THE SPARK ENERGY TEST MACHINE:

Dr. H. Holden 2012.

FIGURE 1.

INTRODUCTION:

Figure 1 above shows a view of the completed machine.

The spark at a car's spark plug is hot ionised gas known as a plasma. In many ways the plasma has the physical properties of a gas, but the electrical properties of a metallic conductor as the mobilised electrons result in a highly conductive pathway

through the gas. During the spark's existence energy is dissipated as heat, light and noise. The job of the spark is to ignite the fuel/air mixture in the combustion chamber.

In automotive spark generating systems the source of the spark's energy is from some "storage reservoir" which can be suddenly dumped over a brief period to create the spark.

Electrical energy can be stored conveniently in the magnetic field of an inductor, or just as easily in the electric field of a capacitor. Those systems, such as the well known Kettering system, store energy in the magnetic field of an inductor (the ignition coil) and are called **magnetic discharge** systems. Other systems that store the energy in a capacitor are known as **capacitive discharge** systems. These still require an ignition coil to transform the voltage to a high enough level to initiate the spark, but the initial energy storage is not in the coil's magnetic field.

Over the last 60 years multiple spark generating systems for automobiles have been invented, many claiming all sorts of improvements to a motor vehicle's performance.

Examples include many aftermarket or "add on" kitset devices such as Dwell extenders, or electronic ignition modules including CDI's (capacitive discharge ignitions). Some claims relate to improved miles per litre and fuel economy. Other claims relate to improving the life of the spark plugs, or improving the life of the contacts in the distributor.

Various spark testers also appeared on the market some claiming to "analyse sparks" but few if any are calibrated in scientific units of milli Joules per spark. To do this both the spark current and the spark voltage and duration need to be accurately measured or known and appropriately processed and displayed.

The usual defect pointed out in the standard Kettering ignition system is that fact that at high range rpm's there is less time available to store magnetic energy in the field of the ignition coil, so the spark energy drops off at high range RPMs. The rising current in the ignition coil primary has an inverted exponential profile. At low RPM's it saturates to a fixed value, but at high RPM's the current rise can be nearly linear with time and reducing nearly proportionally to the RPM value.

Other Kettering defects cited include points bounce at higher RPM's and points (contact breaker) burn due to arcing. Also 4 cylinder cars run a lower system operating frequency, 16.6Hz to 166 Hz over the 500 to 5000 RPM range and the demands are lower. Eight cylinder cars however have double these frequencies allowing a shorter time interval time for magnetic energy storage in the ignition coil in any magnetic discharge ignition system.

In the 1970's the marketing for CDI's made claims for example that while a longer spark improves the combustion a shorter spark time lengthens the spark plug life and that the short sparks, usually around 200 to 300microseconds for CDI (vs typically 1.5mS for Kettering) resulted in better spark plug life but poorer combustion. Later on multi-spark CDI's were used.

In addition the energy per spark claims in some CDI marketing related instead to the energy stored in the CDI's discharge capacitor, typically in the 100mJ arena but only a proportion of this, typically 15 mJ, ends up as spark energy due to ignition coil and other losses so the marketing was somewhat misleading.

Before fitting a supposed spark enhancing device to my Triumph TR4A car I required some evidential proof that the device or system in question is an improvement and a quantifiable measurement of the magnitude of the improvement.

To this end the **Spark Energy Test Machine** was designed and built. The machine synthesises a distributor with a varying dwell angle which can be used to drive the standard ignition coil, or any other ignition coil placed on a stage area on the unit's front panel and coupled to the external spark plug assembly.

Electronic add on ignition modules, CDI units or other modules can also be tested with the aid of the machine. HEI ignition units can also be tested with a points (contact breaker) to reluctor interface circuit where the switching signal generates a bipolarity voltage analogous to the output of a magnetic reluctor in the HEI distributor.

The energy per spark (measured in milli-Joules per spark) is displayed by the spark test machine over the full range of RPM's and dwell angles. In addition the machine has outputs for oscillographic monitoring and data storage. These outputs

include the drive signal to the output stage synthesising the distributor contacts and a spark current and ignition coil primary current sample.

The machine computes the energy per spark and displays this in milli Joules (mJ). The spark current amplitude and time profile can be viewed on an oscilloscope. These features are strikingly different between magnetic and capacitive discharge ignitions.

The Synthetic Distributor:

This was created with an XR2206 frequency synthesiser IC to sweep the range of frequencies corresponding to 500 to 8000 rpm for 4 cylinder motor frequencies. This corresponds to a frequency range of 16.66Hz to 266 Hz. (For 6 cylinder or 8 cylinder frequencies, if required, different capacitors can be switched on to pin 5 and 6 of the XR2206). Figure 2 shows the arrangement:
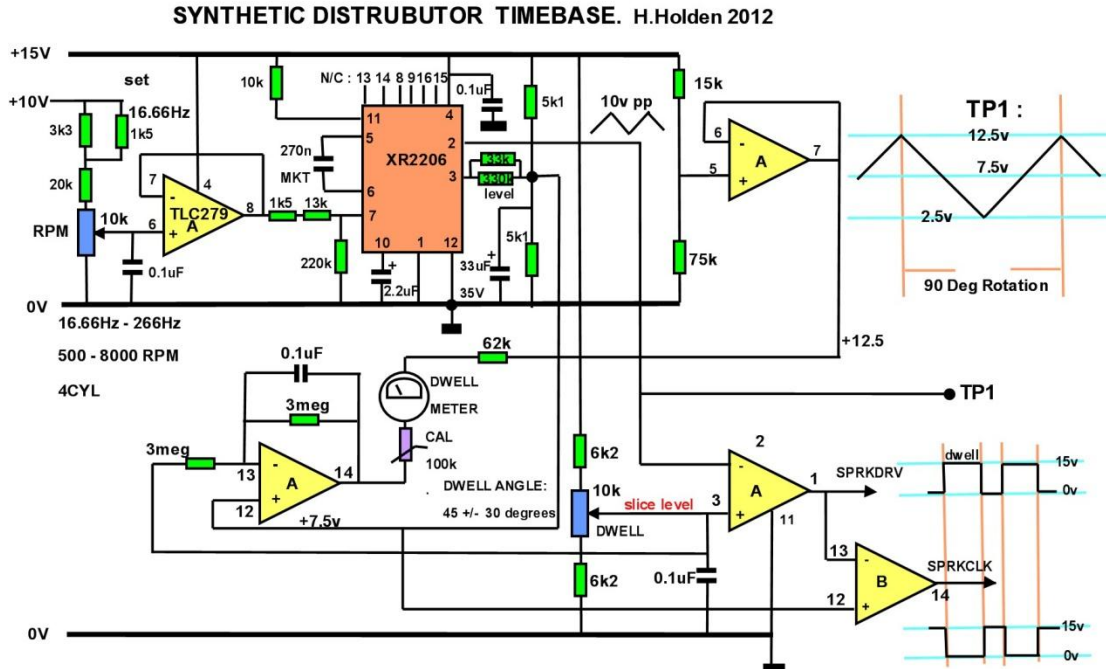

FIGURE 2.

The synthesiser outputs a triangle wave which drives a comparator and the comparator's reference or "slice level" sets the dwell time. The dwell time corresponds to the degrees of rotation of the distributor shaft where the ignition coil is connected to the car's 14 volt supply. The control signal called **sprkdrv** (spark drive) ultimately drives a power output transistor (a BU941) which acts as an artificial contact breaker.

In this instance a 6A10 rectifier is placed in series with the BU941's collector so as to isolate the internal BU941 Collector-Emitter diode so that negative going primary voltages are not clamped to ground so the assembly behaves more like a mechanical contact breaker but with a small fixed forward voltage drop due to the rectifier and the BU941's C-E combination voltage drop.

The BU941 emitter has a 10mR current sensing resistor (composed from a 42 mm length of 1.6mm diameter 0.244 Ohm/m Constantan wire) to enable the primary coil current to be monitored on the **ext.coil current** connector, see figure 3:
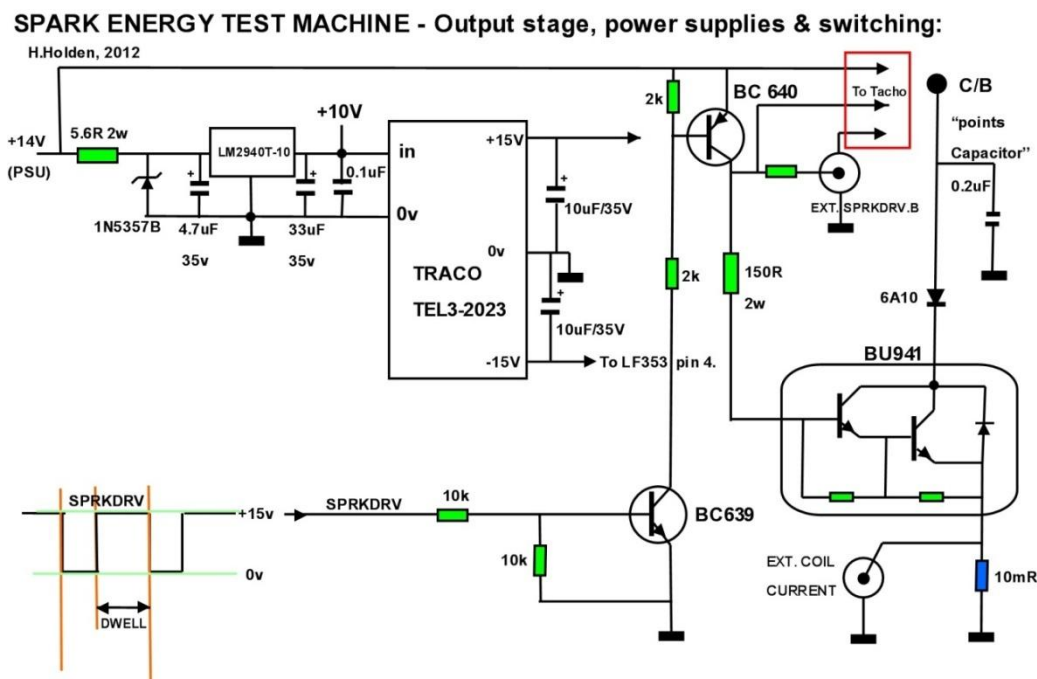

FIGURE 3.

Measuring, calculating and displaying consecutive spark energies:

Spark current can be easily measured by placing a low value resistor in series with the earth connection of an actual spark plug (or dummy zener diode spark plug). The resistor converts the current to a voltage. The voltage waveform can then be processed. See figure 4:

SPARK CURRENT SIGNAL:

To COIL

Spark
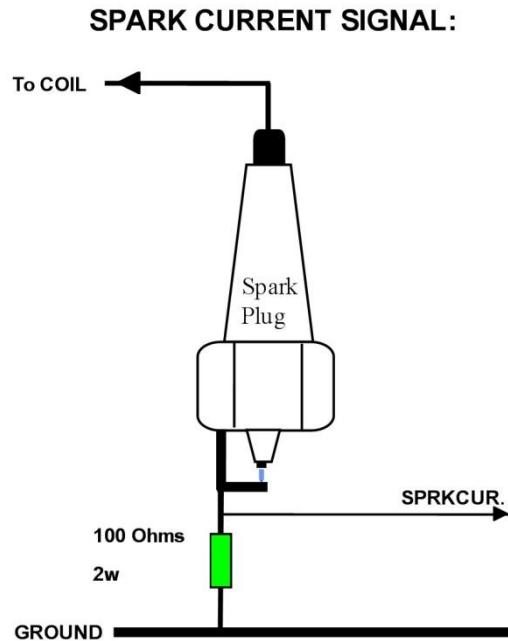Plug

SPRKCUR.

100 Ohms

2w

GROUND

FIGURE 4.

Since the spark voltage (voltage developed across the spark plug terminals) is a near constant during the spark time this aids the energy calculation as will be shown. It pays to use a robust 100R 2W resistor, regardless of the power dissipation being lower because if it goes open circuit the secondary coil voltage materializes on the **sprkcur** signal line.

If the spark current I which is a function of time or in math notation I(t) is integrated with time over the length of the spark's time, call this time t_{spk}, then this yields the total charge in Coulombs Q transferred across the spark plugs terminals, which is the shaded red area, figure 5:
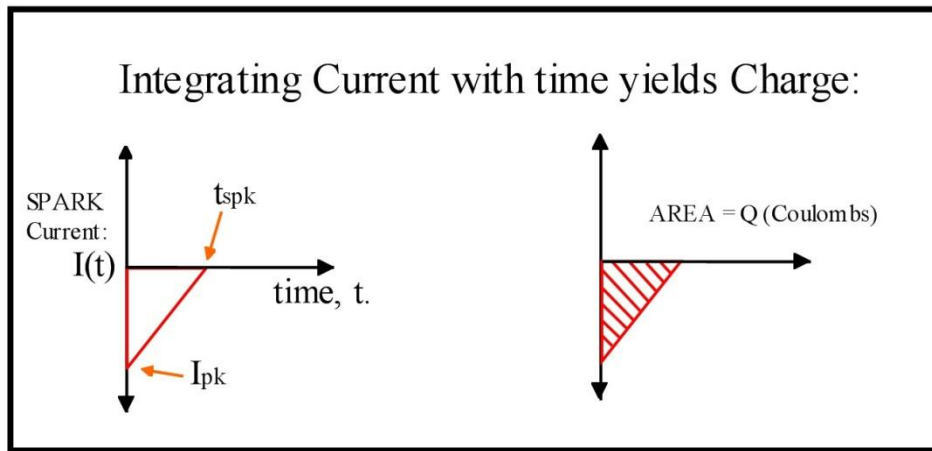
FIGURE 5.

The standard configuration of the ignition coil in a negative ground car running an *inductive discharge* ignition system is such that the coil high voltage side is a negative going voltage and the spark current is a negative value as depicted in figure 5.

On the other hand CDI ignitions for example produce a narrow bipolarity spark, in that initially the spark current is negative for a 100 microseconds or thereabouts and shortly afterwards goes positive at a lower amplitude and for about the same time course. Therefore the spark current signal must be effectively full wave rectified or passed via an "absolute value circuit" before it is integrated and the energy calculation performed, more about this interesting complication below.

In general, if the spark current profile was perfectly linear then the charge transferred due to the spark process would simply be: $I_{pk}.t_{spk}/2$ where I_{pk} was the peak current and t_{spk} the spark time. It is not in reality perfectly linear and it also contains multiple oscillations in its early phase. These oscillations occur because the spark effectively shorts out the coil's secondary circuit and the leakage reactance appearing in the primary circuit resonates with the primary side capacitances (for more detail on the 14 electrical parameters of an ignition coil see my article on Electronic Ignition for TR cars on www.worldphaco.net). Fortunately the oscillations do not affect the situation if a true integration is performed by an electronic integrator over the spark time.

The spark time is conveniently measured because spark current only exists during the presence of the spark and vanishes after the spark time.

The generally accepted spark voltage drop (with the spark plug in use in the engine) is 1000v and the industry standard "dummy spark" plug is composed of zener diodes is 1000v. Figure 6 below shows a dummy spark plug created from 20 100V Zener diodes. The plug must have a bidirectional current conducting & voltage drop property because some sparks are bidirectional polarity (such as those from CDI's) One group of zeners simply forward conducts in one polarity with a low voltage drop while the other group zeners at 1000v:
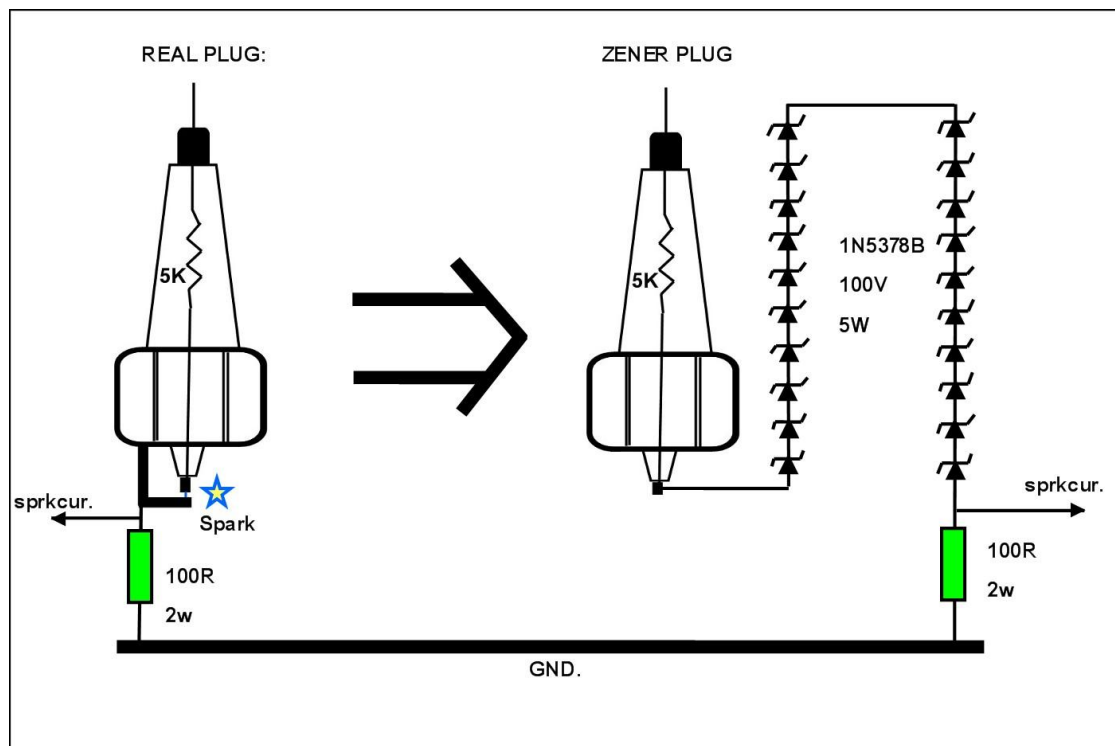
FIGURE 6.

Differences between the real spark and the zener diodes:

In the case of the real spark, the voltage required to strike the spark is much higher than the voltage across the spark once it has begun. In the standard Kettering system an event occurs when the contact breaker closes. 12v is applied to the coil

primary and at this moment it is transformed upwards by the coil turns ratio and appears as a *positive* voltage on the coil secondary. If the ignition coil turns ratio is 85:1 or more then a *positive* going 1020v spike appears on the secondary. The is not enough to initiate a spark or spark current in a real spark plug, but can cause a small amount of conduction for a brief period in the zener system. Examples of this effect will be shown below in some recordings with a 85:1 turns ratio coil.

The test machine incorporates a dual zener plug system, one for the internal coil and another for the optional external test coil. In addition real spark plugs with one electrode removed were used to couple the connection into the zener array as feed-through connectors. This is so good insulation was maintained and standard plug connectors could be used.

The plugs used were 5K ohm resistor plugs, which are commonly encountered in practice and they are useful for RFI suppression. Also they provide a mild ballast for the zeners. Even though the coil secondary in a coil such as a Bosch GT40 has a DC resistance of 17k ohms, the plug resistor helps to isolate the distributed capacity near the output side of the coil and slightly reduces the peak currents at the instant the zeners conduct. (These resistor plugs dissipate or waste a small amount of energy about 1.5 to 2 milli Joules of spark energy per spark in the standard Kettering system depending on the spark current and duration).

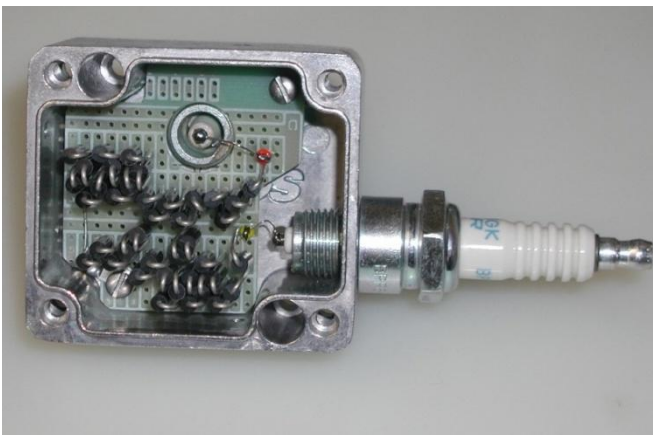Figures 7 and 8 show the dual zener spark plug chamber:

FIGURE 7.

FIGURE 8.

The spark energy test machine described here works nearly identically with a real spark plug or the zener plug, but the zener plug is better as it does not produce ionized gases which are quite corrosive to both zinc and copper surfaces.

The spark current I(t), which is some function of current with time comes into existence when the spark begins and finishes when the spark ends:

$$\text{SPARK CURRENT} = I(t) \qquad equ.\ 1$$

If the current function I(t) is integrated over the spark time t_{spk}, from zero to t_{spk} this yields the charge transferred across the spark during that process:

$$\int_0^{t_{spk}} I(t).\,dt\ = Q\ \text{(Coulombs)} \qquad equ.2$$

Voltage has units of Joules per Coulomb so the product of charge and voltage is energy in Joules. The spark energy E for a 1000V spark is:

$$E = 1000 \int_0^{t_{spk}} I(t).\,dt\ \text{(Joules)}\ equ.\ 3$$

If the spark current function I(t) is converted to a voltage by a series current sensing resistor then the voltage can be electronically integrated to yield the same result as equation 3.

One useful feature is that as the OP amp integrator is inverting, this deals with the negative going voltage signal and converts it into a positive one.

In addition, because the negative OP amp input acts as a virtual earth, the OP amp may be powered by a single positive supply. However it is important that the OP

amps output does not clip to the supply rails and the OP amp should be a type where the input voltage range includes ground and preferably a little below.

The circuit of Figure 9 below shows the OP amp voltage integrator and equation for it which will integrate the waveform over time regardless of its shape or exact profile:

OP AMP INTEGRATOR:

RESET

C

Input: Vin

R

Vo
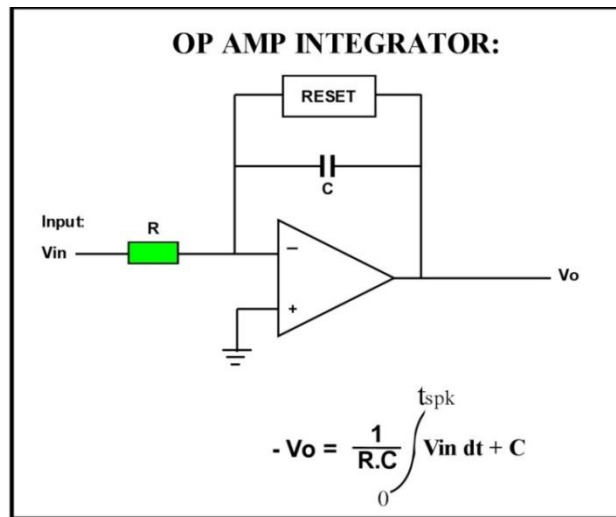
$$-Vo = \frac{1}{R.C} \int_0^{t_{spk}} Vin \, dt + C$$

FIGURE 9.

The integrator output and the constant becomes zero every time the integrator is reset. The reset discharges the capacitor to zero volts. The negative going input voltage is integrated with time after that.

If Rs is a spark current sensing resistor, I(t) the spark current function and substituting Rs.I(t) in for voltage Vin and due to the fact the sensed voltage is a negative value, then the integrator output Vo is positive and:

$$Vo = \frac{1}{RC} \int_0^{t_{spk}} Rs.\, I(t).\, dt \qquad\qquad equ.\ 4$$

The ratio of comparator output voltage to spark energy E:

This is the Voltage Integral equation 4 divided by the Energy equation 3. As can be seen it doesn't depend on the spark function with time I(t):

$$\frac{Vo = \dfrac{1}{RC} \displaystyle\int_{0}^{tspk} Rs.I(t).dt}{E = 1000 \displaystyle\int_{0}^{tspk} I(t).dt}$$

$$Vo/E = \frac{Rs}{1000RC}$$

Therefore with an Rs = 100R, R = 100k, C= 10nF:

$$Vo/E \quad = 100 \text{ V/J or } 0.10 \text{ Volts per milli-Joule}$$

With these values the output voltage of the integrator has a scale of 0.10 V/mJ.

So a 100mJ spark for example (planing on a spark energy meter with a 100mJ per spark full scale deflection) is a 10 volt deflection on the integrator output (in range for a 15 volt powered integrator OP amp) and the meter driven by the integrator output can be easily calibrated accordingly. For example a 10v fsd meter simply requires a 100k series integrator resistor and a 10nF integrator capacitor and full scale deflection corresponds to 100mJ.

A lower value integrator resistor increases the gain and this effect has some use in increasing the dynamic range of the allowable voltage corresponding to the spark

current. Positive going components of spark current can be compressed and expanded again later. More about this below.

Sampling, storing and displaying the integrated value:

To allow the meter to display a stable reading a spark is sampled and held every other spark. During every other spark the integrator is reset. The timing diagram of this process I created for this is shown below in Figure 10:
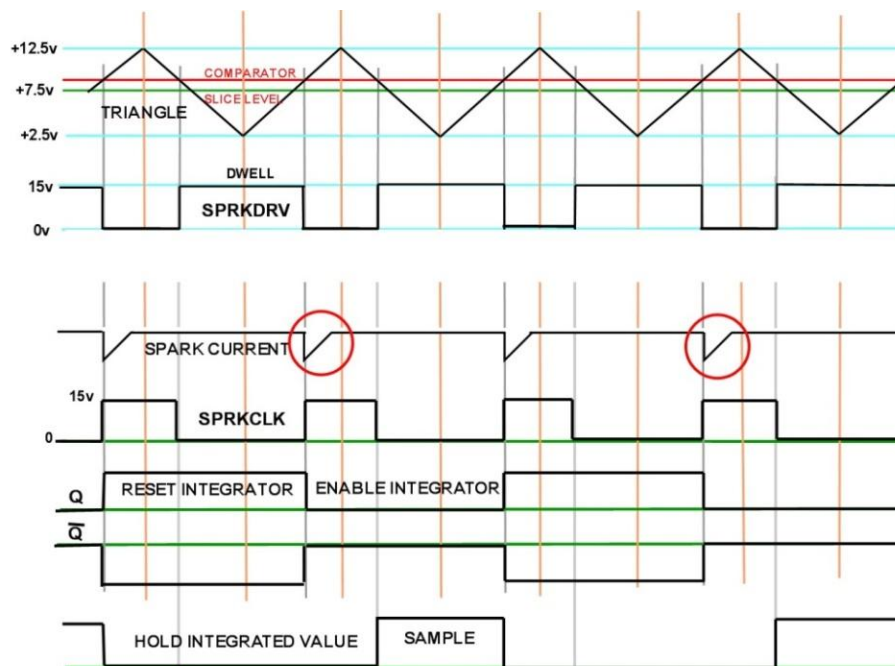
The integrated spark current, from every second spark, shown in the red rings, is stored in the sample hold. As the spark current time integral is a measure of the total electric charge transferred and the spark voltage is close to a constant during the spark, the spark energy (Volts x Charge) is proportional to the integrated spark current. The S&H control timing is generated from $\overline{Q}$ & SPRKDRV

H. HOLDEN, 2012.

FIGURE 10.

The following circuit of Figure 11 below is based on a CD4013 and anCD4066 and a quad TLC 279CN. This performs the functions outlined in the timing diagram of figure 10.

ENERGY PER SPARK METER. See text for operating theory.
H. Holden. Dec 2012.

FIGURE 11.

One advantage of the negative inputs of OP amps configured with feedback as amplifiers or integrators, provided the output remains within the confines of the allowed values, which for a TLC279 is close to the supply rails, is that the input behaves as a virtual earth. This is an advantage for integrating negative going voltage signals which have a very brief duration but a high voltage which can be more negative than ground or more negative than a typical -15V supply rail.

If the spark current were always negative the design would be easy and it would simply be a matter of connecting the integrators 100K input resistor directly to the 100 ohm resistor which senses the spark current. However one complication is that CDI units produce a dual polarity spark.

The signal therefore needs to be full wave rectified or pass through what is an *absolute value circuit* with a negative going output to ensure all waveforms presented to the integrator are negative in polarity. While this can be done with series diodes, the voltage drop of the diode causes errors in the meter reading for low level signals, making the meter inaccurate in the low range. In addition active rectifier circuits using op amps generally have output and input voltage ranges that are limited by the power supply rails. Also if the detected voltage corresponding to the spark current is made small, say by using a 10 ohm rather than a 100 ohm sensing resistor, then any drifts or amplifier offsets and noise are much larger compared to the measured signal.

So the question becomes: How to make a zero forward voltage drop full wave rectifier which has a much wider input voltage range than the +/- 15V power supply rails ?

Given that the integrator is well suited to dealing with a large negative voltage range, then for that polarity of the spark signal it is merely a matter of clamping out any positive going component and ensuring there are no significant DC offsets. A BJT makes very effective signal clamp.

For the positive going component one solution which works very well is to clamp off the negative going component, then pass the signal via an inverting amplifier with a gain of 0.25. This inverts the signal to a negative going attenuated signal. As the inverting amplifier (just like the integrator) has a virtual earth input, the positive signal voltage swing can exceed 4 times the negative power supply rail value before the OP amps output saturates.

This means that the input compliance or dynamic range can approach 50V. In addition the loss of the gain can be easily recovered. Due to the fact the integrator also has a virtual earth input, the series integration resistor for the x 4 attenuated & inverted signal simply passes to the integrator with a 25K resistor rather than a 100k resistor used in the negative going direct non attenuated channel. The diagram of the circuit which achieves this is shown below in Figure 12:
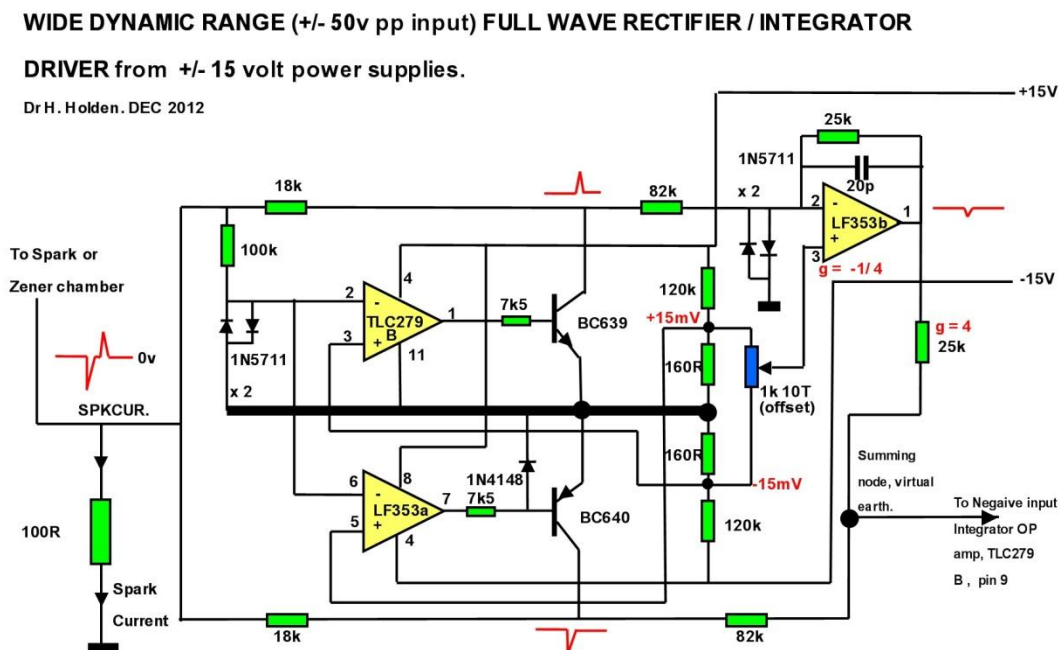
FIGURE 12.

The highest peak short duration spark voltage I have measured so far from a CDI was a 16 volt amplitude (160mA) 100uS long . Therefore this test machine could measure any much more

energetic CDI's (if they exist) with much higher peak voltages & currents without any difficulty with circuitry overload/saturation.

The integrator is reset every second spark and during that time the integrator output from the previous spark measurement is stored in the sample hold. The sample is taken after the spark when the integrator output is stable and the dwell component of the artificial distributor's **sprkdrv** signal and the divided **sprkclk** signal is used to coordinate that by two series CD4066 switch gates that are effectively configured as an And gate.

Example spark current recordings:

Figure 13 shows a spark current recording of a CDI unit using a real spark plug and figure 14 shows the result using the zener plug. (The real plug in air has about a 600v drop so the peak currents are a little higher compared to the 100V zener system shown in figure 14). CDI units tend to have a very uniform spark energy over the full rpm range, in this instance the meter reports 15mJ per spark across the full rpm range and unaffected by dwell angle. As it turns out 10mJ of this is in the negative going component and 5mJ in the positive going component. (this proportion was measured by alternately disconnecting the negative and positive channels of the rectifier system before the feed to the integrator.)
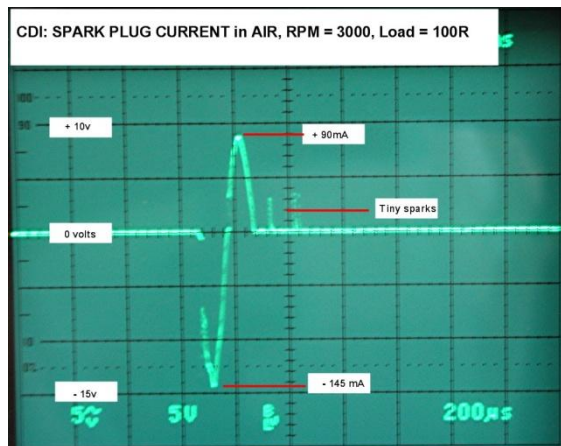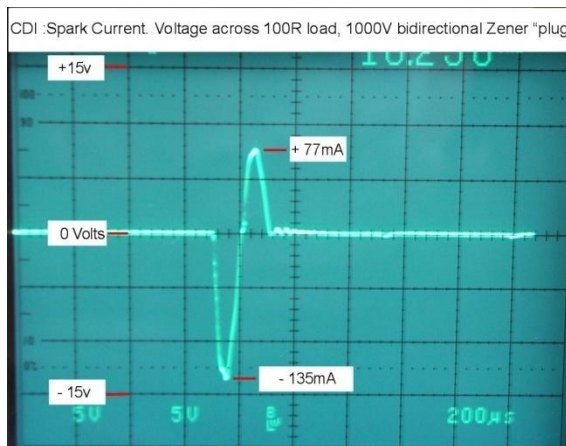
FIGURE 13.   FIGURE 14.

In the recording with the real plug the CDI is just able to produce some tiny weak sparks after the main two with the 600V real plug in air. Probably in use with a 1000V spark the result would be the same as the 1000V zener exactly and these would not be present.

As can be seen the CDI spark duration is short, the negative spark being about 100 uS long as is the positive going part.

It is interesting to look at the voltage across the zener plug. Doing these tests requires a 100:1 ratio scope probe, figure 15:
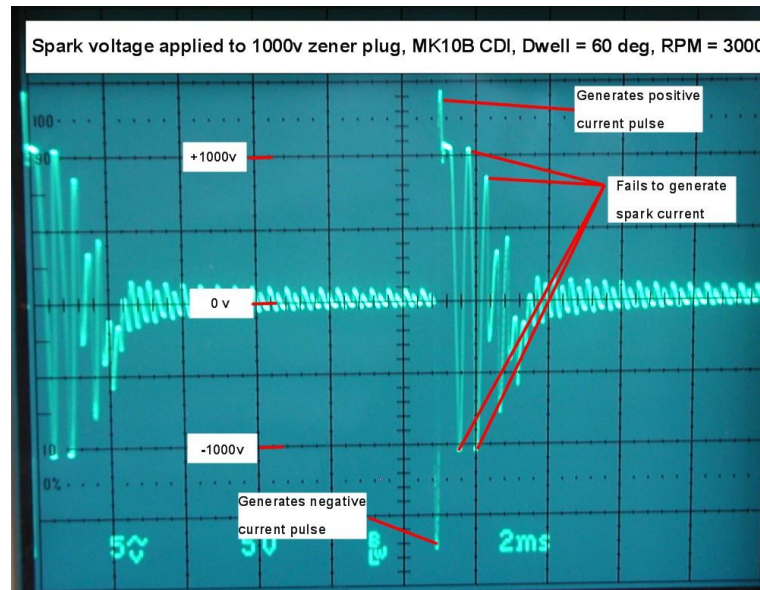

FIGURE 15

Only the first negative and then positive going voltage peaks significantly exceed the spark (zener) voltage and produce spark current. The remaining peaks have a lower energy and do not produce any spark current. For a close look at this voltage waveform, see figure 16 below:
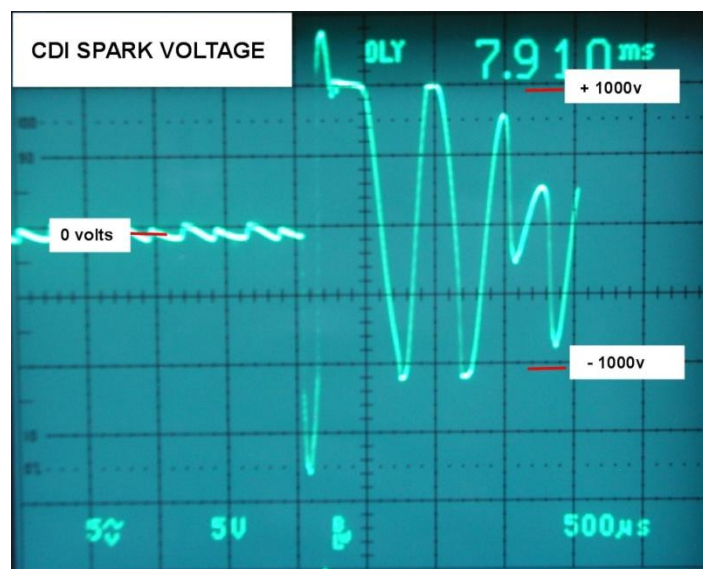
FIGURE 16.

Kettering recordings:

At 3000 rpm (4cyl car) for example and a 60 degree dwell the Kettering spark energy with the same ignition coil used with the CDI tested above (a Bosch GT40 cold) the spark energy is around 37mJ and 30mJ hot (twice that of the CDI) due to the longer duration of the spark at around 2mS, even though the peak and average currents are lower. Using the 1000V Zener plug is shown in figure 15. The spark current is the upper trace, the lower trace is the voltage applied to the zener plug which includes the 5K resistor) so the voltage measured there is a little higher than the 1000V zener voltage during the spark time; Figure 15:
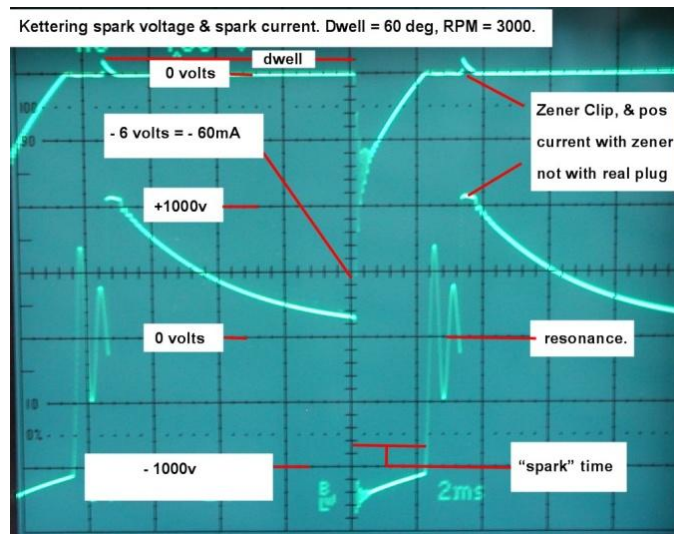
        FIGURE 15.

When the spark stops conducting, and prior to the dewll time, the coil is unloaded and its inductance and self capacitance resonates at around 2kHz. When the points close, this generates the small spike that causes a signal artefact in the zener system as can be seen just at the start of the dwell time. With the 85:1 ratio ignition coil this causes a small 1 to 2 mJ over estimation of the spark energy as the area inside the signal artefact is integrated and added to the total.

Figure 16 below shows a real plug (in air) substituted for the zener plug. Due to the fact the spark voltage is lower the spark current is elongated because, as it turns out, the energy delivered to the spark is about the same, with a 600V or a 1000V spark. For example using the 600V spark voltage and modifying the spark current sensing resistor from 100 to 60 ohms, to maintain the energy meter calibration, the spark energy was close to 37mJ in both cases.

With time and coil heating after 20 minutes or so the spark energy drops from 37mJ to 31mJ as the coil's DC resistance increases with heat.
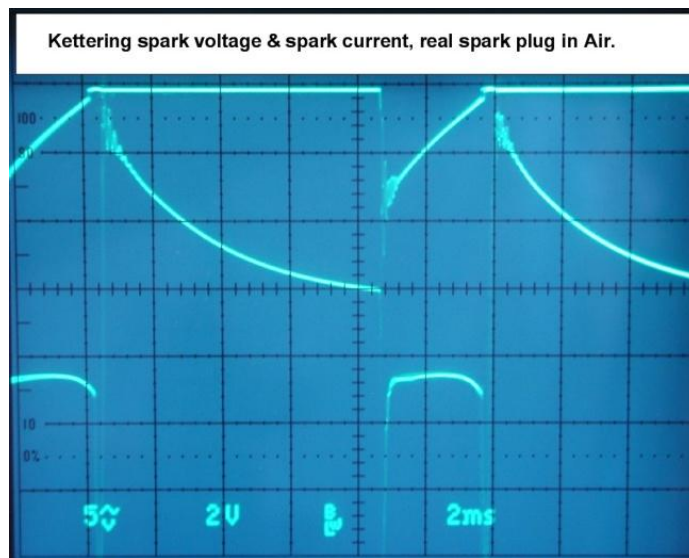
FIGURE 16

As can be seen from figure 16 with the real spark plug, the positive going peak of primary voltage, which exceeds 1000v just after the points close, is not conducted by the spark plug and the small signal artefact is not present in the current recording. In addition, the very long spark time with the plug in air has encroached a little into the dwell time. The spark voltage is fairly uniform over the spark time at around 600v.

As can be seen for Kettering the spark current is unidirectional (unlike the CDI) and has on this recording (figure 15) is a -60mA peak corresponding to 6 volts developed across the 100R resistor. The waveform contains decaying oscillations in its initial part but these are not large enough to drive the waveform into the positive region. Inspecting these more closely, figure 17:
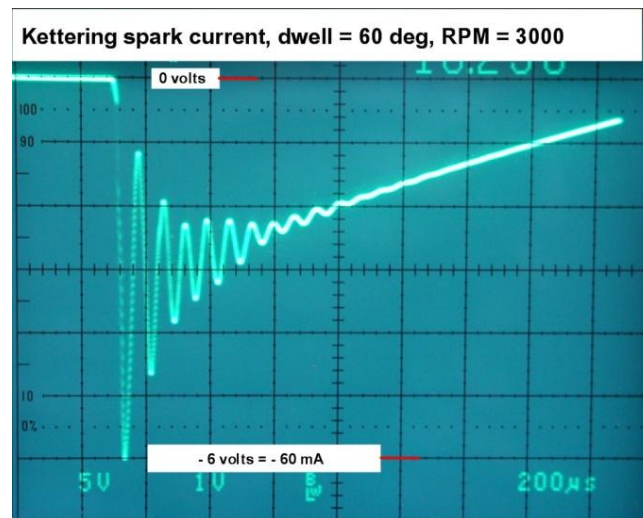
FIGURE 17.

The initial negative going spark current pulse is about 40uS to 60uS wide. (lower in amplitude than the 100uS wide initial spark current from a CDI). Then rather than returning to zero, the spark current maintains a DC value, albeit with superimposed oscillations and decays to zero after about 2mS when the spark disappears. As noted these oscillations are due to the leakage reactance of the primary resonating with the contact breaker capacitance and the primary self capacitance values.

The Kettering spark energy (without the meter) can be roughly assessed by inspection of figure 15. On the average it is a roughly triangular shape of -36mA amplitude and roughly 2mS long. Multiplying this current by time and dividing by 2 yields the charge transferred, about 0.36 micro Coulombs (uC) and multiplying this by 1000v (the "spark voltage") yields 36mJ. The actual calibrated meter reading reported 37mJ cold and 31mJ hot coil.

The same process can be used to assess the spark energy from the CDI. Looking at figure 14 and assuming the shapes of the current pulses are sinusoidal, then the negative pulse has an rms value of 95mA and a duration of 100uS making the charge transferred 9.5 uC and its energy 9.5mJ, while the positive pulse has an rms value of 54.4 mA and over the 100uS then 5.4uC is transferred making its energy 5.4mJ. The total being 5.4 + 9.5 = 14.9 mJ. The meter reports 15mJ not affected by temperature/time and the coil runs cold.

So on the *average*, over the period that the spark/s exist, the spark from the CDI is half as energetic as the spark from Kettering. *However within the first 100uS the spark from the CDI is over twice as energetic as Kettering* which is very interesting. The Kettering spark lasts 10 times longer than the CDI spark/s, 2mS vs 200uS under the same conditions.

Kettering energy loss with RPM:

As noted the main complaint or defect with the Kettering ignition system is energy loss at increasing RPM. However this is not as extreme as one might imagine, especially for the 4 cylinder motor. The 4 images below figure 18 to figure 21 show the Bosch GT40 coil tested at various RPMS and a recording of the BU941'1 emitter current, which is very close to the coil's primary current:
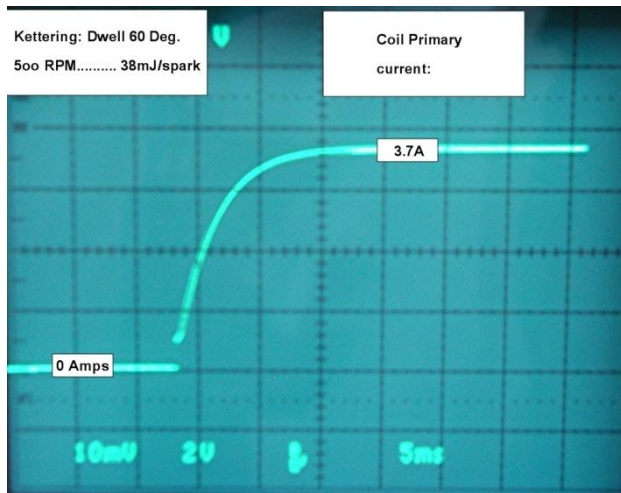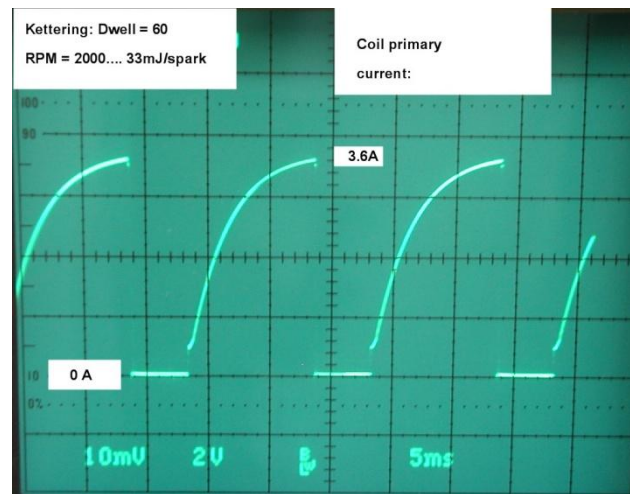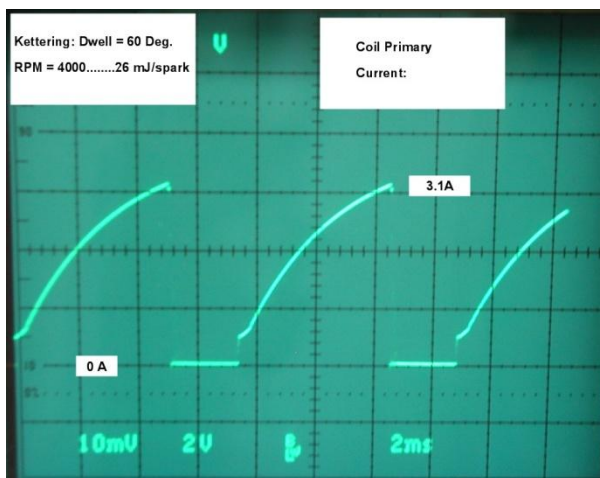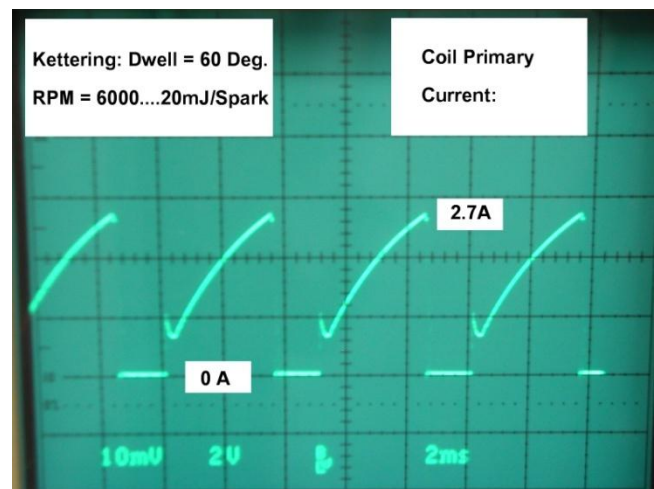
FIGURE 18.

FIGURE 19.

FIGURE 20.

FIGURE 21.

As can be seen at low range RPM's ie 500, the coil primary current has reached a stable saturated value. The rpm needs to be elevated to at least 2000 before the primary current and therefore energy storage drops. By 4000 RPM the energy has dropped to 26mJ spark and by 6000RPM, probably the upper range for a 4 cyl vehicle, the energy has dropped to 20mJ/spark.

Reducing the dwell angle also lowers the spark energy. In contrast the CDI unit is not affected by the dwell setting and maintains a uniform energy of around 15mJ/ spark but with a short high intensity spark compared to Kettering.

Physical Construction of the machine:

The machine was built using a 3mm thick aluminium base plate with 3/8 square machined bar sections on the corners tapped with 6-32 threads which are suitably coarse for aluminium.

FIGURE 22.

3mm thick side plates were crafted to support signal (BNC) connector, mains connectors and fuse & main switch:

FIGURE 23.

The "contact breaker" output stage was made with a piece of extruded aluminium to become a heat sink for the BU941 and a carrier for a standard distributor condenser:
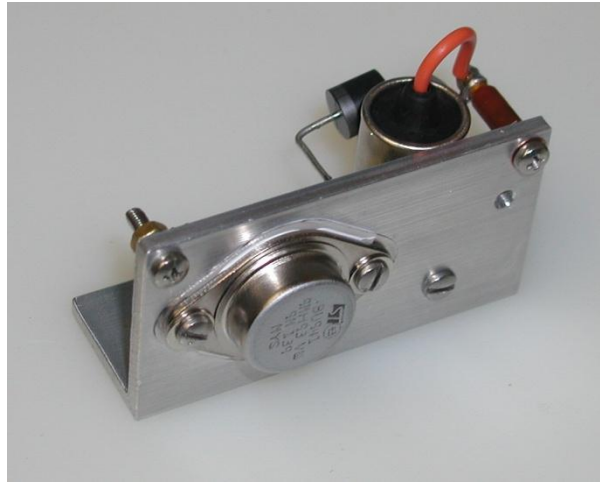

FIGURE 24.

The front panel was constructed from a product called BRAMITE. This is a unique Australian made insulating panel designed for mains power breaker boxes. The physical properties of this material are remarkable. Very strong & tough and heat resistant with excellent dielectric properties and easy to work with & machine and drill and a very pleasant finish:
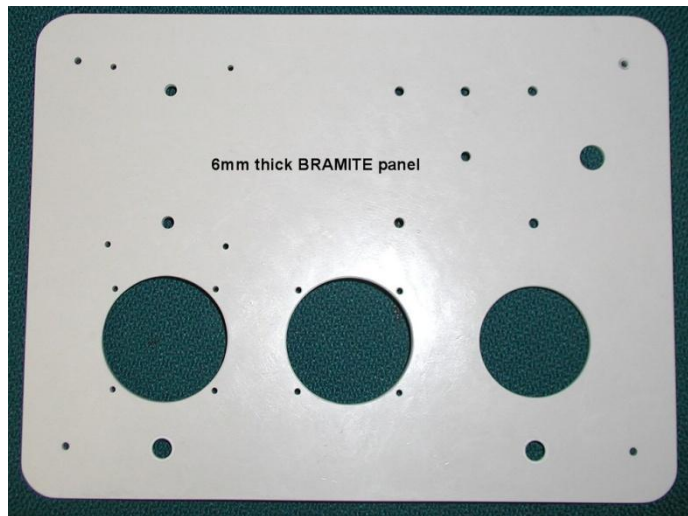

FIGURE 25.

Figure 26 shows the instruments mounted to the panel. The internal coil negative has a separate connection to the contact breaker (C/B) with nickel plated knurled brass nuts. This coil is disabled when external coils are being tested. The internal coil is very useful when it comes to testing ignition amplifier modules. A dropping resistor (ballast) is included for testing coils which require these. The two meters are 100uA fsd with series calibration resistors for 10V fsd. These meters are high quality bakelite cased jewel bearing types with the scales re labelled to degrees and mJ. The RPM meter is a standard automotive type made by AUTO Meter in the USA.

FIGURE 26.

FIGURE 27.

Figure 27 shows the rear panel which has two high quality 10K potentiometers. The wiring is Teflon covered and the connectors are gold plated Jaycar 0.9mm single pin types. Figure 28 shows the main components inside the unit:
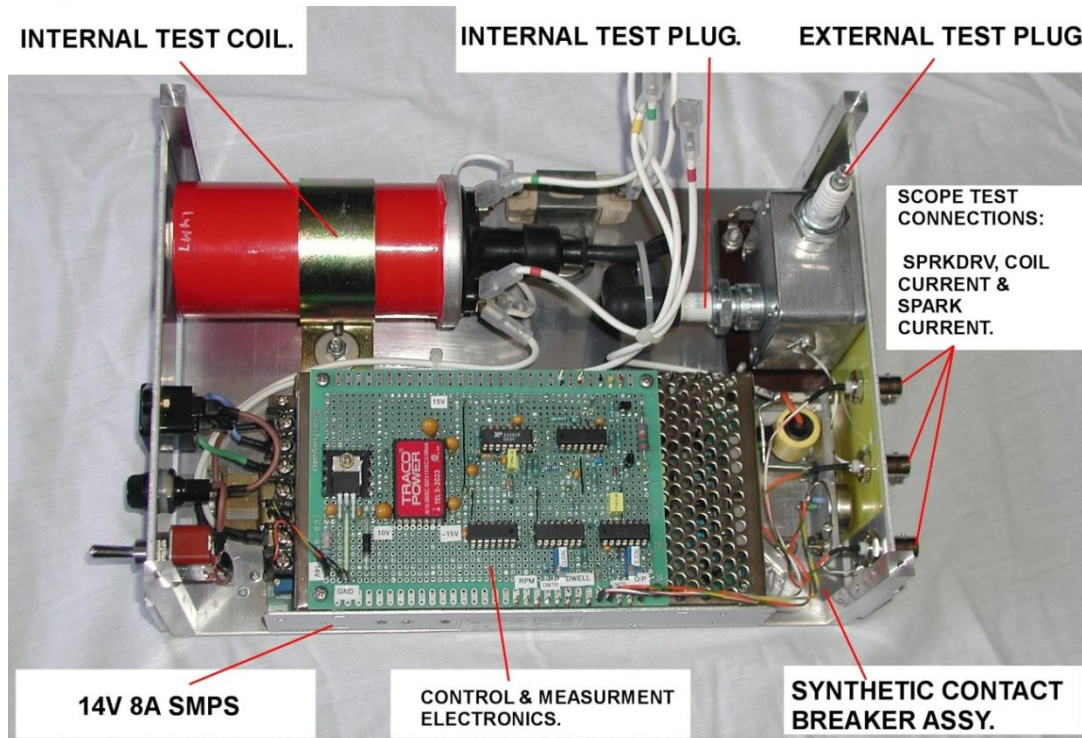

FIGURE 28.

The "spark chamber" is mounted on a phenolic block and connects to ground via the 100 ohm 2 watt resistor. The electronics for tis one off unit were hand built on plated through hole spot board.

Figure 29 and 30 below show some side views:

FIGURE 29.

FIGURE 30.

The unit was designed to fit inside a standard Pellican industrial case to protect it and provide a strong housing and make it easy to carry about.

Figure 31 below shows a test setup with an external coil, in this case a Bosch GT40.
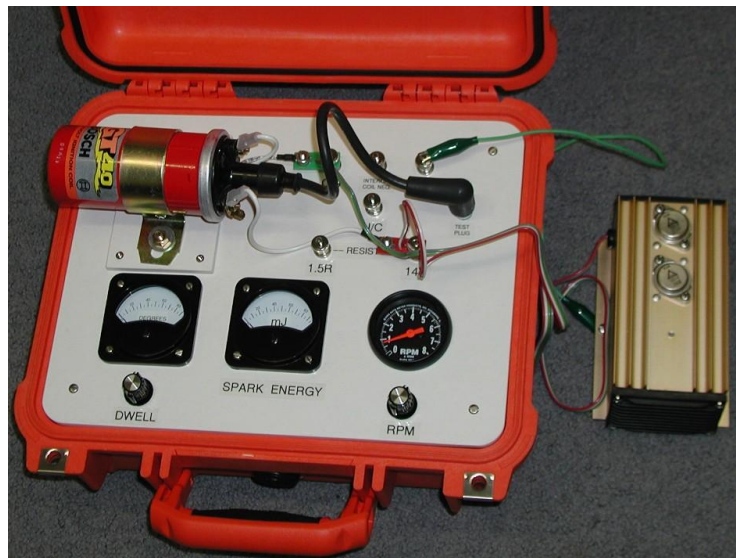
FIGURE 31.

FIGURE 32.

Figure 32 shows a combination of the GT40 coil with a vintage aftermarket device such as the original Delta 10 CDI. These were the prototypes of CDI technology appearing on the automotive ignition scene in the late 1960's.

Basically they contain a DC/DC converter which is a circuit known as a Royer Oscillator. This charges a 1.5uF capacitor to around 400 volts DC. The capacitor's energy is then dumped into the coil by an SCR triggered by the opening of the contact breaker. At the moment this occurs

the output of the DC/DC converter is transiently shorted out and it takes a few cycles of oscillation to recover. This is shown below in figure 33. (The lower trace is a test full wave rectified version of the spark current which as noted above is actually bipolarity current for a CDI).

The upper trace of figure 33 is the inverter transformer primary voltage waveform. As can be seen at the time of the spark the inverter is heavily loaded and stops and re starts after a few cycles. Royer Oscillator are "self protected" from being shorted out as the oscillations rely on feedback from the transformer to be maintained. When they are shorted or overloaded the feedback diminishes.

The inverter frequency in the MK10B CDI unit tested is about 1.6KHz. Later on the inverter frequencies in CDI's were increased around 8KHz to avoid audio interference among other problems such as the inverter synchronising with the ignition rate.
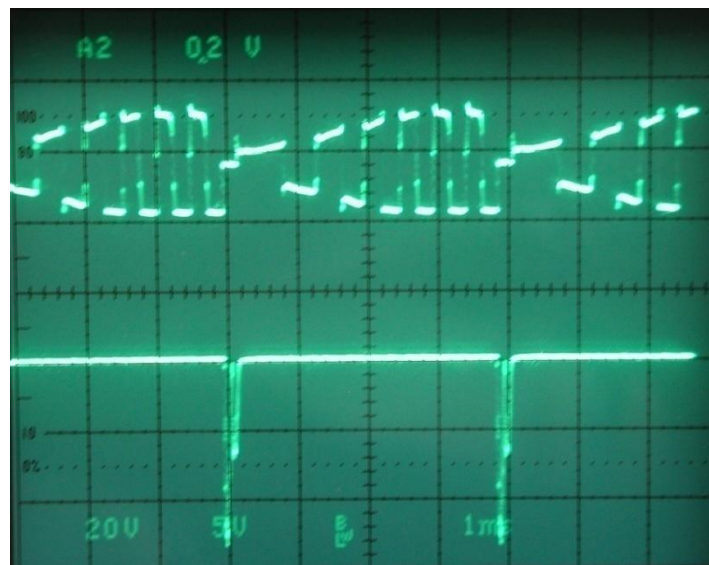

FIGURE 33.

Calibration of the spark test machine:

Calibration of the dwell angle is achieved by setting the **sparkdrv** wave to a 50% duty cycle with the dwell control and calibrating the meter series adjustment potentiometer so the meter reads 45 degrees.

Calibration of the spark energy meter is done by removing TLC279 IC B from its socket and connecting the socket pin 7 to the 10volt reference and setting the series meter adjustment potentiometer so the meter reads 100mJ.

The calibration for negative going spark signals then only depends on the tolerances of the 100 ohm current sensing resistor and the 100K resistor (composed of the 18k & 82k resistor in the negative channel of the rectifier) and 10nF capacitor forming the integrator.

For positive going signals the resistor tolerances of the values associated with the gain x ¼ of the LF353 OP amp affect the accuracy. In general the unit on account of these component values (1% tolerance) the unit is basically well "self calibrated"

A small amount of current is drawn by the rectifier circuit which has an overall input resistance of about 33k. This acts in parallel with the 100R sensing resistor to make it behave as though it were a 99.97R resistor which is an insignificant error. Most of the possible error would relate to reading the face of the analog meter. The calibration can also be checked by feeding a known rectangular test voltage to the 100R resistor, synchronised to the **sparkdrv** pulse and comparing the calculated to the measured energy value.

Conclusion & initial results:

The machine has already revealed interesting data about the differences between Kettering and CDI systems. One interesting feature is that that the Kettering system heats the ignition coil significantly. For example from ambient temperature the initial Kettering energy per spark at 3000 RPM with a Bosch GT40 coil and a 60 degree dwell time is in the order of 37mJ, after 20 minutes, with coil heating, this drops to around 31mJ. This is due to the increase in primary resistance of the coil and the peak primary currents are a little lower. In the CDI system the coil remains cool and the wasted system heat is largely generated by the transistorised DC/DC converter in the CDI unit and the overall energy is stable with heating.

One question remains as to whether it is better to have a short duration high energy spark or long duration lower energy spark. The information in early CDI literature was that longer sparks were unnecessary and simply burnt away the spark plug's electrodes. Other data suggests that a longer spark may assist combustion and result in less unburnt hydrocarbons exiting the exhaust system.

Now that the test machine is built and ready to use I will be able to test and document a wide variety of ignition coil drive systems and ignition coil combinations. For example there are high energy ignition projects, such as those published by Silicon Chip over the years which can be tested on this machine.

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