating with the primary leakage inductance Lip of 0.86 mH. As can be seen the resonant frequency from the *recording* has a period of about 200uS or about 5Khz and *calculation* suggests it would be 225uS. The reason it is resonating with the leakage inductance and not the coil's primary inductance is that the spark as a constant voltage load effectively shorts out the coil secondary (or loads it very heavily) during the spark time. As soon as the 360V charged storage capacitor is switched onto the coil, for example with the GT40 oil coil with a 1:95 turns ratio, then 34.2Kv appears across the secondary, the spark starting shortly after loads the secondary coil voltage down to 1000v to 1500v.

All CDI's do not produce bipolarity sparks. The MSD 6A CDI series for example has a clamp diode that prevents the positive going spark current along with a capacitor charging pathway that would not support them as well. As will be demonstrated this clamp diode does not significantly affect the spark energy though and results in a negative polarity spark current only.

CDI TOPOLOGY & DESIGN VARIATIONS:

There are a number of CDI circuit variations with two rectifiers instead of a bridge rectifier and some such as the Delta 10C placed a capacitor in series with the transformer feed to the bridge rectifier so that the inverter was not stalled or "shorted out" when the SCR fires. This prevented synchronization of the inverter frequency with the ignition frequency. In addition some of the transistor circuits driving the transformer primary are single ended oscillator designs rather than push pull like the Royer Oscillator. Sometimes the secondary circuit only contains one rectifier (or two rectifiers in series) and the capacitor discharge pathway to negative must pass through the inverter transformer secondary, this attenuates the positive going component of the spark current. Also some SCR trigger circuits like those in the MSD 6AL unit were multi-spark.

Regardless of these variations the physics of transferring some of the capacitor's stored energy, via the ignition coil to become spark energy is the same in all cases.

In the system such as the original Delta MARK 10, when the SCR fires the inverter is transiently shorted out and stops. It has to restart again to recharge the CDI's storage capacitor and it takes a few inverter cycles to do it. It also meant that a lot of the time the operating frequency of the inverter becomes synchronised to the spark frequency and the radio interference from this produces a buzz which is related to engine rpm. There are frequencies of spark timing that do not result in synchronisation of the inverter and these occur at narrow intervals about 400 rpm apart over the rpm range.

Later on it was realised that placing a series capacitor on the inverter's transformer output would create an impedance high enough so that when the SCR fired the inverter would keep free running and its frequency be independent of the spark rate and it could recharge the capacitor more quickly as it did not need a few cycles of recovery time. This meant the CDI could have a larger storage capacitor 3uF *vs* 1.5uF and significantly increase the spark energy output. This was done in the Delta MARK-10C where they also used a higher inverter frequency of around 5KHz vs about 1.4 KHz for the Mark10B.

Figure 30 below shows some of these design variations. The most "powerful" of the shelf CDI in the 1970's was the Mark 10C and as far as I'm aware this has not been out done by any other unit as the MK10C had a very large SCR capacitor (3.0 uF) charged to 400V and had a system which enabled the inverter to free run over the spark discharge time.

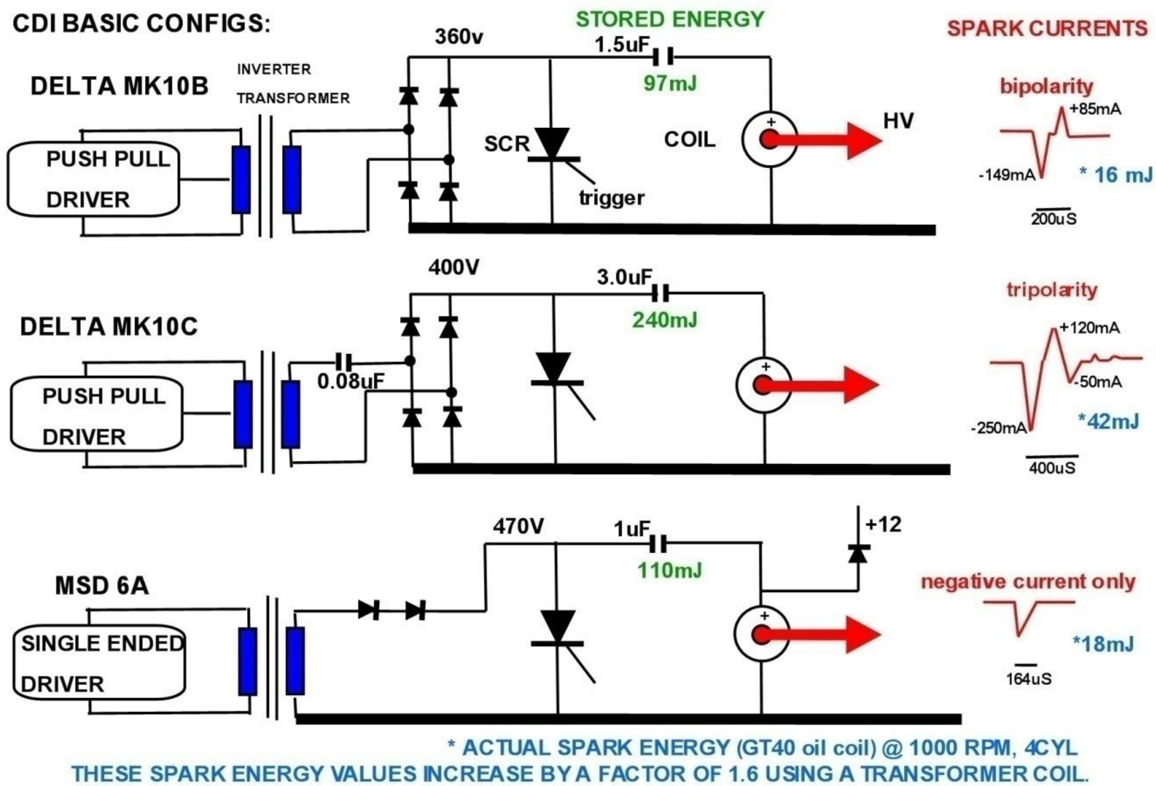


FIGURE 30.

The MSD circuit, by its rectifier design on the output of the inverter transformer, meant that current could not be returned from the transformers (coil's) magnetic field to the SCR capacitor, it would have to pass via the secondary winding of the inverter transformer, so a weak positive going spark current component would be produced. To prevent this and recover the energy that would be in the positive component of the spark current they incorporated a clamp diode to the +12 volt supply. Therefore the bipolarity spark is eliminated and the negative spark current elongates in time. The effect of this diode on CDI function is shown below, first without the clamp diode figure 31, then with a clamp diode added (to a Delta MK10B) figure 32 to demonstrate the effect. The spark energy, by adding the clamp diode is virtually unaffected, increasing by about 1mJ on the test machine.

FIGURE 31.

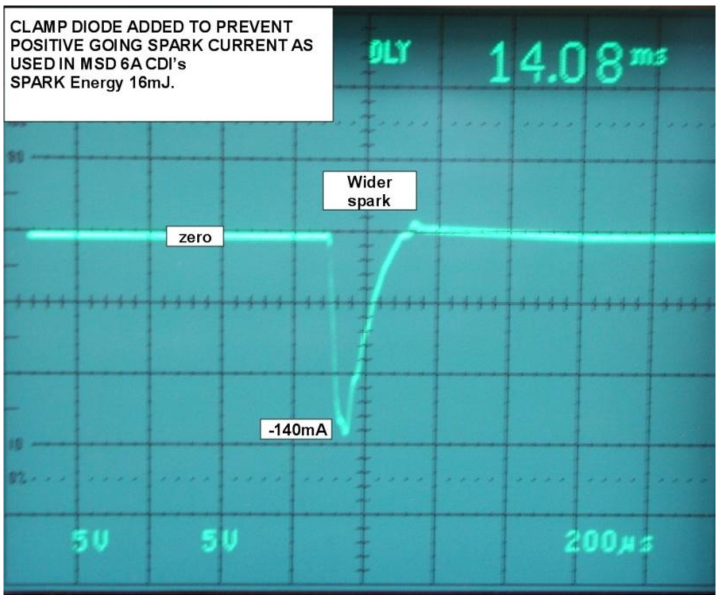


FIGURE 32.

The following is a spark current recording on Delta's Mark 10C, which shows it to be a multi polarity spark with a series of small trailing sparks at the inverter frequency, figure 33:

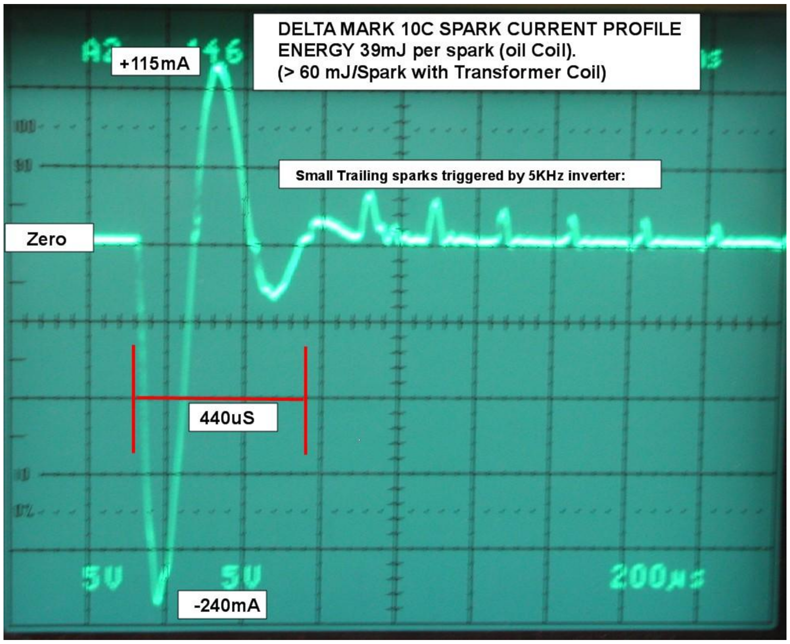


FIGURE 33.

QUOTED vs REAL SPARK ENERGIES:

In a simple CDI experiment with a Delta 10B CDI with a Bosch GT40 coil on the test machine, even though 92 mJ was stored in the capacitor, it turns out that only 15 mJ ends up becoming spark energy. Specifically this is the energy in milli- Joules delivered to a 1000V zener spark plug and would also be the energy delivered to a 1000v voltage drop physical spark inside the combustion chamber.

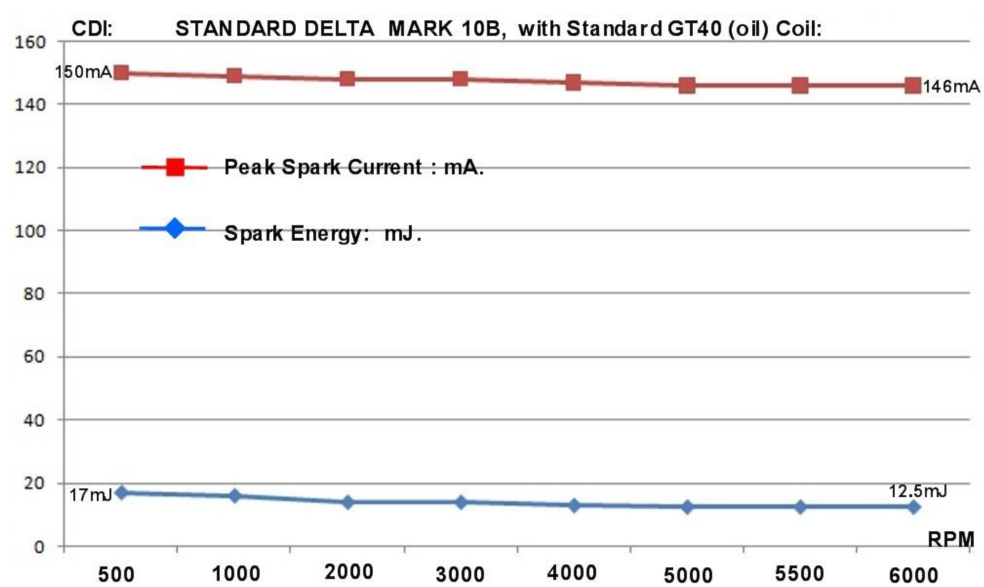
This is why it is misleading when a CDI manufacturer quotes the capacitor's stored energy as the "spark energy". Sometimes the wording is very clever to say something like: "available power" = 0.15 Joules per pulse which was done in the 1970's vintage Tiger 500 marketing literature. Another version of this is the wording "energy output" and it is obviously not widely known that this value is not in fact the spark's energy.

It would appear that very few true spark energy test machines have ever been built, so it became customary to measure the energy per discharge from a CDI unit into a resistive load for comparison with other CDI units. So perhaps this leveled the playing field in terms of comparing the specs of different brand CDI's for marketing purposes. It should be remembered that the figures quoted are not the actual "spark energy" which as noted for CDI is very dependent on the ignition coil design. It is good with a transformer design coil, but very poor with an oil filled standard coil due to its high leakage inductance. Also, in practice, there is a small energy loss in the distributor's spark gap that is not accounted for.

In CDI systems, only about 16% of the energy stored in the electric field of the capacitor transferred to actual spark energy with a standard oil filled coil design such as the Bosch GT40, and around 28% transferred with a more efficient transformer coil, such as the Bosch GT40T.

The following figure 34 shows a standard MARK-10B recording with an oil coil:

FIGURE 34.



Referring to figure 34, the low uniform energy per spark around15mJ per spark comes from the fact that the duration of the spark is very short, only about 200 uS (for the negative and positive sparks added) vs over 1mS for MDI even though MDI peak currents are much lower at around 30 to 60 mA for MDI vs >150 mA for CDI. The width of the spark in CDI is determined by the leakage inductance Lip of the coil (referred to the primary side) and by the energy storage capacitor value that define a specific resonant frequency. The Lip is a little higher for the GT40T than the GT40, the GT40 has a much higher Lis than the GT40T.

As one might expect, since the ignition coil in a CDI system is used in a transformer mode, the results are substantially better when the CDI is used with a transformer coil. However it is interesting that the original CDI marketing for aftermarket CDI units denied that there was any improvement with special coils. As can be seen from figure 35 below (compared to figure 34) there is a substantial improvement.

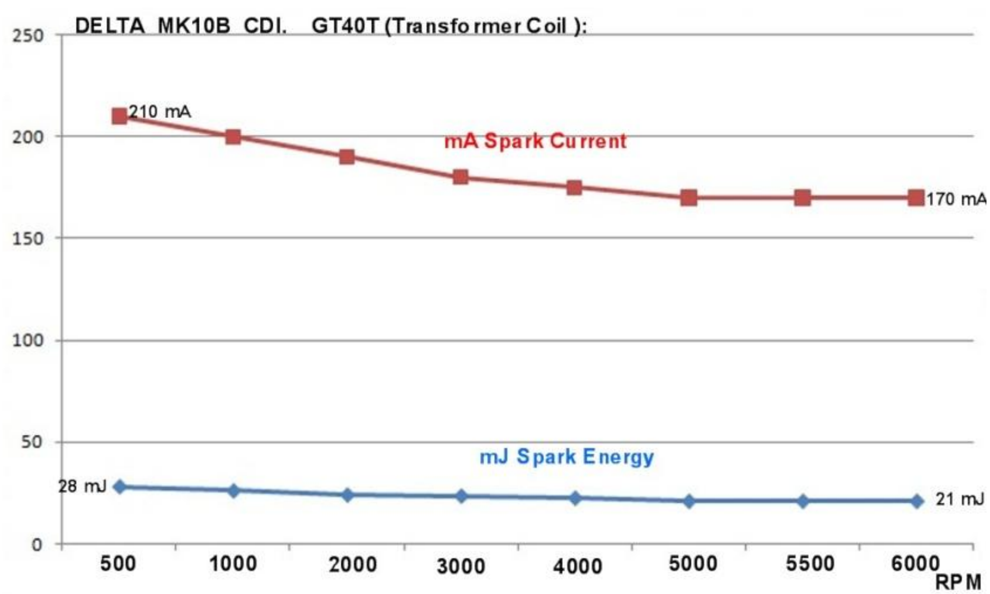


FIGURE 35.

This is a transcript from marketing paraphernalia on a CDI unit made in the 1970’s with regard to using a special coil with the CDI unit:

“Although many experiments have been conducted with regard to special coils, these studies have shown that the increase in efficiency bought about by special coils is so small that the additional expense is unjustified. The same tests proved that the standard coil supplied with the automobile is more than adequate”

The graphs of figure 34 & 35 above disprove that statement completely.

With a superior transformer coil the CDI spark energy is nearly doubled and the peak spark current substantially increased. This is because standard oil filled coils with an open magnetic pathway with their high leakage inductance are not very suitable for CDI use. However the manufacturers of CDI’s in the 1970’s were trying to sell an aftermarket device and if the owner had to buy a special new coil as well as the CDI unit it would have been a commercial failure. Note also the clever wording of the above remark, using the words “increase in efficiency” which does not relate to spark energy at all, merely the ratio of energy in *vs* energy out from a system under consideration.

MODIFYING A MK10B CDI UNIT SPECIFICALLY TO SUIT THE TR4:

While a DELTA MARK 10B could be fitted directly to a TR4, the following modifications improve its performance. Even without these modifications it would work well, provided it was used with a non resistor type of transformer coil such as a Bosch GT40T or equivalent.

The photo below, figure 36, shows a typical aftermarket CDI unit available in the late 1960's and early 70's. The early ones such as the Delta 10 have astonishingly good manufacturing quality shown below. These were designed to be able to provide CDI spark in an 8 cylinder system which has twice the spark repetition rate as a 4 cylinder car like a TR4. It appears to be not widely known that these units produce two very closely spaced sparks of opposite polarity. They were never marketed as multi-spark, but they are in fact a dual closely spaced spark system.

FIGURE 36.

The inverter's ability to recharge the capacitor in a certain time frame set a limit on the size of the storage capacitor that could be used while still being able to recharge it adequately between sparks at maximum rpm in an 8 cylinder system. It means for a TR4 application the units output and spark energy can be substantially increased by increasing the value of the CDI storage capacitor. The inverter can still recharge the capacitor up to about 6500 to 7000 rpm in this 4 cylinder application which is higher than the TR4 engine will be running.

The physical construction of this unit is something I'm sure the manufacturers where proud of. It contained high quality Siemens and ERO brand capacitors, Siemens diodes and an RCA SCR. The resistors were a mix of Philips & Allan Bradley brands. The case was a very attractive gold anodized aluminum and the changeover switch very high quality. The inverter was a push pull design known as the Royer Oscillator based on two TO-3 germanium power transistors which are very efficient in the application as they have a very low C-E saturation voltage drop, better than a silicon transistor in fact.

Internal circuit of the MK10B, figure 37:

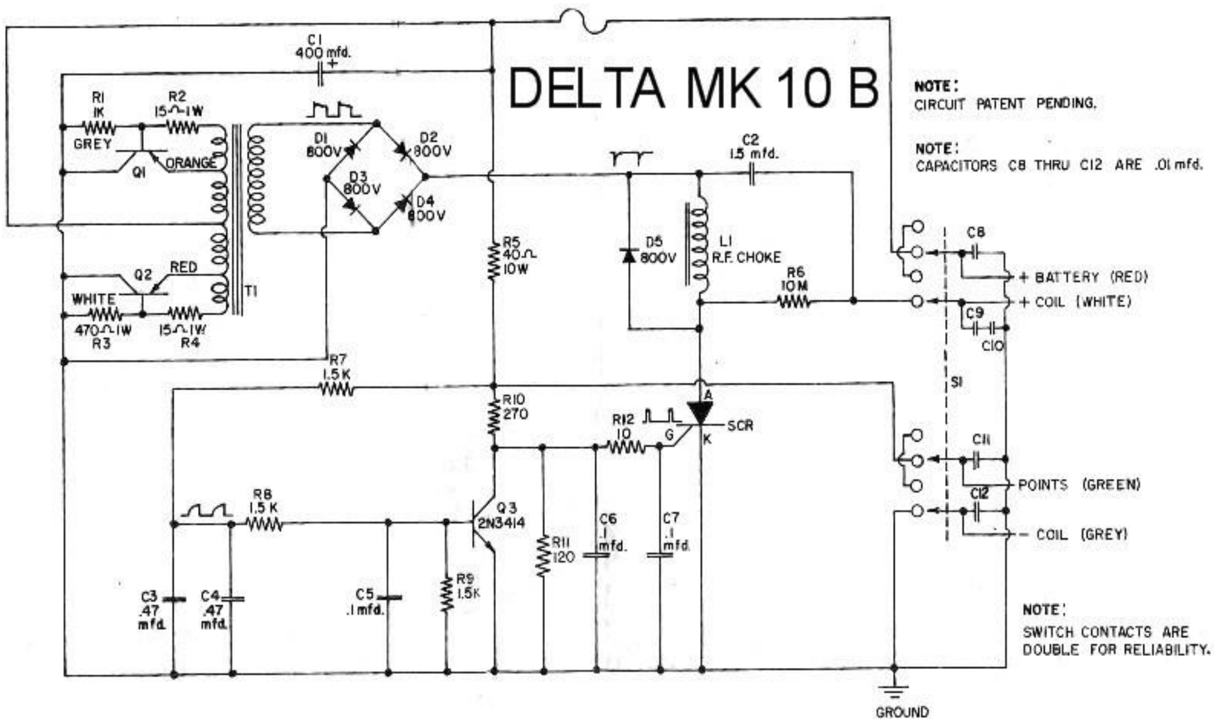


FIGURE 37.

The SCR is a small TO-3 package RCA type 39938 and it was not particularly well heat sunk to the case, only via a small brass clip. It is wise to upgrade this if the unit is up-rated with a larger storage capacitor as shown here.

The output voltage on the cathode of D2 & D4 in use, between sparks, is close to 360V. The SCR trigger circuit is quite clever in this MK10B version. When the contact opens, the current supplied via R5 and R10 and via R12 triggers the SCR on. R7 begins to charge C3 and C4 and after a short time Q3 conducts switching the SCR gate of. So this arrangement synthesises a short drive pulse to the SCR's gate. C6 and C7 reduce the overall frequency response so that any points bounce is ignored and the SCR doesn't retrigger with points bounce.

Notice also, unlike many push pull inverter circuits, the value of R3 does not match R1. This imbalance in the transistor bias ensures a good re-start after the inverter gets shorted out and stops oscillating during the spark time. It's a subtle but important feature.

The Delta 10B is significantly improved (for 4 cylinder use) by adding a 1uF 600V (or 800v) capacitor across C2. This increases the total capacity to 2.5uF and the inverter still operates to 7000 rpm. Over 7000 RPM the inverter fails to charge the higher capacitor value and the spark drops out.

The following figure 38 shows the PCB's from a MK10B. These PCB's were modified with 1.5mm brass eyelets to strengthen the mountings for the wires and components and to prevent PCB track damage by repeated re-fitting of the wires or components.

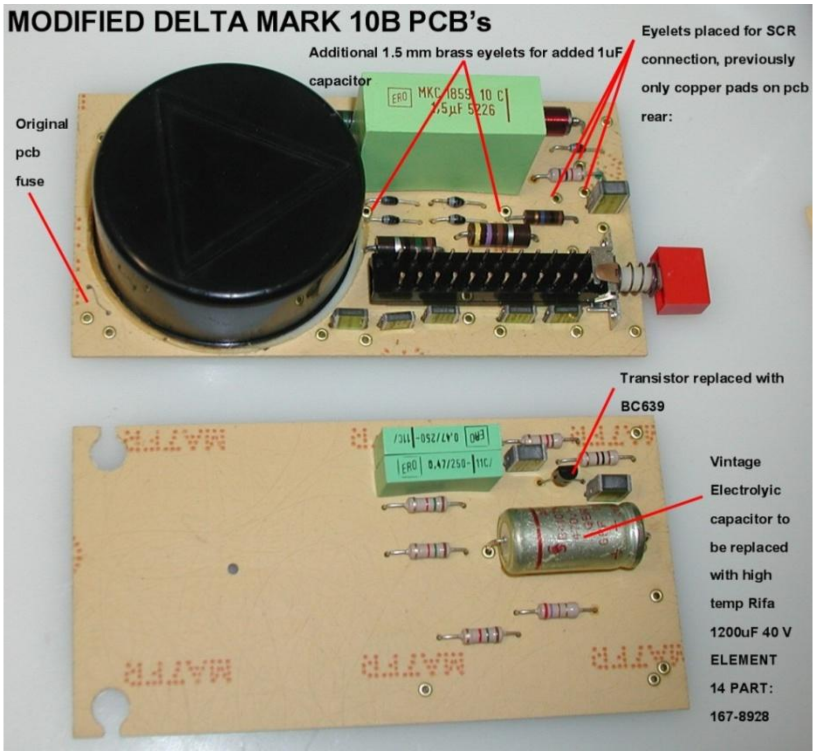


FIGURE 38.

It is important that the aged original 470uF electrolytic capacitor is replaced. An ordinary electrolytic won't do. It must be an extended temperature range part for under bonnet use. These are made by RIFA and are available from Element 14 (or Newark USA).

Also the SCR is best changed to a TO-220 version screwed to the internal case for better heat sinking. A 6010L SCR is very suitable. So the original TO-5 package SCR is removed from its mounting below where it was simply soldered to the surface tracks. Three 1.5mm diameter holes were drilled and brass eyelets were fitted through the PCB's pad copper pads in that location. Also two brass eyelets are fitted to allow the addition of the extra 1uF storage capacitor. The new SCR is mounted to the aluminium casing for better cooling, figure 39:

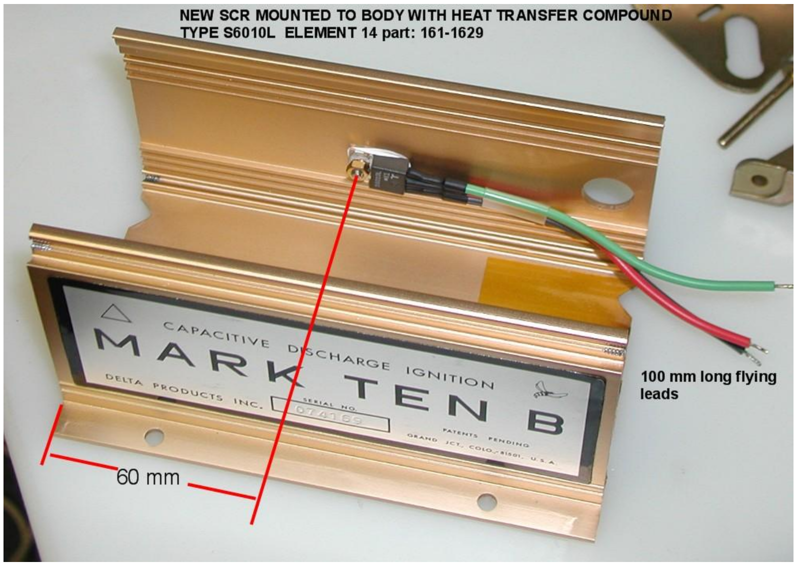


FIGURE 39.

The figure 40 below shows the PCB's with the added 1uF capacitor:

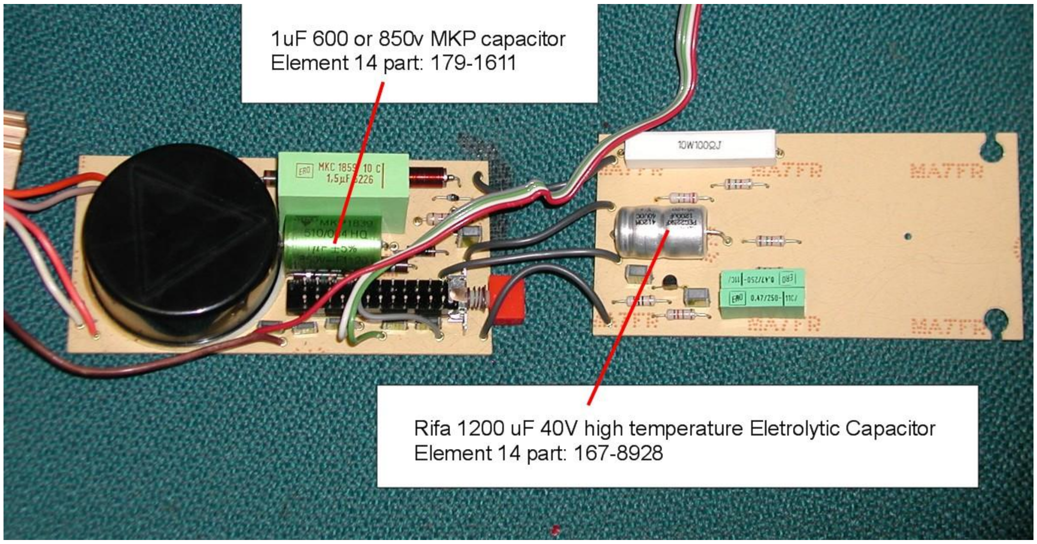


FIGURE 40

The figure 41 below shows another view during reassembly:

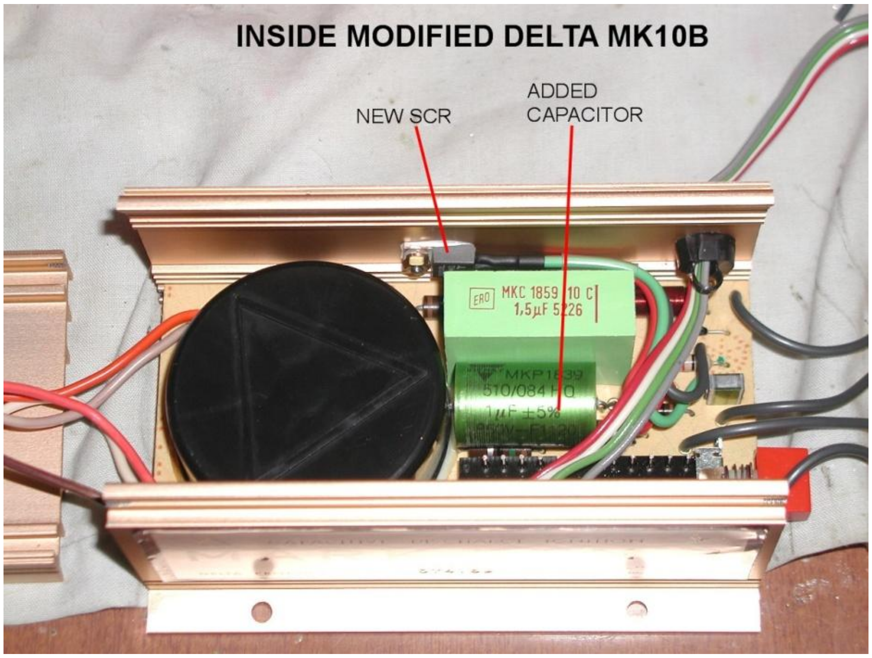


FIGURE 41.

The following figure 42 shows the unit installed under the bonnet:

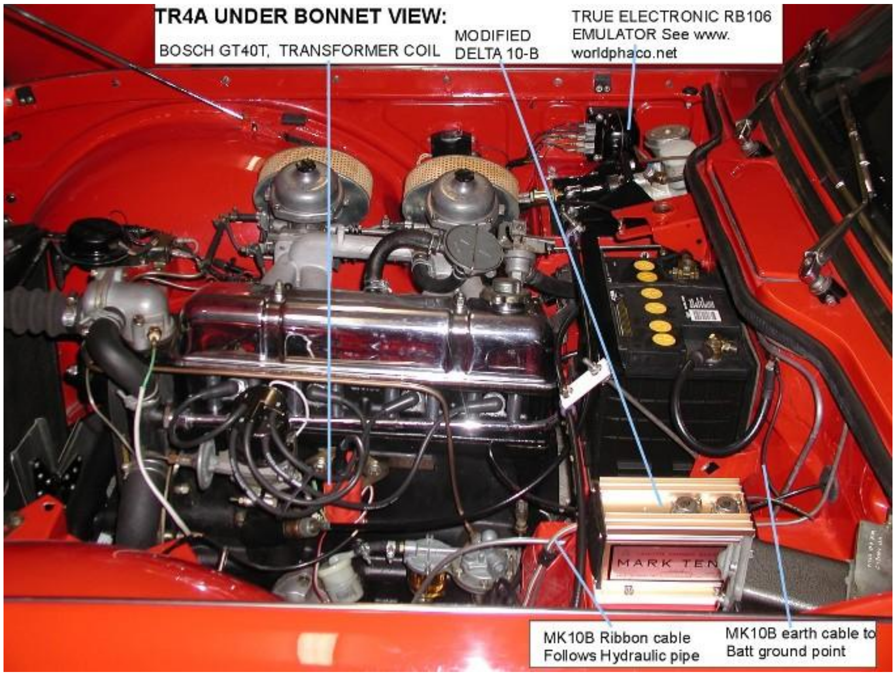


FIGURE 42.

The following graph figure 43 is a measurement of the real spark energy and peak spark current. (The magnitude of the peak negative spark current is plotted as a positive value for convenience)

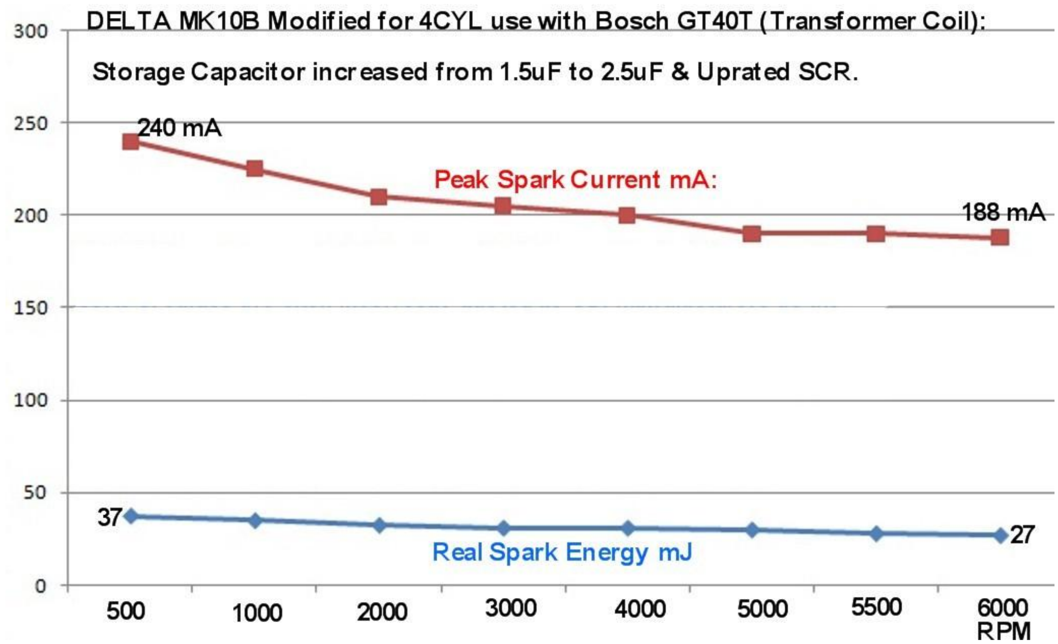


FIGURE 43.

The stored energy is in the 2.5uF capacitor 153mJ. Combined with the superior Bosch GT40T transformer coil the actual spark energy is excellent and fairly uniform across the rpm range from 37 to 27 mJ per spark, which as noted is a dual polarity spark. The peak spark currents are 3 to five times that of an MDI system.

However, as noted above, the spark energies are not nearly as high as reluctor driven (45DM4 distributotr) & HEI with a 1.5R GT40RT ignition coil and this is a much simpler system.

Summary:

So after extended investigations of CDI, the ideal partnership for a TR4 for CDI is the Bosch GT40T transformer coils coupled with a Modified Delta MARK TEN B CDI unit, figure 44:

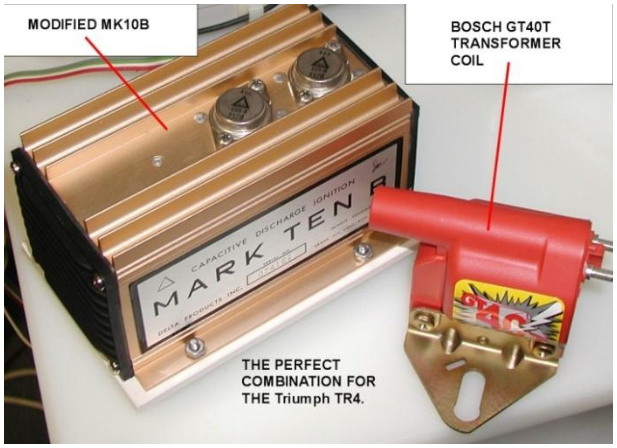


FIGURE 44.

This unique combination has higher peak spark currents than any modern Kettering (MDI) based ignition system, be it either transistor and/or microprocessor based. It also has reasonable total spark energy in the high RPM range compared to MDI. To confirm this assertion, study the graphs and data in this paper vs other CDI or MDI specs and be sure to remember that the energy which is stored in the CDI's capacitor is not in fact the actual spark energy which is much lower. In addition if a CDI is a "multi-spark unit" adding the spark energy from a series of consecutive sparks is not as meaningful as the energy per spark of the initial spark. Combustion is initiated by the first spark and the utility of any later sparks is limited.

However on balance this is rivalled and probably beaten with a 45DM4 reluctor distributor driving an HEI module and using a GT40RT coil. So it would appear MDI wins out, but this requires a new distributor. The pertronix units which use magnets and Hall switch devices, or optical encoders or contact breakers cannot produce the spark energy & dwell control of the reluctor driven HEI system which cam maintain spark energies over the 65 to 40 mJ range over the engine's full rpm range vs 37 to 27mJ for the CDI. The reluctor-HEI is reliable & simple too.

Even without the aid of a "spark energy test machine" the energy of the spark can be assessed by looking at the spark current by placing a 100 Ohm 2 watt resistor in series with a working spark plug's ground (negative) connection, or zener plug (as described in the article in the Spark Energy Test Machine) in a test jig. By looking at the current time profile on an oscilloscope and assessing the average charge transferred over time and then multiplying that by the spark voltage drop to yield an approximation of the actual spark energy. The test machine simply does it automatically and very accurately using Analog integration and displays the result on a meter.

CAPACITANCE DISCHARGE PHYSICS:

This section is included for those who are interested in the physics of a capacitance discharge system. Figure 45 below shows a capacitor, charged up to 360V (as it is in a Delta Mark Ten ignition) and being discharged by a switch into a load which contains both resistance & inductance:

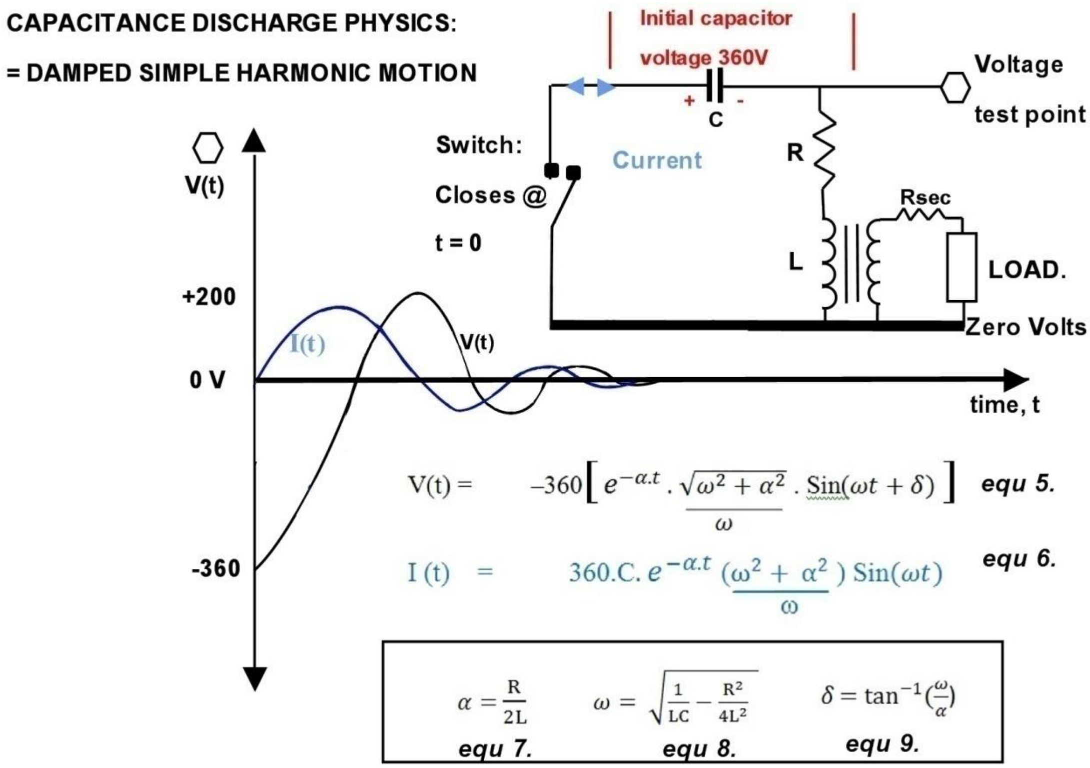


FIGURE 45.

The equations 5 and 6 show the current and voltage with time starting at t = 0 when the switch closes. Equation 7 is the damping constant. In the electronic version the switch corresponds to the SCR switching on for the positive polarity of the primary coil’s current and the bridge rectifier conducting for the negative polarity of the coil’s current.

As can be seen the circuit current (equation 6) leads the voltage across the capacitor (equation 5) because a capacitor’s current is proportional to the rate of change of voltage with time.

In the case of the ignition coil, the secondary load impedance (which is composed of leakage inductance and resistance) is transformed into the primary winding (scaled down by the square of the turns ratio) and this along with the primary coil's resistance R, and the primary side leakage reactance the forms R & L circuit of figure 45 which the charged storage capacitor is loaded into.

The relatively low (1500V) fairly constant 1000v voltage of the spark plug's spark and the distributor's spark act as a load similar to shorting the coil out because the 1500V is a relatively small percentage of the 20 to 35kV generated by the coil's secondary winding.

Figure 46 again shows the coil parameters for the Bosch GT40 regular coil and it transformer coil counterpart; the GT40T:

PARAMETER	GT40T	GT40(oil)
Rp	3 Ohms	3 Ohms
Rs	8.56k	17.5k
Lp	13.5mH	8.16 mH
Ls	38H	73.6H
Lip	1.4mH	0.86mH
Lis	3.53H	7.92H
TR	53	95

FIGURE 46.

The electrical model of a transformer has a useful function where the resistance, say of the secondary winding and the leakage reactance of the secondary winding can be "transposed" into the primary winding (or visa versa). This is done my multiplying the value to be moved from one winding to the other by the transformer's impedance ratio (which is the square to the turns ratio). This is shown in the diagram below in figure 47.

This conversion allows one total value of R and L to be known and also demonstrates the load that the capacitor discharges into. It also allows the calculation of the voltage and current with time functions of equation 5 and 6 and an easy calculation of the resonant frequency from equation 8 and the relation; $\omega = 2\pi f$.

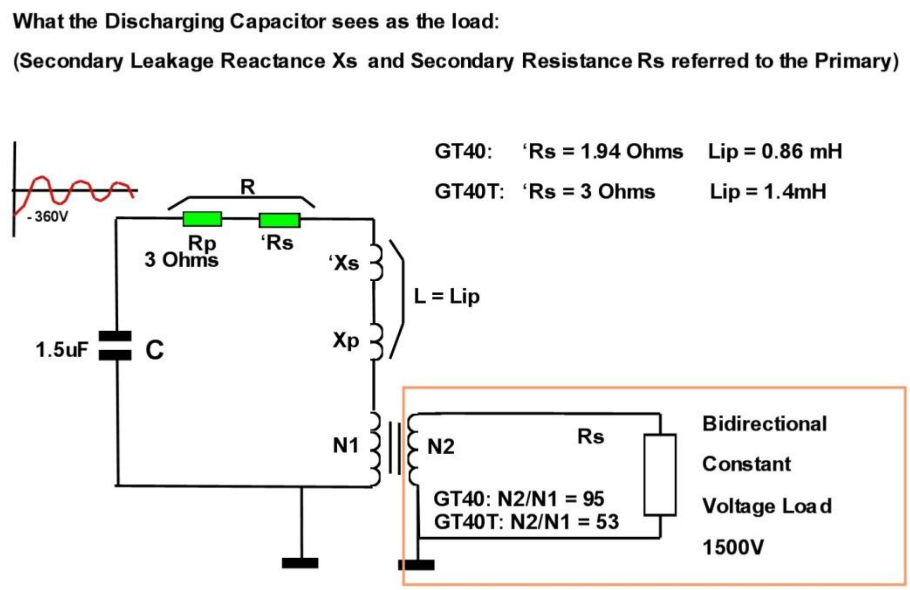


FIGURE 47.

As can be seen the leakage inductance (Lip) total all referred to the primary side is a little higher for the GT40T than for the standard GT40 oil coil. The resonant frequency is in the order of 4360Hz for the 1.5uF capacitor discharging into the GT40 coil.

Then for analysis it is useful to move all of the resistance and leakage inductance to the secondary winding. The total leakage inductance Lis is composed of two leakage reactances; Xs which is the secondary leakage reactance and 'Xp which is the transposed primary's leakage reactance after multiplying by the transformer's impedance ratio. ('Xp or 'Rp indicate primary values that are transposed into the secondary) Figure 48:

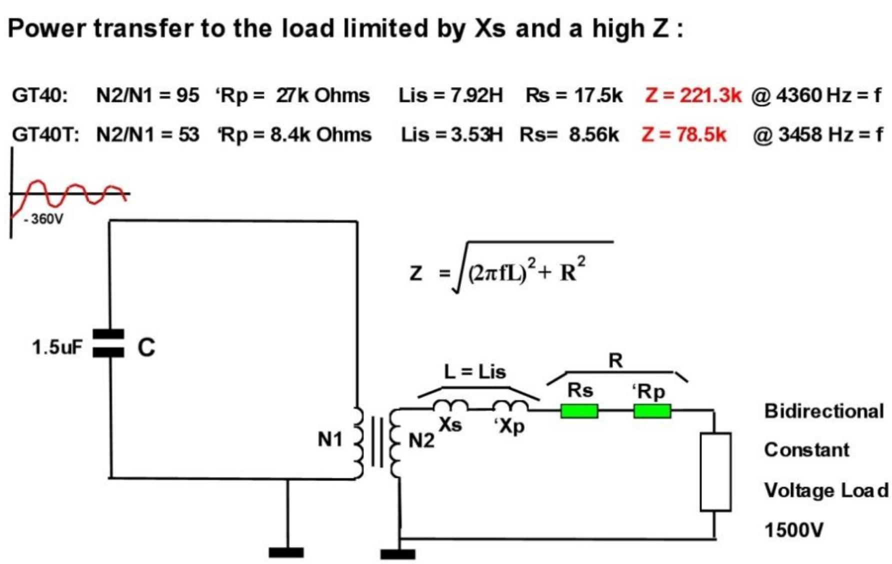


FIGURE 48.

The same applies to the DC resistance of the primary (3 ohms) which is transposed into the secondary circuit. The total leakage reactance Xs + ‘Xp and the total resistance Rs + ‘Rp

The impedance in the secondary circuit Z is calculated from the data as shown in figure 48.

As can be seen from figure 48 above, the impedance of the secondary circuit is substantially higher at 221.3k for the GT40 coil than the GT40T at 78.5k and this is why the transformer coil out performs the standard coil in a CDI application, even though the GT40T turns ratio is lower and it’s a “lower voltage coil” The main cause for the higher impedance is the much higher secondary leakage inductance for the GT40.

For example if 360V peak is applied to the primary winding (N1) for the GT40, it is transformed up to 360 x 95 = 34.2Kv (which appears on N2). The load is 221.3k, so the peak current (spark current) is in the order of 150 mA.

For the GT40T, with the 360V applied the voltage on N2 is 360 x 53 = 19.08 Kv and the impedance is 78.5k, so the peak current is 243 mA, which is higher despite the significantly lower turns ratio of 1:53 for the transformer coil compared to the standard oil coil at 1:95.

Three reasons why the transformer coil is superior for CDI:

The analysis above has explained some very interesting features of the standard ignition coils used as transformers. The first is that a standard coil it is a type of transformer with very poor regulation in that the output voltage drops with load to the total spark voltage (1500v). The current however is limited by the high leakage reactance which dwarfs the value of the DC resistance. The value of the secondary current (spark current) determines the energy of the actual spark along with the time course that the spark exists and this current is reduced by the high leakage inductance.

The transformer coil therefore wins out in three ways over the conventional coil for CDI:

Firstly the time course of the spark is longer because the transformer coil, with its higher primary inductance than a conventional coil, has a slightly higher primary leakage inductance. This lowers the resonant frequency of the oscillation with the CDI capacitor and broadens the spark time. *Secondly*, the transformer coil, despite having a lower turns ratio and lower open circuit output voltage than the conventional coil can still maintain an equal or higher spark current simply because the coil’s leakage inductance Lis is much lower than a conventional coil 3.53H vs 7.92H). This results in a substantially lower leakage reactance Xs in series with the load.

Thirdly, although the DC resistance of the primary winding of the transformer coil and the conventional coil are the same (3 Ohms) for the coils compared, the secondary resistance is lower in the transformer coil (8.56k vs 17.5k) and even allowing for the increased spark current with the transformer coil the energy losses are lower than for the standard coil.

So the answer is simple. CDI units perform much better with transformer coils with low leakage inductances compared to standard ignition coil designs. On practical testing with the Spark Energy test Machine as an aid, the spark energy improves by a factor of close to 1.6 when using the transformer coil vs the standard ignition coil.

CDI *vs* MDI – Brief Summary:

(For all the supportive data for the remarks below please study the entire document above)

"Transfer Efficiency" = the percentage of the stored energy (either stored in magnetic field of a coil or electric field of a capacitor) which becomes actual spark energy.

The actual spark energy from an MDI system is usually in the order of 25mJ to 60 mJ per spark, falling at higher RPM's, even with dwell extension and falling with coil heating. The actual stored energy responsible for these sparks is typically in the order of 40 to 80 mJ depending on the coil type and the dwell time.

The width of spark time is in the order of 1ms to 2mS for MDI systems. The peak sparks currents in MDI are usually in the order of 30mA to 80mA and the spark current profile is a right angle triangle shape with the negative going spark current trailing linearly with time towards zero after it starts. Depending on the coil driver system oscillations may be seen in the spark current in its early phase but these do not extinguish the spark or have any significant effect on the overall spark energy.

If one compares the stored energy in the ignition coil's magnetic field with the actual spark energy obtained from that, the transfer efficiency is about 62%.

In the MDI system the utility value of changing from a standard ignition coil to a "transformer" ignition coil, due to its higher inductance gains an increase in spark energy output in the low rpm range (< 4000 RPM 4 cylinder system or < 2000 RPM 8 cylinder system). This gain is lost at the high RPM range as the increased inductance slows down the build up of stored energy. However, going to a lower primary resistance coil, provided it is electronically current limited (as in the HEI system) allows much higher spark energy over the full rpm range,

The property of leakage reactance of the ignition coil is not a problem for MDI systems, but it is for CDI systems.

The CDI system is completely different to MDI. Typical actual CDI spark energies are in the low range in the order of 15mj to 30mJ per spark. They can be improved by a factor of 1.6 by using a transformer coil.

CDI sparks are briefer than MDI, typically in the range of 150us to 350uS long and have much higher peak spark currents in the order of 100mA to 200mA, often as much as 5 times the peak current of the MDI system. Some CDI's produce dual polarity sparks such as the Delta 10 & 10B. A dual polarity spark represents a full cycle of oscillation of the CDI's capacitor resonating with the leakage inductance of the ignition coil. Other CDI's such as the MSD 6A series produce a single polarity negative spark as the positive going spark component is clamped out with an energy recovery diode. This does not significantly affect the overall spark energy. The Delta 10C has a tri-polarity spark (which is one and a half cycles of oscillation of the CDI's storage capacitor resonating with the leakage inductance of the coil).

The shape of the spark current in CDI is generally sinusoidal unless the positive going spark current is not allowed (clamped out as in the MSD 6A series) and the waveform becomes more like a MDI system but with a shorter duration.

The transfer efficiency of stored energy in the CDI's capacitor to actual spark energy is very low with a standard design ignition coil. Only about 16% of the stored energy becomes actual spark energy. With a transformer coil this improves to 28% at best. CDI's therefore depend on a good coil with a low leakage inductance, not a standard oil filled coil. However when CDI's were marketed in the 1960's it was denied that a "special coil" would be helpful and the car's standard coil was recommended.

One astonishing thing this investigation has uncovered is that quoted spark energies for CDI's are often the energy stored in the storage capacitor and not the spark energy at all. This is very misleading as there is a temptation to try to compare that to the energy stored in a magnetic field in MDI, however they are not comparable due to the completely different transfer efficiency of stored to actual spark energy between the two systems. This misunderstanding of spark energy versus stored energy appears to have been going on for at least 50 years. Look at this quote taken from Wikipedia about a CDI system that was marketed in the 1960's:

A company was formed in Ottawa in early 1963 called Hyland Electronics building CD ignitions using the Winterburn design. It provided a 75 milijoule spark at all engine speeds up to 5,000 rpm on an eight cylinder (10,000 rpm on a four-cylinder) and consumed only four amperes at that speed.

The 75mJ refers to the stored energy in the CDI's capacitor but it is called "Spark Energy" (If the spark energy was truly 75mJ the unit's storage capacitor would be storing about 470 mJ which is impractical). Typical stored CDI energy values range from about 70mJ to 150 mJ depending on the charging voltage and the capacitor value.

It should be remembered that voltage is potential energy. Work is only done when a charge is transferred across the voltage field. Ignition coils with very high output voltages designed to impress the customer with “big numbers” can in fact deliver lower spark energies and are not necessarily better. This is because the spark as a load tends to have a constant low voltage (1000V to 1500V) compared to the coil’s secondary voltage usually 20Kv or greater, so the coil secondary is effectively “shorted out” or overloaded during the spark time. Higher voltage coils tend to have higher secondary DC resistances and higher leakage inductances. Tests show that for both CD and MDI(low rpm range) using a 1:53 ratio transformer coil, Bosch GT40T(19Kv out for 360v peak input) significantly out performs a 1:95 ratio standard GT40 coil with a 34Kv off load output voltage. Therefore an ignition coil’s off load voltage rating is not very relevant as long it is over 15Kv to 20Kv and can reliably initiate the spark.

Sparks themselves need to be assessed from the three perspectives to total spark energy, peak spark current and spark duration. This is done using a SPARK ENERGY TEST MACHINE in conjunction with an oscilloscope.

This investigation has concluded that the superior system is the reluctor driven HEI system which has unbeatable spark energy across the full rpm range, wide duration sparks, simplicity and reliability, followed by CDI as a second best choice. This may well be why over the years many auto manufacturers have stuck with MDI systems and not gone to CDI.

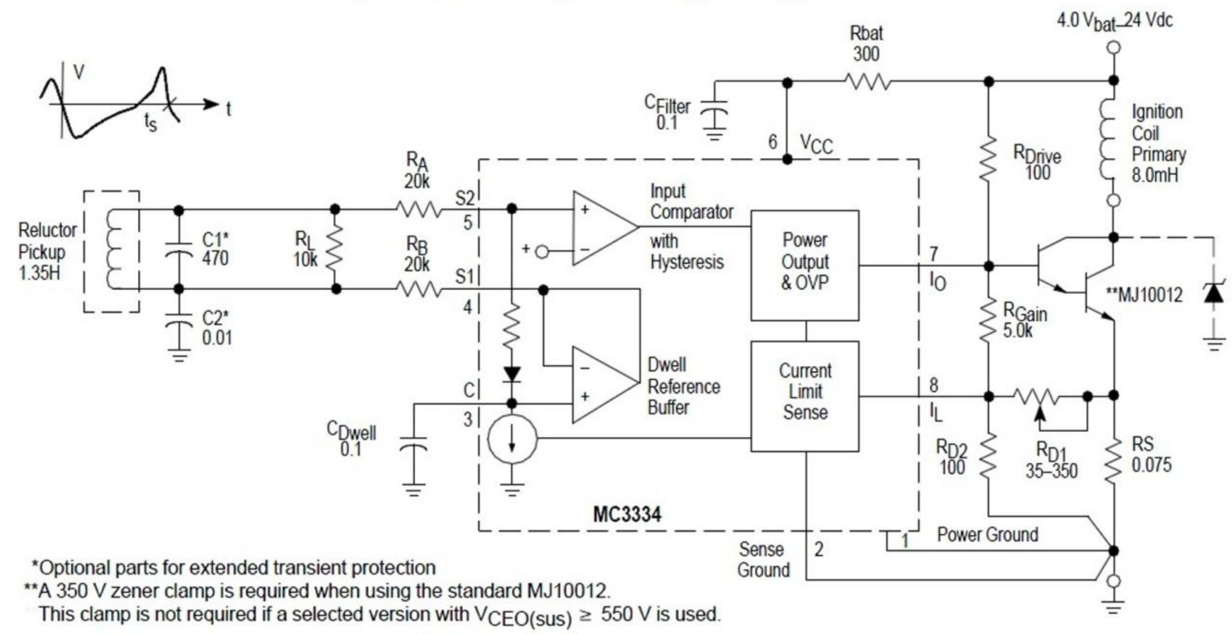
HEI vs other MDI SYSTEMS: Added Jan 2015 from Distributor test machine data:

Apart from being able to test distributors to determine the RPM and vacuum related advance characteristics, the Distributor Test Machine machine (see worldphaco.net)is useful for running up reluctor style distributors and testing them with the type of amplifier/switching system that the manufacturer of the system designed. In this type of distributor the signal generated is unique and its voltage-time profile combined with the type of switching amplifier that it drives determines the dwell.

For example with a simple threshold switching amplifier the dwell at low RPM is around 20 degrees, and at high RPM around 45 degrees from a typical reluctor. However in the HEI system (based on Motorola's MC3334 IC) where there is bidirectional dwell control, the results are quite different.

The diagram below again shows the HEI module's circuit, which is based on the Motorola MC3334 integrated circuit:

Figure 1. Block Diagram and Typical Application

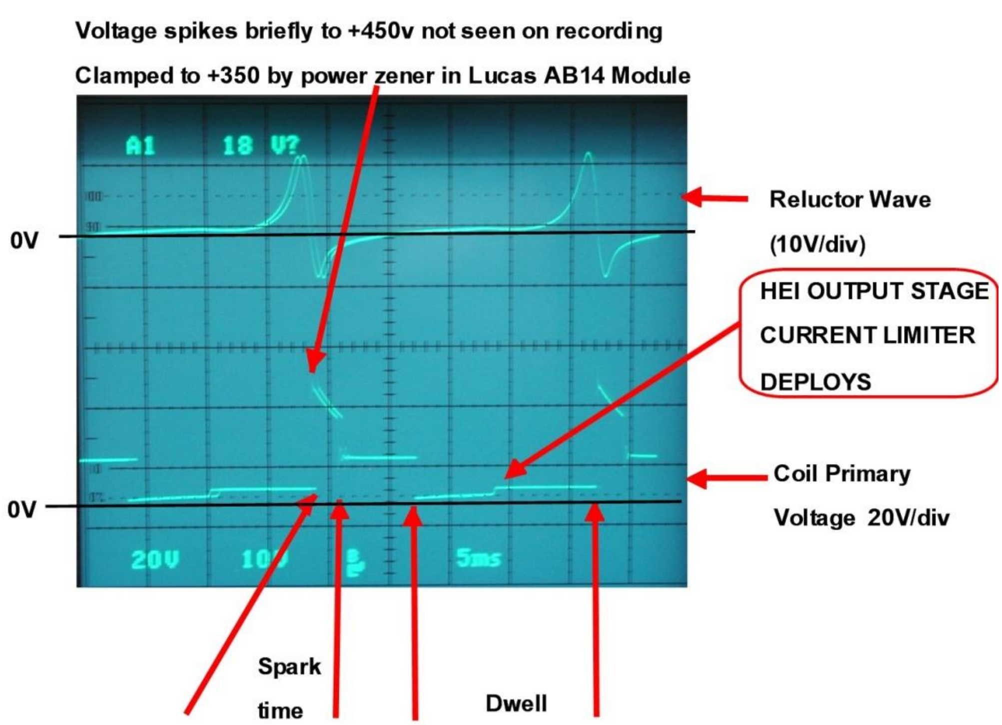


In the HEI system a dwell capacitor (CDwell in the diagram above) is charged in proportion to the reluctor signal's peak amplitude, which is proportional to the RPM. Also though in the HEI system, generally a low primary resistance coil is used and the Darlington transistor power output stage driving the coil is configured to limit the primary current to around 5.5A detected across resistor RS. However at the time this current limiter deploys, the dwell capacitor is discharged. The HEI system enables current control of the coil at low rpm to prevent overheating and at the same time maximum coil output and spark energy at high RPM because the dwell is optimized to the maximum available time leaving about 1mS time for the actual spark itself. (See notes below in "Discussion" for what can happen if the coil primary resistance is so **high** as to not initiate the current limiter in the HEI unit and see notes below in "Discussion" about what can happen if the coil primary resistance is too **low**.)

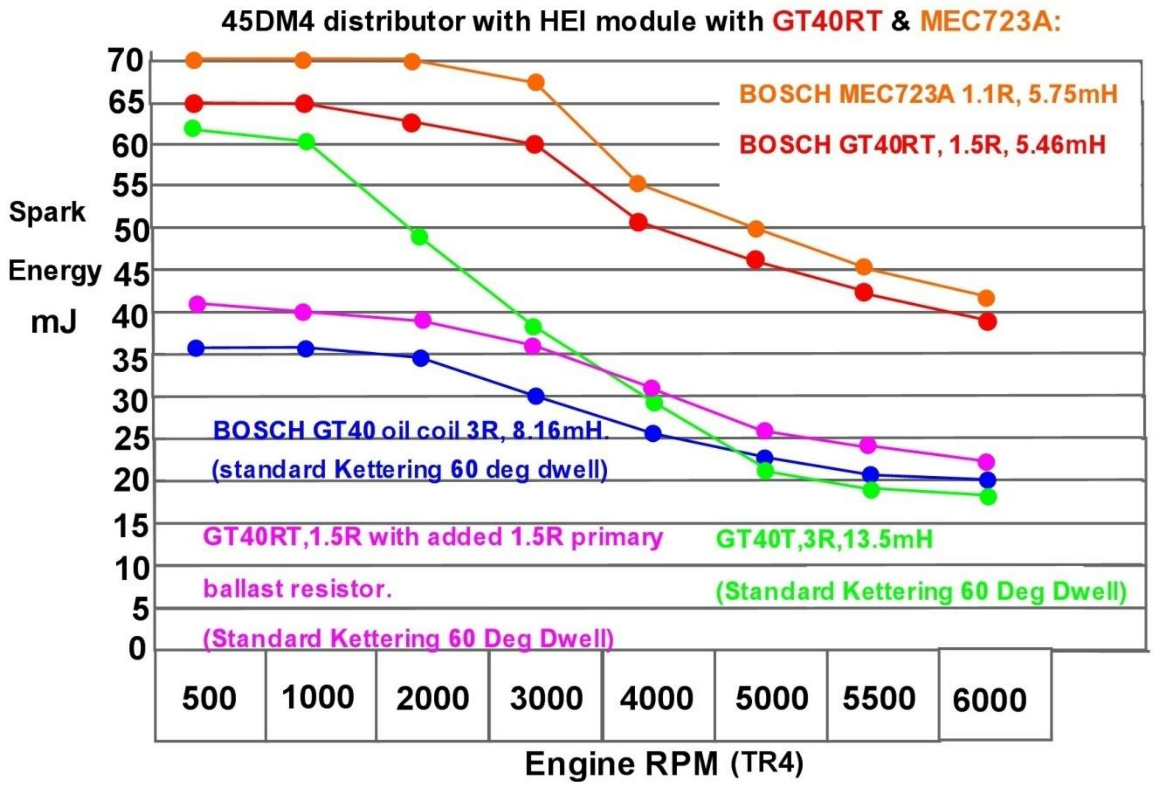
With low R primary ignitions coils (between 0.5R to 1.5R) the HEI system delivers nearly a constant spark energy output across the full RPM range, though it always falls in the higher RPM range because there is not enough time for the coil current to reach the 5.5A threshold. The Lucas version of this system, fitted to MG Midgets, Triumph Spitfires, TR7's and other British cars such as Jaguars was called CEI (Constant Energy Ignition).

The Lucas CEI modules of the early 1980's actually have the GM HEI module inside them which is based on Motorola's MC3334 IC. With a 1.5R coil the spark energy is excellent also, despite a small reduction at the high RPM end however it is still twice as good as standard Kettering.

The photo below is a simultaneous recording of the reluctor voltage and the ignition coil's primary voltage with an HEI module and a 1.5R primary resistance ignition coil. It is a low rpm recording (around 1200 rpm) and it is easy to see on the waveform when the HEI's current limiter activates for about 33% of the operating cycle. During this time the amount of heat generated in the module is significantly increased:



The following graph is a spark energy recording (mJ per spark) of a reluctor driven 45DM4 HEI system with the Bosch GT40RT (1.5Ohm) transformer ignition coil and the Bosch MEC723A which is a 1.1 Ohm primary transformer coil similar to the GT40RT. The standard Kettering system energies measured for a typical 3 Ohm ignition oil style coil and for a 3 Ohm transformer style coil is shown in blue and green & pink for comparison:

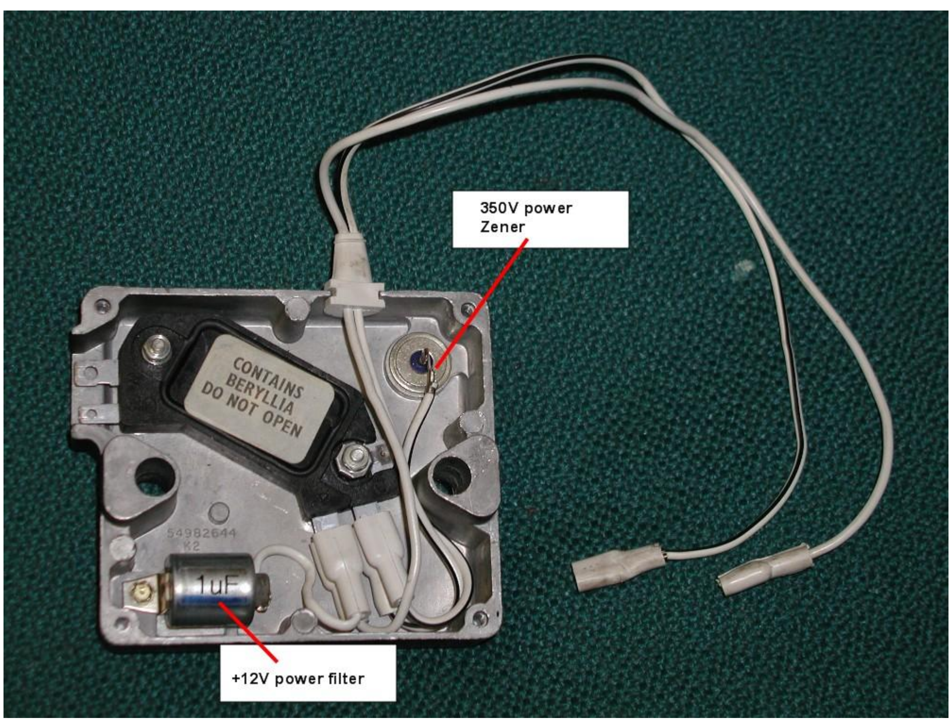


(Of note: The above graphs also shows that simply going from a standard oil coil to a transformer version of a standard 3 Ohm ignition coil, in the Kettering system, results in an improvement in spark energy at the low rpm range only due to the higher primary inductance and therefore more stored energy if the coil current profile has time to level off. However less spark energy at the high rpm range because the transformer coil has a higher primary inductance and therefore its L/R ratio or “time constant” is a little longer than the standard oil style coil and the current doesn’t climb to a very high value per cycle prior to the spark)

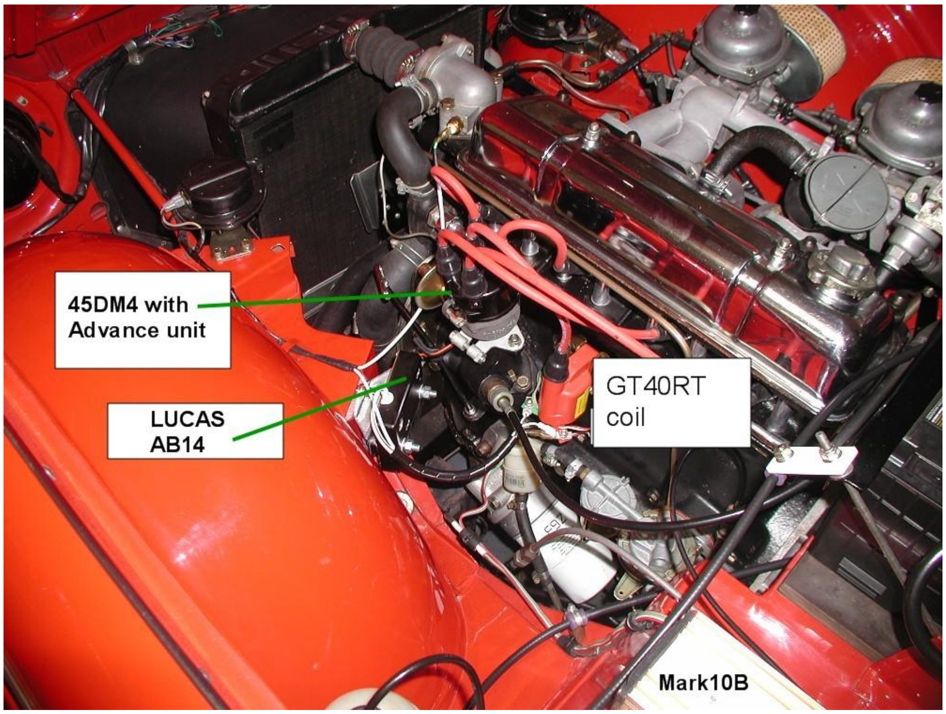
The spark energy results for standard Kettering (60 Degrees dwell) and a standard 3 R primary coils are above shown in blue & green, with the GT40RT (1.5 ohm coil) operating in standard Kettering with the recommended 1.5 Ohm ballast resistor, so as to compare these with the HEI recordings. These “standard Kettering spark energy results” are nearly exactly the same as for electronically assisted Kettering, such as with a distributor insert with rotating magnets, or a contact breaker with a transistor amplifier, although sometimes the energy can in fact be even little lower with the inserts because the output transistor in them, typically a Darlington, has about a 1 volt voltage drop which is higher than a contact breaker's voltage drop. For this reason some manufacturers have gone to an IGBT output stage device or a Mosfet in their distributor inserts to get the result as least as good as the contact breaker. Despite these facts, distributor insert marketing often claims "high energies" & powerful sparks. In fact the spark energy is determined by the type of ignition coil and its primary current prior to magnetic field collapse (all other things such as dwell and coil inductance being equal) and not the device or distributor insert switching the coil on & off which doesn't contribute to the spark energy at all unless there is some dwell manipulation involved as there is in the HEI system.

The other advantage of the HEI system, apart from the higher spark energies is that with no distributor rotation the ignition coil is in the OFF condition, which saves a lot of coil heating if the ignition switch is left on without the engine running.

The photo below shows the inside of the 1982 vintage Lucas LUCAS CEI system amplifier module type AB14. It uses GM's HEI module, with an additional 1uF filter capacitor on its 12V supply feed and a power zener diode on the HEI's coil connection. This diode snubs of the peak voltage to 350V (otherwise it is around about 450V which is a threat to the Darlington output transistor in the module):



Lucas produced the 45DM4 reluctor distributor to accompany the AB14 amplifier as a replacement for the troublesome Opus style systems, for cars such as the MG midget, Triumph Spitfire and TR7. The 45DM4 for the Midget was supplied with a vacuum retard unit, but these are easily changed to an advance unit. This system was fitted very successfully to the author's TR4A see photo below. For experimental purposes the car is also fitted with a modified Delta MK10B CDI, so it can operate with one system or the other:



Discussion on HEI & coil resistances:

The issue of the ideal resistance primary coil comes up in use with the HEI module. It depends on the requirements. In 8 cylinder motors the demands for spark energy in the high rpm range are double that of a 4 cylinder motor. So lower R coils in the 0.5 to 0.7 Ohm range are needed. These reach the 5.5A saturation current sooner, but still at the high rpm end the HEI module current limiter is not driven into its 5.5A threshold and the current limiter doesn't deploy. Some HEI modules may also have different current limiting values, however all the units I have tested are similar and around the 5.5 Amp mark.

The lower the resistance of the coil's primary, then the lower the coil's voltage drop at the HEI's 5.5A saturation or threshold limit current. This causes more voltage drop across the output transistor in the HEI module. For example a 1.1 Ohm coil will be dropping 6.05 volts at that current, leaving 14-6.05 = 7 .95 volts across the HEI's transistor output stage and dissipating about 7.95 x 5.5 x 0.3 =13 Watts in the HEI module assuming say at the low rpm range the current limiting was occurring for about 1/3 of the operating cycle as shown in the above recording. The heat dissipation (in the module) is lower with a higher resistance primary coil.

So going to a lower resistance primary coil in the HEI system (in the low rpm range where the HEI's current limiter is active) shifts heat dissipation from the ignition coil to the HEI module.

For example the HEI module will run a little hotter in the low rpm range with the 1.1R MEC723A coil than the 1.5R GT40RT coil. But as seen from the graph the MECH 723A gives a little more spark energy than the GT40RT.

So it is very important that the HEI module is attached to a good heat radiating metal surface with ample heat conducting compound. It should be noted that when Motorola designed the MC3334 IC, it was for use with a separate transistor in a TO-3 package, such as an MJ10014 or MJ10012, on a good heat sink. In the HEI module this transistor die has been fitted inside, along with the IC and the supports resistors & capacitors. All of these parts get heated by the transistor's dissipation.

It is probable that some of the failures experienced with HEI modules therefore are a combination of using low primary resistance coils, in the range of 0.5 to 0.7 Ohms in conjunction with poor or inadequate HEI module heat sinking.

Also there are some interesting things that can happen if the ignition coil resistance is such that it is high enough on its own, such as a 3 Ohm primary coil. The maximum current they can achieve is 14/3 =4.66 amps. Therefore the current limiter in the HEI module does not reach its 5.5A operating threshold. It depends on the particular module what happens here. Earlier 1980's vintage modules I have tested continue to operate. But the newer ones drop output of operation in the low rpm range. This occurs because the charge on the dwell capacitor becomes excessive and since the current limiter is not activating, there is no effect to discharge the capacitor, so the input op amp in the IC gets biased out of conduction. So it appears some of the newer HEI clone modules, and clone MC3334 IC's inside them, require that the primary ignition coil resistance is at least low enough to operate the current limiter which, if 5.5A, would mean that the coil would have to have a primary resistance lower than about 2.5 Ohms or the newer clone HEI modules will malfunction.

It should be pointed out that all the data I have acquired about a combination of a reluctor driven HEI system is clear & conclusive. **Witha reluctor –HEI system** it is possible to attain four very important things which substantially improve spark energies:

1) Excellent bidirectional Dwell Control.

2) Low RPM coil current control and reduced coil heating.

3) Significantly higher spark energy output compared to a conventional Kettering system or any system with a fixed switching signal derived from the distributor, such as rare earth magnets & Hall devices common in aftermarket "distributor inserts" or an Optical sensor systems. This is especially so in the higher RPM ranges.

4) Freedom from coil overheating with the ignition left on and engine not running.

It is the unique nature of the reluctor's signal combined with the processing by the MC3334 IC which allows the above features. The reluctor's signal amplitude, being an AC generator, is proportional to the rpm and it is this unique feature of the reluctor as a distributor "shaft encoder" in conjunction with Motorola's MC3334 IC which allows the above functions to be possible.

The signals derived from the magnets & Hall switch sensors in distributor inserts, or optical distributors do not contain amplitude information related to the RPM, they only contain timing or switching 0n-0ff information, and this severely limits their performance compared to reluctor driven HEI. The signals detected by Hall devices are proportional to the magnetic field strength, so they are useful as an angle or on-off position sensors, whereas the voltages generated by a reluctor are proportional to the rate of change of the magnetic flux and so their amplitude is dependent on the rpm and this information can be used, as it is in the HEI system, for dwell control. It would be possible to build a unique type of Hall sensor input system (distributor shaft encoder) where the Hall sensor signal was linear and electronically differentiated to gain the rpm related information required for dwell control, to achieve similar results to HEI. However dwell control is only part of the HEI system, there is also the need for coil current limiting in the low rpm range and this is a heat dissipative process with over 10 watts to dissipate. The distributor inserts already appear to have heat dissipation issues affecting their reliability and adding the HEI style 5.5A current limiter to their internal design would aggravate this issue and probably make them even less reliable.

Therefore the reluctor-HEI system completely trumps standard Kettering, Optical or Hall – magnetic detector systems or distributor insert systems (replacing contact breakers) for spark energy.

Some distributor inserts on Ebay are now claiming to have "dwell control" I have yet to test any. If they were effective they would also require as noted above, in addition to the claimed dwell control, have coil over-current control and be designed for use with low R primary coils *without* series coil resistors to achieve results similar to reluctor-HEI and in that case als be able to handle over 10watts of thermal dissipation which is a highly unlikely scenario in my view.

Reluctor-HEI also trumps CDI systems for spark energy, although the spark energy is delivered in a shorter time with CDI (typically around 150uS vs 1.5mS) and CDI has higher peak spark currents than MDI systems. The effect of this on fuel combustion is open to conjecture, but a CDI system is more complicated than HEI and has higher component stressors.

If you are stuck with a non reluctor style distributor, then CDI is advantageous as it ignores the dwell issue and has uniform, although much lower spark energy (typically 10 to 20mJ/spark) across the full RPM range. The spark energy value depending on the type of ignition coil used (Standard Oil type or Transformer type) and the values and charging voltages of the discharge capacitor (typically 1.5uF & 400V) and the recharging capacity of the CDI's DC:DC converter.

If you plan to move to a reluctor style distributor for your TR car be aware that there are basically two types of 45DM4's. Although they have the same mechanical features, some have a different reluctor coil with a low resistance & inductance compared to the type needed to drive the HEI module. These have about 8" leads exiting the distributor not 4.5" ones, so they are fairly easily recognized and from the distributor numbers:

BEWARE DIFFERENT RELUCTORS IN 45DM4 DISTRIBUTORS:

R= 3.3k Ohms, L= 2.42 Henry

45DM4 41804A- 1182

(MG unit fitted with

Vac advance)

R= 300 Ohms L = 0.23 Henry (see text)

45DM4 41719A-1378

?Sunbeam unit.

Calculations indicate that the low R and Low L unit was wound with thicker wire and 1/3 the number of turns to fill the coil bobbin (it is not a faulty unit with shorted turns). Presumably the low R and low L reluctor drove a different type of switching amplifier designed by Lucas and not GM's HEI module containing the MC3334 IC.

Without spring and weight modifications, some types of 45DM4 are not suited to the TR4 especially if they have high value vacuum advance units on them.

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