OPERATIONAL ASPECTS OF CLASSIC COIL IGNITION SYSTEMS

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I N D E X

OPERATIONAL ASPECTS OF CLASSIC COIL IGNITION SYSTEMS – PARTS 1 AND 2

1.0 PREAMBLE

Coil ignition has been successfully used for many decades, and the majority of motor cyclists are quite au fait with it and are able to carry out their own running repairs, servicing and maintenance. Despite this, the theory and basics of coil ignition are not always appreciated and understood. Recent letters to the Jampot magazine seem to confirm this. While certain technical liberties have been taken to simplify this presentation, the theory is correct. The mathematics illustrating the theory can be ignored by those who are only interested in the practical aspects of these systems. The diagrams are of an illustrative nature and should not be taken as wiring diagrams.

2.0 SYSTEM COMPONENTS

Before considering the system itself it is useful to recall what each component in the system is and what each component does. The various elements of a coil ignition system are shown in fig. 1. This diagram represents a single cylinder application consisting of;

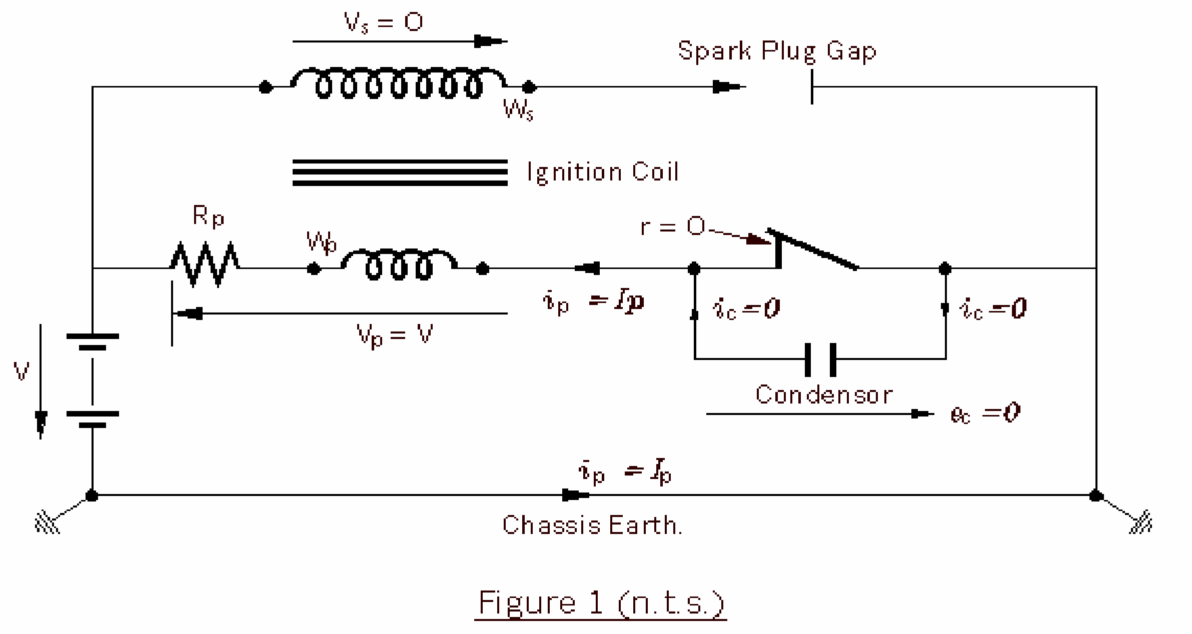


Figure 1 (n.t.s.)
Equivalent circuit steady state situation with contact breaker closed

i) <u>the ignition coil</u>: This is really a small transformer in which two windings are wound onto and are insulated from a low reluctance (i.e. low magnetic resistance) iron core and also from each other. For those who may be interested, the relationship between these coils is given by :

$$\frac{V_p}{T_p} = \frac{V_s}{T_s} \qquad 1$$

i.e. the volts per turn of the primary (low voltage) winding (W_p) must equal the volts per turn of the secondary (high voltage or H.T.) winding (W_s). In addition to voltage "balance" across the windings, current balance must also exist. i.e.

$$I_p \cdot T_p = I_s \cdot T_s \qquad 2$$

i.e. primary winding ampere turns must equal the secondary winding ampere turns. Now if these two equations are combined it is possible to calculate the necessary turns ratio for a given primary voltage and for the desired secondary voltage. It is also possible to calculate what the secondary current through the spark plug would be for the particular turns ratio. For example a 6 or 12 volt system would require a turns ratio of 3 500 or 1 750 to 1 if a 21 000 volt output voltage was required. Using these ratios it will be found that for primary coil currents of approximately 3 amps the spark plug current would be of the order of a milliamp. It is due to this small secondary (high tension) current that the roads are not littered with electrocuted motorcyclists. (A healthy person, assuming no heart or respiratory problems, can safely endure a body current of 10 to 20 ma before fillibration of the heart sets in.)

The transformation of 6 or 12 volts to 21000 volts can only occur if the magnetic field created by I_p is changing and moving across the H.T. windings. The magnetic field grows to a maximum from zero as the contact breaker is closed, is maintained briefly at a maximum value and is then collapsed by the contact breaker opening and interrupting I_p. An engine speed of 6000 rpm yields a contact frequency of 50 cycles/sec. and an induction frequency of 100 Hz, with the field growing to a maximum from zero and then collapsing for each power stroke. A static magnetic field is a source of potential energy but it cannot induce a voltage in another coil.

ii) <u>The battery:</u> Batteries produce direct current (d.c.) and direct voltages i.e. voltages and currents that do not vary with time or in direction of "flow", as happens with the electricity supplies used for domestic and industrial purposes (i.e. alternating current a.c.). In the discussion that follows, actual current flows are used i.e. electron flow from negative terminal of the battery through the external circuit to the positive terminal of the battery. It may also be helpful for the non electrically orientated reader to know that electrical current consists of the movement of electrons through a conductor. The unit of current is the ampere and;

1 ampere = 1 coulomb per second

The movement of one coulomb of charge every second is due to the battery voltage i.e.

1 volt = 1 joule per coulomb

Note : a coulomb is a measure of electrical charge.

This means the battery must expend one joule of energy to move one ampere of current through the external circuit. Hence if the battery is in a low state of charge it simply contains too little energy to move the required current around the circuit.(The water analogy of course is voltage ≡ water pressure, and current ≡ quantity of water flowing through the pipe.)

With the rapid opening and closing of the contact breaker points, the d.c. currents and voltages become time varying quantities. This introduces a.c. resistance and inductive effects into the system. The effects of this can be seen by switching on the ignition key and taking note of the amp meter reading with the points closed. For a G80 Matchless 6 volt system, this is of the order of 3 to 6 amps. Starting the bike with the alternator disconnected will show that the initial current flow reduces substantially. This is a result of the slight increase in circuit resistance and the inductive reactance (i.e. resistance) of the ignition coil windings.

iii) **<u>The contact breaker contacts</u>**: These contacts or "points" open and close the primary winding circuit once every two crankshaft revolutions for a four stroke engine, resulting in the magnetic field in the ignition coil being established and collapsed for each compression power stroke of the piston.

The setting i.e. gap of these points is critical for smooth reliable ignition. Too small a gap generally leads to erratic high speed sparking and too wide a gap erratic or rough low speed operation.

iv) **<u>The condensor (or capacitor)</u>** : This has the dual function of assisting to collapse the magnetic field in the ignition coil rapidly and cleanly , as well as absorbing the associated stored magnetic energy of the system. This prevents arcing and erosion of the contact breaker contacts i.e. too small a capacitor will generally result in erosion of the fixed contact with an oxide deposit on the moving contact. Over capacity reverses this and erodes the moving contact.

Condensors are sensitive to over temperature and over voltage; especially short duration and "spiky" transient voltages which can puncture the dielectric (insulation) between the condensor plates. An increase of +5°C for a lengthy period of time will result in the life of the capacitor being reduced by approximately 50%. An increase of 10°C reduces life expectancy to 25%. The capacitance of a capacitor is a fixed quantity and is a function of plate area, plate separation, and the permittivity of the dielectric between the plates i.e.

$$C = \xi \cdot \frac{S}{d} \qquad \text{3A}$$

Where	C	=	capacitance in farads
	ξ	=	permittivity of the medium (farads per metre)
	S	=	Area of capacitor plates (m^2)
	d	=	plate separation (m)

In charging a condenser the current flow leads, in time, the voltage build up across it. (For alternating systems the current leads the capacitor voltage by 90 electrical degrees). It is this aspect that helps collapse the magnetic field rapidly, thus inducing a healthy secondary voltage in the high tension winding. The amount of charge and hence current flow is given by;

$$Q = C \cdot V \qquad \text{3B}$$

Where	Q	=	charge in coulombs
	C	=	capacitance in farads
	V	=	Voltage across the capacitor

v) **<u>The spark plug</u>**: The spark plug gap is the trigger point of the system and needs to be correctly set to suit the maximum combustion chamber pressures that are being produced at each compression stroke. The heat grade of the plug, as mentioned recently in the Jampot magazine, is also very important for efficient and regular combustion, particularly at high speeds.

OPERATIONAL ASPECTS OF CLASSIC COIL IGNITION SYSTEMS – PART 3

3.0 PRINCIPLE OF OPERATION

3.1 Overview :

In brief and simple terms a coil ignition system operates as follows :

i) The contact breaker "points" close, allowing a d.c. current to flow from the negative side of the battery through the points through the primary winding (W_p) and back to the battery (see fig 1 and fig 3 blue curve)

ii) As the current I_p starts flowing a magnetic field builds up in the ignition coil linking both windings and remains at a maximum steady state value, until such time as I_p changes value.

iii) Following this, the contact breaker opens, interrupts I_p and the magnetic field of (W_p) collapses, rapidly, with the aid of the condenser.

iv) This collapse generates a high voltage across the other winding (W_s) which in turn results in an arc current "bridging" the spark plug gap in the combustion chamber.

v) This "spark" ignites the fuel vapour in the cylinder at precisely the right time and the engine "fires".

Under steady state conditions with the contact breaker closed the current through the primary winding is given by ohms law i.e.

$$I_p = \frac{V}{R_p} \qquad \text{3C}$$

Where R_p is the equivalent resistance of the primary winding, contact breaker resistance, internal battery resistance, the wiring and wiring connection resistances.

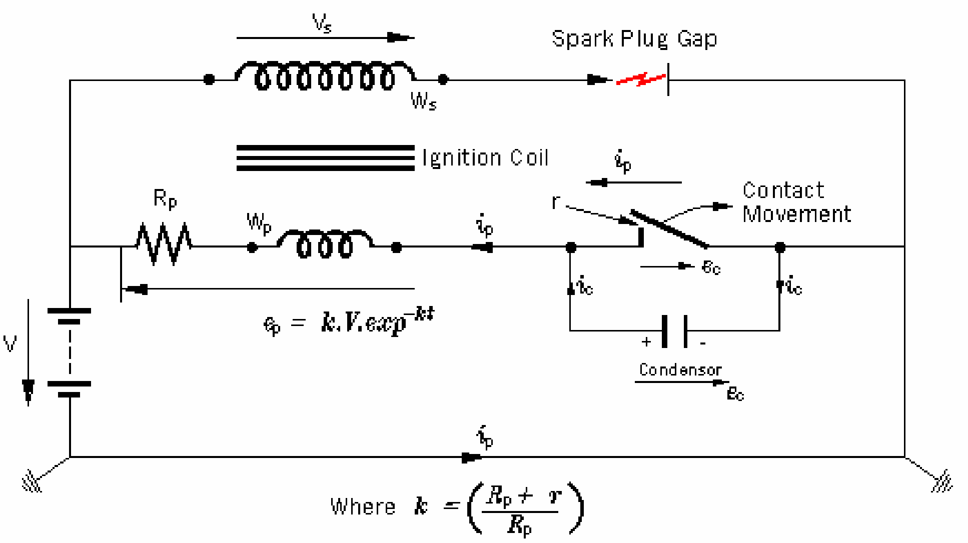
This process seems quite simple and basic when taken slowly at an analysis pace. At high or low engine speeds, a few fairly serious complications arise that only a correctly sized condenser can sort out. So the least expensive and most insignificant component in the system becomes   it's cornerstone for successful operation. To illustrate this it is necessary to look beyond the simple "steady state" d.c. situation, and consider what happens at higher speeds when current flow begins to vary with time, and becomes (a distorted) "alternating" current.

3.2 **<u>The "Firing" Cycle</u>** :

This is most easily explained by considering what happens at each step of the cycle i.e.

a) <u>Contact Breaker Opens</u> :

Fig 2 illustrates the equivalent circuit as the contact breaker starts to open from the fully closed position. It is at this point that the "complications" come into play ;



<u>Figure 2</u>
Equivalent circuit - Transient situation
with contact breaker beginning to open.

To deal with the first complication, a little theory is necessary, starting with Heinrich Lenz who discovered in 1834 that any attempt to change the state of a magnetic circuit resulted in a reaction which opposed and resisted the cause of the change. In the case of the ignition coil, as the contacts begin to open, a change in I_p occurs which results in an emf (i.e. voltage) being induced in the coil, in such a direction as to sustain the flow of I_p. This is caused by the change in I_p reducing the magnetic field i.e. partially collapsing it, and producing an emf as a consequence of the field cutting through the windings of both coils. (i.e. a voltage in the same direction as that of the applied voltage across W_p and additive to it). This voltage has the effect of prolonging the flow of I_p. This emf is described by;

$$e_p = -L\frac{di}{dt} \tag{3D}$$

Where	L	=	inductance of the primary winding (W_p) and is
		=	$N \cdot \frac{\Phi}{I}$
	e_p	=	back emf (Volts)
	Φ	=	magnetic field strength (Wb)
	I	=	current causing the field = I_p (amps)
	N	=	number of turns of winding W_p
	$\frac{di}{dt}$	=	rate at which I_p decreases from t = 0 secs

Time dependant currents and voltages are depicted as lower case letters in what follows. The back emf affects the rate at which the original current starts to decay as the "points" begin to open i.e. the back emf reinforces the battery voltage delaying the interruption of I_p. This decay is given by;

$$i_p = I_p \cdot \exp^{-\frac{Rt}{L}} \qquad 4$$

Where i_p = the instantaneous value of current at time t (secs)

R & L = the resistance and inductance of the circuit as a whole

exp = a mathematical operator = 2.72 (approximately)

Thus at time t = o before the points open, the term $\exp^{\frac{-Rt}{L}}$ is equal to 1 and hence the d.c. situation exists and $i_p = I_p$

For time t equal to a large value, $i_p = o$, and the contacts have opened and I_p has stopped flowing altogether. The way this current behaves is illustrated in fig 3 via the solid red curve. The blue curve illustrates the current growth as the points initially close.

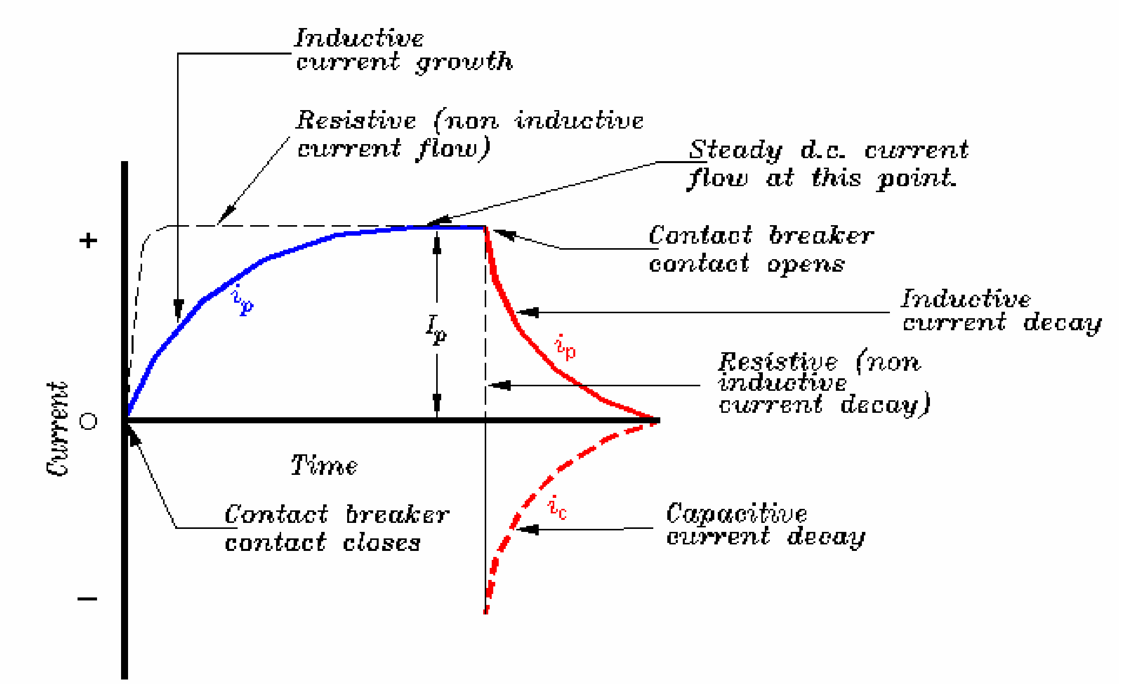


Figure 3 (n.t.s.)
Variation of switch-on & switch-off currents in a coil ignition (inductive) circuit.

So I_p can not suddenly stop flowing, but reduces gradually to zero. This is not good from a spark point of view. As previously mentioned an efficient induced voltage into W_s, requires the W_p magnetic field to collapse suddenly. The slow decay of I_p prevents this happening, and the coil H.T. voltage output is reduced dramatically. This need for a rapid collapse of the field is illustrated by equation (5);

$$e = l \cdot v \cdot \beta \quad \text{volts} \qquad 5$$

Where β = flux density of the magnetic field

l = conductor length i.e. no. of winding coils

v = velocity at which the field cuts the coils of W_p

This indicates that the faster the rate of cutting the magnetic field i.e. v metre per sec. the greater the induced voltage for a given field and length of winding.

Before explaining how the problem of this back emf is overcome in practice, it is necessary to consider a second complication that makes the situation worse. This complication arises from the fact that in opening a d.c. circuit containing a magnetic field element, the induced back emf from W_p appears across the contact breaker contacts according to the following relationship;

$$e_p = k \cdot V \cdot \exp^{-kt} \qquad 6$$

Where $k = \left(\frac{R_p + r}{R_p} \right)$

r = transient additional resistance that occurs in the circuit across the contact breaker contacts

R_p = equivalent resistance of the circuit as before

This resistance can become significant due to the resistance caused by the initial separation of the contacts and the ac resistance effects. At the instant of opening i.e. t = o+ equation (6) reduces to;

$$e_p = V \cdot \left(\frac{R_p + r}{R_p} \right) \qquad 7$$

This can become a very large voltage if r happens to be very much greater than the circuit resistance. The effect of this high voltage is to produce severe arcing at the contact breaker with the ultimate and rapid destruction of the contacts. This arcing can be seen quite clearly by disconnecting the capacitor and operating the contacts manually.

It is at this point in time the condenser must be introduced into the circuit in order to:

i) reduce i_p to zero instantaneously and

ii) to overcome arcing at the points by absorbing the magnetic energy

To illustrate how this is achieved consider fig 3 and fig 4;

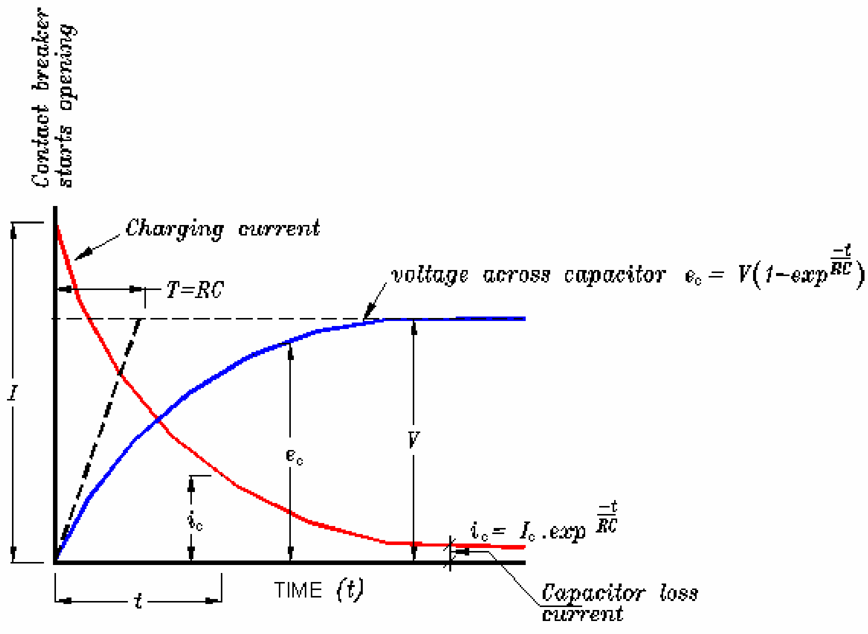


Figure 4 (n.t.s.)

Variation of current and voltage during the charging cycle of a capacitor.

From figure 2 it is apparent that the battery and or the induced voltage e_p does not appear solely across the contacts and therefore the capacitor. This voltage is distributed around the various elements in the circuit once a current begins flowing e.g. the internal resistance of W_p, the internal resistance of the battery, the resistance of each wiring connection point and the distributed resistance of the circuit wiring. Thus only portion of this voltage causes i_c to start flowing at a maximum value in advance of e_c as shown in figure 4. This current decays to zero slowly as the capacitor voltage builds up in <u>opposition to the voltage causing the current flow</u>. The graph of fig 4 illustrates how a capacitor reacts to an applied voltage in terms of capacitor charging current and voltage i.e. as voltage is applied to the circuit the current flow through the capacitor immediately reaches a maximum condition according to ;

$$i_c = I_{c.} \cdot \exp^{\frac{-kt}{r_c}} \qquad 8$$

Again at t = o $i_c = I_c$ and in practice electrons are stripped from the positive plate of the capacitor at a maximum rate and begin being deposited on the negative plate. This electron stripping causes the capacitor to build up potential until it reaches its maximum value, which must then equal the applied voltage V and be of opposite polarity in order to reduce i_c to zero.

Fig. 2 illustrates an interesting situation in that both i_c and e_c are in opposition to V and e_p, as well as i_p and I_p. This is also shown in fig. 3 dotted red curve. In practice the sequence of events is as follows :

a) the contact breaker starts to open and interrupts I_p in accordance with;

$$i_p = I_p \cdot \exp^{\frac{-Rt}{L}}$$

b) this produces a back emf in accordance with;

$$e_p = k \cdot V \cdot \exp^{-kt}$$

c) this back emf appears partially across the capacitor resulting in a current flow i_c in opposition and hopefully equal to i_p in accordance with equation (8).

d) a voltage builds up across the capacitor with opposite polarity to e_p in accordance with;

$$e_c = V\left(1 - \exp^{\frac{-t}{R \cdot C}}\right) \qquad 9$$

This opposition current and voltage, if correctly timed and sized, in terms of capacitance, and circuit resistance, reduces contact arcing to zero by stopping i_p instantly. This abrupt interruption then allows the magnetic field to collapse instantaneously, while the capacitor holds the contact gap resistance to an acceptable finite value, thus limiting the transient back emf increase across the contacts to levels that will not damage the capacitor nor the contacts.

Combining figs 3 and 4 into fig 5 graphically shows how this is achieved and how the time phasing of currents and voltages interact to reduce electrical activity at the contact breaker to small values. i.e. adding the two red curves of i_p and i_c at any point in time results in zero current as the currents cancel out each other. In a nutshell, the humble capacitor removes all the complications. Clearly a case of saying Q.E.D. to a previously complicated problem.

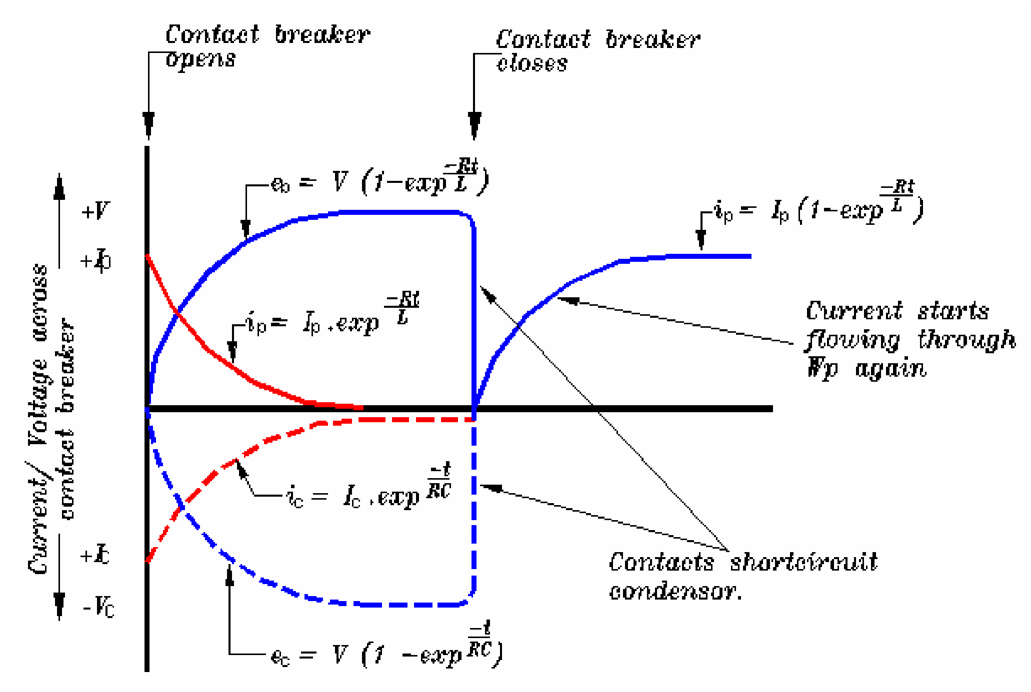


Figure 5 (n.t.s.)

Electrical activity at contact breaker contacts. (events superimposed)

b) **Contacts close :**

Once a spark has traversed the spark plug gap, the contact breaker recloses in order to prepare the ignition coil for the next compression stroke, thus permitting current i_p to start flowing in accordance with equation (4) and as illustrated by the blue curves of fig 3 and fig 5. This current builds the magnetic field up to a maximum value again. This build up of the field lags the current that causes it by approximately 90 electrical degrees. At the prescribed time after time zero, i_p again flattens out into a steady state d.c. current I_p and the magnetic field also stops increasing, and becomes a static magnetic field which has enveloped both windings. This therefore returns the process to the fig 1 situation.

OPERATIONAL ASPECTS OF CLASSIC COIL IGNITION SYSTEMS – PART 4

4.0 CAPACITOR SIZING AND LOCATION

4.1 Sizing :

The previously described process can only succeed if the capacitor size and its timing are correct for the particular circuit and system. (i.e. circuit resistance, inductance and the battery voltage.) This sizing is determined by the manufacturers of the bike and the capacitor and need not concern the enthusiast. To illustrate how this can be done, (for those who may be interested), consider an ignition coil fully magnetised due to a steady d.c. current I_p. This field will persist in this state as long as the current keeps flowing through the winding. Once established, the magnetic field becomes an energy source, that cannot be destroyed or "lost". It can only be transformed into some other form of energy. This magnetic energy can be represented by the following equation;

$$E_p = \frac{1}{2} \cdot L_p \cdot I_p^2 \qquad 10$$

Where E_p = the stored energy in joules

L_p = inductance as before

I_p = d.c. current as before

To avoid this energy spilling across the contact breaker contacts as these begin to open, it needs to absorbed by using a suitably sized capacitor i.e. allowing the energy to pass into and be stored by the capacitor instead of being transformed into heat in the form of an arc across the contacts.

The storage capability of a capacitor, of C farads, needed to absorb the energy from the magnetic field is given by;

$$E_c = \frac{1}{2} \cdot C \cdot V_p^2 \qquad 11$$

Where E_c = the stored capacitor energy in joules

C = capacitance in farads

V_p = voltage across the capacitor (Volts)

Equations (10) and (11) must be equal to each other if E_c is to absorb E_p. This then yields;

$$C = L_p \cdot \frac{I_p^2}{V_p^2}$$

and this can be rearranged and simplified as follows;

$$C = \frac{L_p}{R_p^2} \qquad 12$$

Another interesting result which indicates that the size of capacitor, while being a linear function of the inductance of the circuit, is inversely proportional to the square of the circuit resistance. This equation together with a few measurements taken on the bikes wiring can be useful in checking capacitor sizes if a “pirate” unit has been installed due to the unavailability of original spares. It can also be used to examine the statements made in letters to the Jampot Editor and to amplify some of the practical variations that one encounters with classic bikes from time to time.

OPERATIONAL ASPECTS OF CLASSIC COIL IGNITION SYSTEMS – PART 5

5.0 PRACTICAL CONSIDERATIONS

There have been a number of queries from club members with ignition or capacitor problems and comments from others in response to these over a fair period of time. For some of the latest, refer to Jampots (from about) No's 594 through to No.600. Some of these aspects are examined in what follows;

5.1 **Condenser and contact "points" failure** :

i) **Heat**:

One members conclusion that his capacitor failure was heat related is probably quite correct. However there are other aspects that could have played a role. Capacitors work extremely hard " fair wear and tear", particularly the more modern replacements one has to use today. This is no reflection on modern components, materials and manufacturing techniques; it is simply a matter of closer build tolerances leaving less margin for overloading, and for that matter, application/usage error.

A capacitor's charge/ discharge mechanism involves the re-orientation and alignment of charged dielectric molecules, (dipoles). As this occurs, losses in the dielectric result in heat being generated. This loss and heat will have an impact on the dielectric over time, resulting in ageing and hardening of the dielectric with ionization and coring taking place. External heating simply accelerates the process; recall the +5°C ambient half life relationship referred to previously!

One reader made a comment that the best place for a condenser is to leave it where the original car/motor cycle manufacturer put it i.e. at the contact breaker points. This may not necessarily be correct. Capacitors intended for the original location would have been specifically designed and built for the application.(and the ambient conditions.) The modern replacement units may not be quite that tolerant in this regard as these may have been intended for a more widespread usage. Indeed two capacitors received from the club spares did not last too well at all. Relocating the replacement units to under the saddle (and taking a few precautions in doing so) has led to trouble free operation.

ii) **Voltage** :

a) **Six volt capacitor in a 12 volt system** :

Overvoltage is the other achilles heel of a capacitor, particularly large spiky transients that can and do occur due to high resistance connections, loose connections, contact bounce, incorrect sizing and incompatibility of components. A personal observation is there seems little or no difference between condensers supplied for 6 or 12 volts? Perhaps one design at these voltage levels was made to fit "all" for economic reasons? However to illustrate what effect voltage can have on a capacitor consider the following exercise and equation;

$$C = \xi \cdot \frac{S}{d}$$

For a given voltage application, the dielectric stress, (or electric field strength or potential gradient E) is given by;

$$E = \frac{V}{d} \qquad \text{(volts per meter)}$$

Using a 6 volt capacitor on a 12 Volt system will clearly double the stress. Taking into account the plate separation could be of the order of two micrometres for high tech capacitors it is evident that this stress can become a very large value indeed.

e.g.. $E = \dfrac{6 \text{ or } 12 \text{ Volts}}{2 \times 10^{-6} \text{ metres}} = 3 \text{ to } 6 \times 10^{6} \dfrac{\text{Volts}}{\text{metre}}$

or $E = 3000 \text{ to } 6000 \dfrac{\text{volts}}{\text{mm}}$

With motor cycle capacitors the value of d is likely to be larger than high tech units and hence the stress will be proportionately lower. This seems to be borne out by the withstand capabilities of these old capacitors to high voltage megger tests. (Perhaps a capacitor expert in the club can advise in this regard?) The original manufacturers did seem to make one unit, for both 6 and 12 volts? However the point being made here is “don’t rock the boat” by using a capacitor that is known to be a 6 volt unit, on a 12 volt system "except in an emergency get me home" situation. Use correctly rated components for the job for trouble free riding.

A second aspect to consider is current flow using equation (3B) which can be written as;

$$\frac{Q_2}{Q_1} = \frac{V_2}{V_1}$$

This can also be rewritten as;

$$Q_2 = Q_1 \cdot \frac{V_2}{V_1}$$

This tells us that twice as much charge (current) will be forced into the 6 volt (V_1) capacitor if 12 volts (V_2) is applied to it. Unless the capacitor design / tolerances allows for this, trouble must surely follow sooner or later. So if twice the current is being absorbed by the capacitor what will the effect on the contact breaker point be ? The energy equation No. 11 suitably rearranged can be used to illustrate what could happen i.e.

$$\frac{E_2}{E_1} = \frac{V_2^2}{V_1^2}$$

So if V_2 is to V_1 as 12 Volts is to 6 volts then the energy (E) absorbed is given by;

$$E_2 = 4 \cdot E_1$$

This indicates that the energy throughput of the capacitor is four times greater than the original design figure and three times more than the stored energy of the magnetic field at 6 volts. This excess energy will probably, depending on the particular circuit parameters, result in reverse arcing at the contact breaker, eventually causing erosion to the moving contact and damage to the capacitor with oxide deposit on the fixed contact (vice versa for a positive earth machine). This is shown exaggerated in fig. 7.

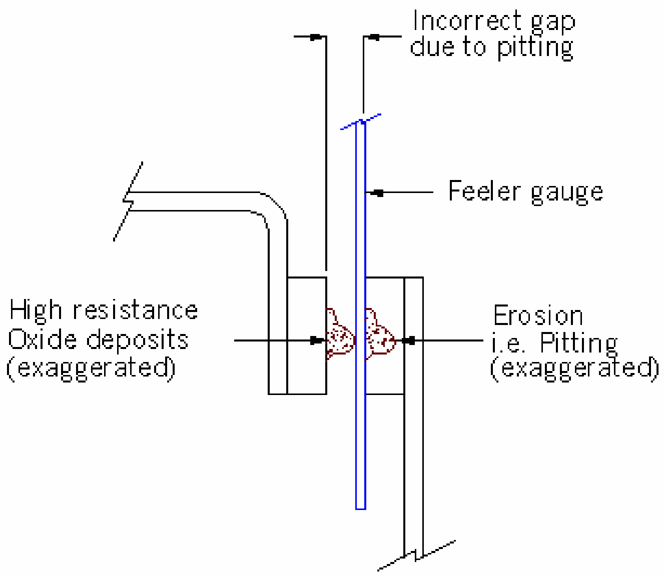


Figure 7 (n.t.s.)
Contact breaker
showing effect of
using the wrong
capacitor

This arcing, if left uncorrected will eventually result in an open circuit due to reduction in conductivity at the "points" contact faces as the oxide deposits increase. It can also affect the timing when trying to set "burnt" contacts using a feeler gauge. This will also result in a much wider contact gap and in turn affect the timing. Perhaps this is what the one writer was referring to in saying that his timing varied by "two degrees in 1000 miles"?

It has not been the author's experience that "points" actually wear (mechanically) as the impact forces are quite low relative to the contact surface area. Wear of the cam follower does occur, especially after a new set of "points" has been installed and the machine has covered 500 to 1 000 miles or so. Perhaps other club members have had experience in this regard?

b) **12 volts versus 6 volts** :

It is not clear what the one writer means by saying that 12 volts will give "….. better sparks/ higher voltage anyway …………" A 12 volt system is definitely preferable to a 6 volt system; more battery energy is available to drive less current through the electrical systems. The benefits of the higher voltage are most noticeable when riding at night with the better lighting that results; however whether we use 12 volts or 6 volts, the quality of spark is the same; with all else being equal. The number of turns on the ignition HT coil (see equations (1) and (2) would have been adjusted by the designer of the coil to suit the system voltage. Irrespective of the coils primary voltage the secondary H.T. output voltage would be the same i.e. say 21 000 volts. To illustrate this a Lucas 6 volt ignition was compared to a 12 volt unit in table No. 1.

Primary Coil		G80	BSA	Units
Battery Voltage (d.c.)	—	6	12	Volts
Current at 6 000 rpm	—	2,03	2,15	Amps
Impedance at 6 000 rpm	—	2,96	5,58	Ohms
Inductance at 6 000 rpm	—	6,1	12,7	mH
I/V phase shift	—	48	45	electrical degrees
d.c. resistance	—	2,2	3,9	Ohms
Copper losses	—	8,14	17,2	Watts

Table No. 1

This table indicates that for a given H.T voltage, primary winding currents are almost the same but the HT coil resistances are very different. So using equations (1) and (2) it is evident that if output voltages remain unchanged then the HT winding of the 12 volt coil has twice the number of windings in it than the 6 volt coil. Furthermore the primary coils seem to have the same number of turns. (usually about 240). The increase in the number of windings is borne out by the doubling of resistance for the 12 volt HT coil in table 1. Thus there is no direct benefit to ones quality of spark by changing to 12 volts from 6 volts.

If on the other hand the writer meant that 12 volts was being applied to a 6 volt coil, then table 1 indicates that trouble is at hand i.e. with a 6 volt coil, a resistance of 2.2 to 2.96 Ω, 12 volts will increase the current through the winding to 4,05 to 5,45 amps and losses on the winding would increase to the order of 48 to 65 Watts. The ignition coil would eventually overheat and fail before it should. The output voltage would be much higher than the original design value and the associated energy, would be substantial. The risk of intercoil and interwinding flashover would also increase considerably. However no one could seriously advocate doing this and clearly this particular writer had something else in mind when writing to the Editor.

It should be noted that table 1 cheats just a little as the tests were done with a sinusoidal supply and this is not what the coil experiences from a rapidly opening and closing contact breaker. There is probably someone in the club who could expand on this, and illustrate the difference more accurately. This could be an interesting bench experiment for the more practically inclined.

Table one also shows that the inductance of the 12 volt coil is approximately twice that of the 6 volt coil. We have previously shown that the 12 volt coil has twice the number of primary turns than that of the 6 volt coil. This dovetails well with equation (3) where;

$$L = \frac{N\Phi}{I}$$

i.e twice as many turns for a given magnetic field and primary current increases the coil inductance by a factor of 2.

c) **Transient overvoltages** :

The statement that induced voltages of 500 volts “peak to peak” and higher can appear across the capacitor (and therefore the points as well) is intriguing. The writer then goes on to say that these “.....capacitors need to be rated for 1000 volts instead of the present 500 to 800 volts”. This may or may not be correct. It would be unwise to say that anything is impossible these days! If this does occur and has been measured then it is doubtful that the system components would survive this treatment for very long. The first query is how was this voltage measured? Oscilloscopes are notorious for picking up spurious signals and noise from the mains, from adjacent equipment as well as from the subject equipment itself. Where were the connections made to get the reading? etc. The comment peak to peak implies that this transient was of an alternating nature and thus mains power related. A 6 volt 232 nano Farad capacitor will withstand a d.c.1000 volt Megger test without apparent damage; whether it could do the same on an alternating transient at the same level of supply for any length of time is open to question and will need to be investigated. Putting this same capacitor onto a 220 volt 50 Hz supply for 10 minutes or so also did not seem to do any harm.

Looking at this a little closer, equation (6) tells us that the back emf is at a maximum when t = 0+ i.e. the point at which the points begin to separate. For e_p to reach 500 volts plus with V_p = 6 or 12 volts, the factor k must reach a value of 83 to 42 i.e.

$$k = \frac{R_p + r}{R_p}$$

and therefore;

$$r = 41 \cdot R_p \text{ to } 82 \cdot R_p$$

For a classic machine, R_p will be of the order of perhaps 6 ohms. This means that r rises to 246 to 492 ohms respectively for 12 and 6 volt system. Is this actually possible in practice?

The two part answer must be;

i) No for a correctly designed, installed and maintained system operating under "normal" conditions as the capacitor should act as a clamp on the contact breaker voltage build up..

ii) Yes if the design has not been maintained or incorrect components used for example.

For situation (i) above the only variable resistive element that can occur, again under "normal" conditions, is contact breaker arc resistance. This arcing occurs in the very best of families due to slight mismatching between components; however it is usually small and no damage results. It does however introduce transient resistance into the circuit.

The arc voltage would not exceed 10 to 20 volts per cm or 1 to 2 volts per millimetre. Thus for a 14 thousand of an inch contact breaker setting this voltage would be 0,36 to 0,71 volts. With a current flow of say 2 amps the arc resistance would be 0,71 to 1,43 ohms. In other words a voltage of 500 Volts seems to be theoretically impossible due to arc resistance.

For situation (ii) the sky is really the limit, but this will only arise due to an intermittent open circuit such as a loose contact, loose battery terminal or the use of incorrectly sized or rated components. Even with a loose connection 500 volts appears to be unlikely as an arc voltage is again introduced at the open circuit position and this introduces added resistance. Theoretically if r tended to infinity, e_p would follow. In practice this does not happen because the arc resistance at the contacts remains finite and the capacitor remains in circuit across the points. These become the limiting factor in the equation. Operating the contact breaker by hand, without the capacitor connected, will amply demonstrate that arcing does increase significantly without a capacitor in circuit and as e_p increases.
If any reader has researched this aspect, and can illustrate that 500 volts is possible, the writer for one and no doubt others would appreciate learning how this can happen.

5.2 **Increased system inductance** :

The same correspondent states that “ the wire between the coil and (a remote capacitor) gets in the way as it acts as an inductance, and within a few miles the points will be fizzing and burning away.” From this letter it is not clear exactly where this wire is routed. There is a fairly long wire between the capacitor/contact breaker and ignition coil in any event, so any inductive effect due to this wire should also impact on the ex factory wiring system. So this unlikely to be the problem.

From fig. 6 we see the situation where the condenser is remotely located from the moving contact and, we assume it is located right at the coil terminal. This does introduce some resistance, say r_c into the “time constant” part of the condenser circuit i.e.

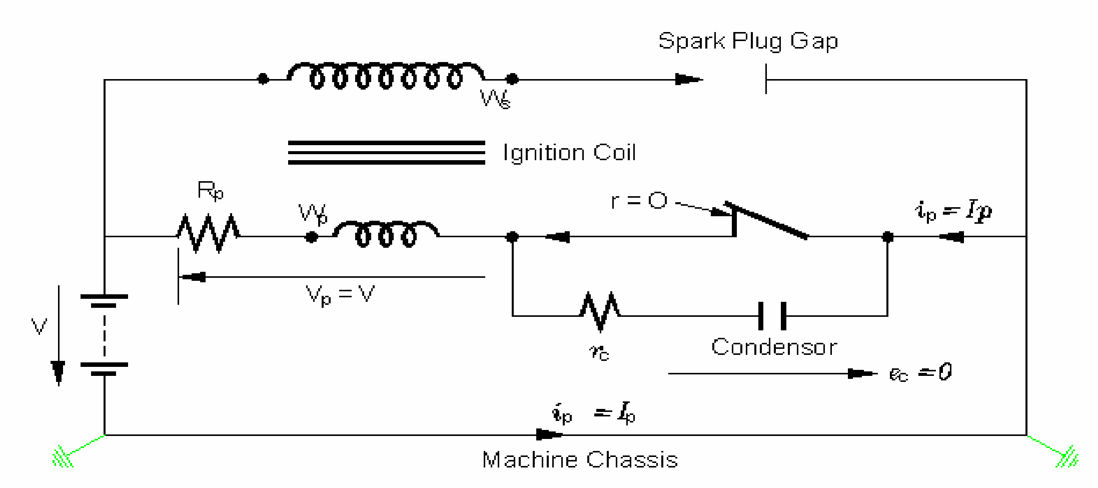


Figure 6 (n.t.s.)

Equivalent circuit with capacitor moved to ignition coil located under saddle

The circuit time constant T = RC

But equations (8) and (9) will show, by inserting typical values for R + r_c for a 1 or 2 micro farad capacitor that the charge and discharge rates remain for all intents and purposes unchanged. Therefore this cannot be the problem. On the other hand if we assume that somehow an owner has introduced four metres of wire between the coil and condenser equation No. 13 can be used to calculate the inductance of this wire.

$$L = \frac{\mu \cdot l}{8\pi} \text{ henry} \qquad 13$$

$$\text{where } \mu = 4\pi \times 10^{-7}$$

with l = 4 m the inductance becomes $L = 2{,}0 \times 10^{-7}$ henry

If this is inserted into any of the back emf equations or the condenser sizing equation the change will be so small as to be negligible. If it is compared to the figures in table 1 it will be seen to be of the order of $0{,}33 \times 10^{-4}$ of one percent. Clearly this cannot be the problem. In fact the only way this wire could become a problem is if a very large magnetic field was operating around it to induce a large voltage into it.

5.3 **Relocating the capacitor** :

The theory may improve our understanding of coil ignition systems and components but it relies on what values of coil inductance, capacitance, and resistance are used to analyse a particular modification. While it is possible to measure these values it would be convenient to know what tolerances to expect with these components and how these vary from component to component, manufacturer to manufacturer. For example a few rudimentary tests in the workshop showed that a brace of A65 capacitors together with a G80 and four automobile units all had a capacity of approximately 0,2 micro farads and all chugged along quite happily on a.c. 50 Hz voltages up to 70 Volts. So perhaps it is a case of seeing ghosts where there are none? Are all these units so similar? Perhaps someone in the club knows, and can confirm the writer's suspicions that the build of the coils and the capacitors are much of a muchness and are over engineered by default. So when it comes to relocating a capacitor on a G80 to a position under the saddle as shown in figure 8, the theory can tell us what may happen, and a little experimentation will tell us to what degree these things may happen; and/or whether there is reason for concern. From equation 12 it is apparent that the size of the capacitor may be important in relation to the system inductance and perhaps we should not meddle with this?

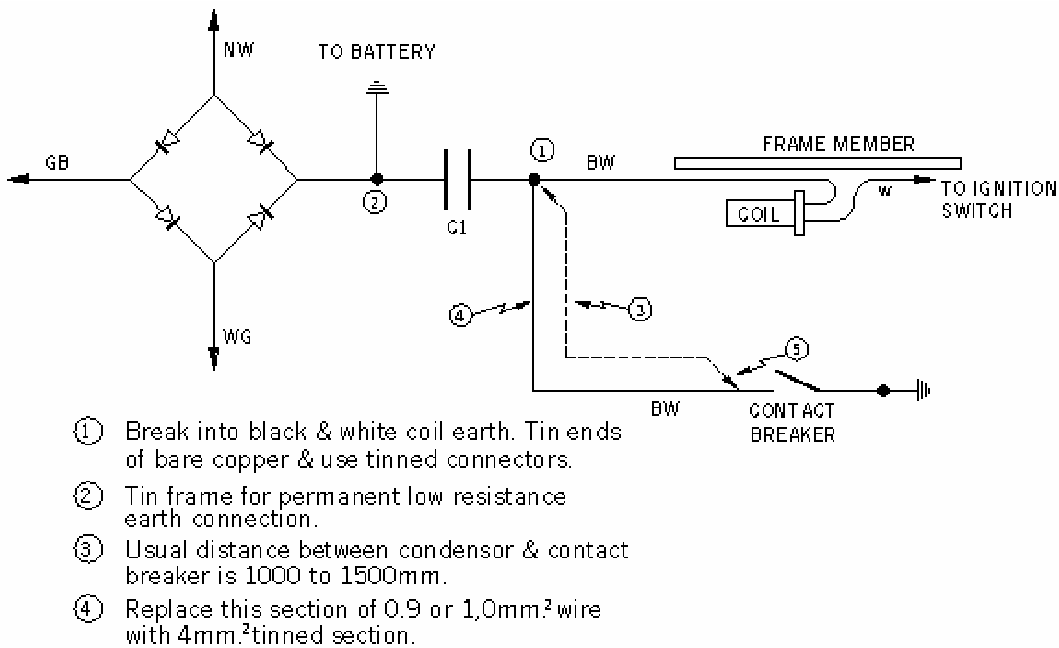


Figure 8
Remotely located condensor

From fig. 9 the increase in r_c due to the length of wire shown in figure 8 at (4) will affect the time constant T of the capacitive circuit and hence the transient performance of the capacitor i.e.

$$T_2 = T_1 \cdot \frac{r_{c2}}{r_{c1}} \qquad 14$$

But how important is this? Will it affect the timing, the contacts or the quality of performance as some reader's claim?

Usually with the condenser directly connected across the contact breaker, via a 1.0 mm² section wire, r_{c1} has been measured on a number of bikes and found to be between 3 to 5 milli ohms. The wire from point (1) in figure 8 to the contact breaker is usually of 1,0 mm² section (or less at times) and at 30°C has a resistance of r_{c2} = 28 milli ohms. All figures are approximate. This seems quite a big difference and equation 14 indicates an appreciable time constant extension. However what does this mean practically? Putting values into equation (14) shows a time constant extension of 56 x 10^{-9} secs.

In practical (mechanical) terms this is microscopic and certainly could not affect the machine's timing or performance. Indeed at 6 000 rpm the flywheels would have moved 0,4 x 10^{-6} mechanical degrees. While mechanically this is a very short space of time, electrically it is not. So if the ideal balance between the stored magnetic energy and condenser absorption existed with

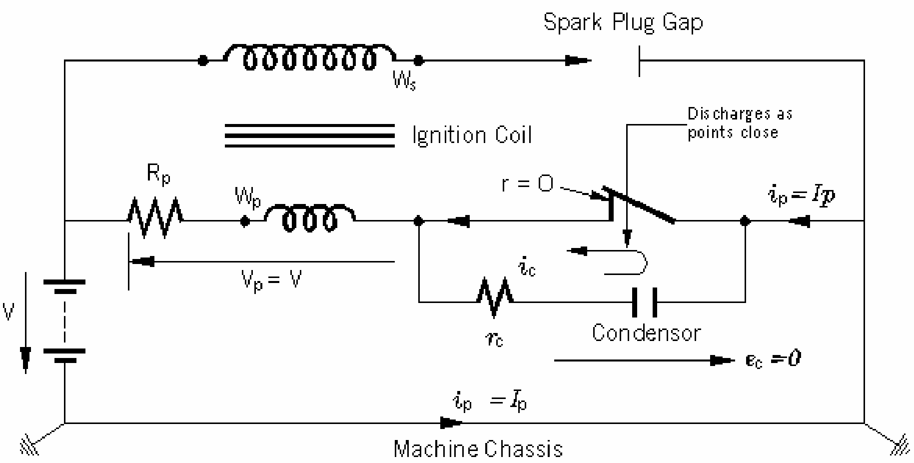
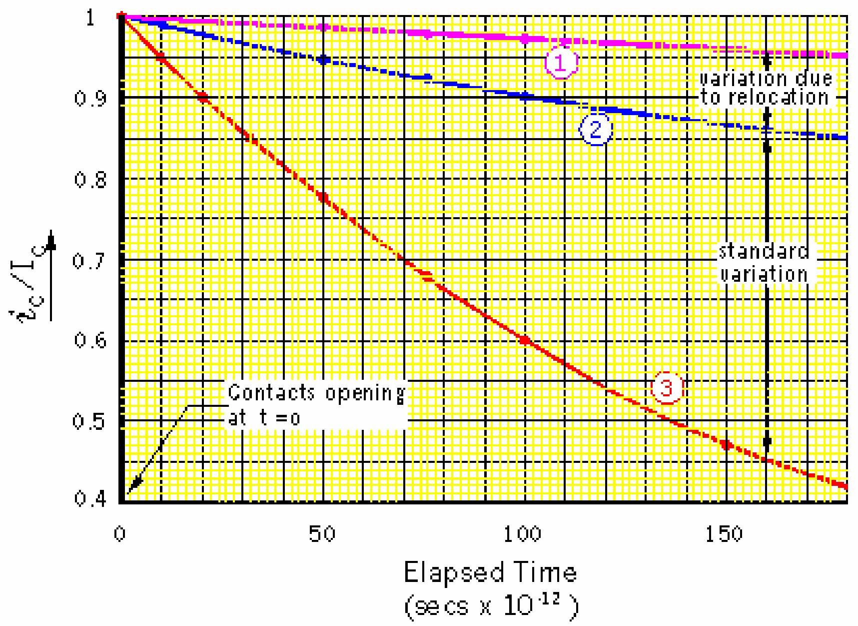


Figure 9 (n.t.s.)

Equivalent circuit with capacitor moved to position under the saddle



① Capacitor under the saddle with r_c = 28 x 10^{-3} ohms.
② Capacitor across contact breaker with r_c = 5 x 10^{-3} ohms.
③ Capacitor across contact breaker with r_c = 1 x 10^{-3} ohms.

Figure 10

the condenser across the points, we could now be facing increased erosion of the contacts due to a slight phase shift between transient currents i_p and i_c which are given by equations 4 and 8.

The family of curves of figure 10 show this displacement. What is of interest is the displacement between curves (2) and (3), (i.e. the variation that can occur with a condenser across the points) is larger than between (1) and (2) which marginally increases the maximum standard deviation of curve (3) i.e. the increased 28 milliohm situation has a minor impact on system performance. In view of this the condenser was relocated to under the saddle, and to date, no trouble has been experienced. For those who like to play safe, table No. 2 shows that a 4.0 mm² wire from point (1) to (5) in figure 8 will give an equivalent resistance of about 4 milli ohms which then takes the situation back to standard values of a condenser connected across the contact breaker.

5.4 **Coil connections**

This aspect can give rise to much debate; with, at times, quite diverse and vigorously stated opinions! The classic British bikes such as BSA, AJS etc used Lucas equipment which connected the positive (and common) coil terminal to earth via the contact breaker. American literature connected the common terminal to the unearthed battery terminal. This practice goes back to the early 20 th century e.g. refer to Dykes Automobile and Gasoline Engine Encyclopedia, and has been carried through to today. So with both systems having been in use for all these years, who is to say that one is preferable to the other? Another point of interest is that the British system tended to earth the positive pole of the battery whereas the Americans seem to have favoured the negative pole to be earthed.

So what are the pro's and con's of each of these connections?

a) **<u>Consider system 1</u>** i.e .connecting the common terminal of the coil to the unearthed battery terminal as shown in figs1 and 4 below;

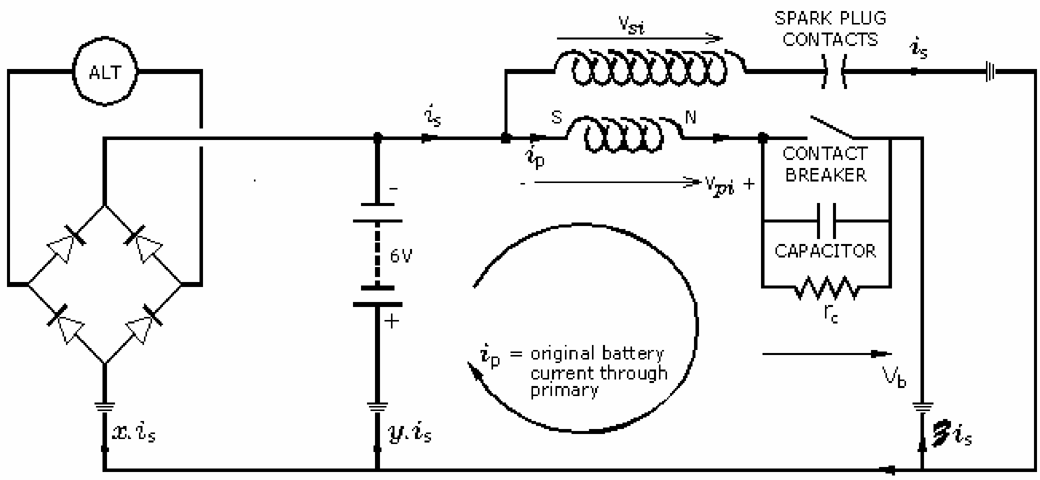


FIG. 1

<u>BOTH COILS WOUND IN SAME DIRECTION</u>

<u>AND LIKE END CONNECTED</u>

V_{pi} = Induced primary voltage as contacts open.

V_b = Applied battery voltage across open contact breaker.

V_{si} = Induced secondary voltage as contacts open.

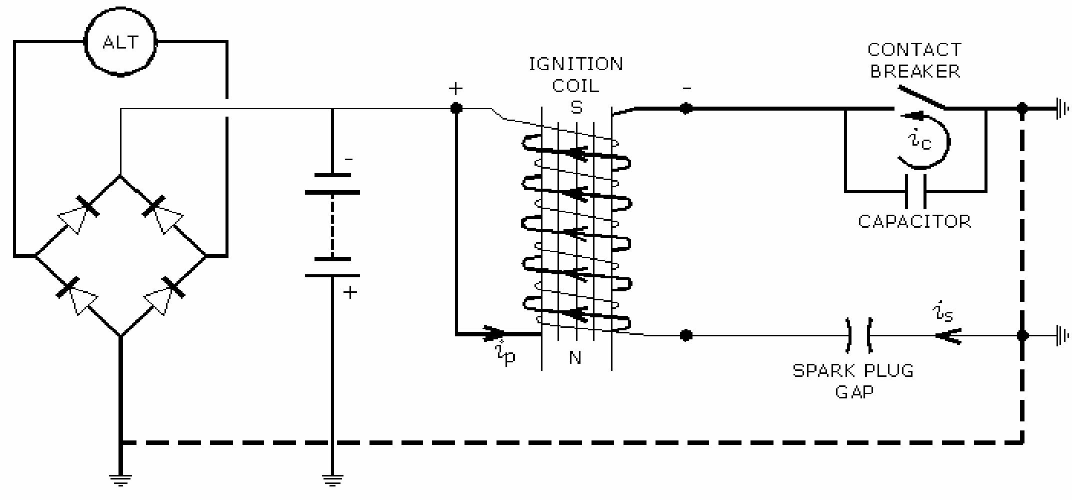


FIG. 4

As the contact points open, currents and voltages are as indicated in fig 1 and the HT current return path is via the battery ($y \cdot i_s$), the rectifier ($x \cdot i_s$) and the condenser ($z \cdot i_s$), where ;

$$i_s = x \cdot i_s + y \cdot i_s + z \cdot i_s$$

All of these paths are of a fairly low impedance (resistance) due to the transient high frequency nature of the current. Fig 4 gives a clearer idea of the direction of lay of the two coils. The direction of i_s <u>in this drawing is that of a reversed HT coil winding direction</u>. In this case the return paths for i_s are reduced to two; i.e. via the battery and the other via the primary winding of the coil and then the condenser where;

$$i_s = y \cdot i_s + z \cdot i_s \quad \text{and} \quad x \cdot i_s \approx 0$$

So it would make sense to have both windings wound in the same direction for this circuit configuration, unless the direction of $z \cdot i_s$, being in opposition to the residual flow of i_c and in phase with the mutual induction of the primary coil, (caused by the growth and discharge of the HT current), has any negative effect on the subsequent firing cycle.

b) **<u>Considering system 2 i.e. the Lucas system, figs 2 and 5 would apply</u>**.

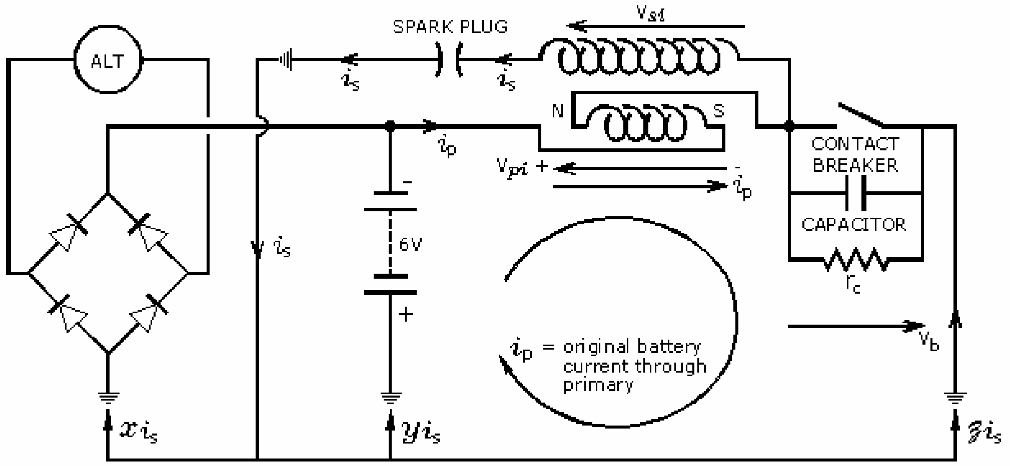


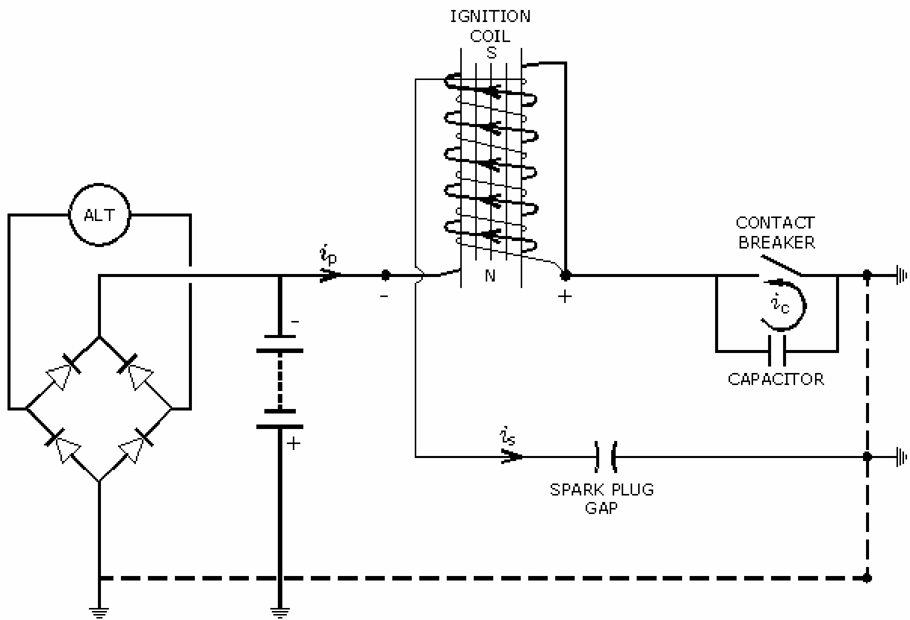
FIG. 2

<u>BOTH COILS WOUND IN SAME DIRECTION</u>
<u>AND CROSS CONNECTED</u>

V_{pi} = Induced primary voltage as contacts open.

V_b = Applied battery voltage across open contact breakers.

V_{si} = Induced secondary voltage as contacts open.



<u>FIG. 5</u>

With this arrangement return current paths are more complicated as currents $x \cdot i_s$ and $y \cdot i_s$ have to return in each case via the primary coil being in series and adding to the rectifier and the battery resistances. Therefore the $z \cdot i_s$ path via the condenser would probably be of the lowest impedance. Reversing the direction of lay of the HT coil in this instance would result in the direction of i_s being opposite to that shown in the drawings. This in turn would reduce the number of return paths to two, with the capacitor route conductivity probably being the better of the two.

The build of the Lucas coil usually had the HT winding connected internally to the LV winding at one end and taken to the +,ve terminal, and to the central iron core at the other end via a flexible copper tail. The HT output socket terminal was in turn connected to the iron core via an internal spring which was in "sprung and permanent" contact with the brass HT socket via a self tapping screw. The insulated cylinder that comprised both windings was itself enclosed by a cylinder of iron sheet laid up in the form of a cylinder and in contact with the earthed aluminium body of the coil. This material was the same as the 35 no. iron strips (65.5x7.5x0.5mm) that made up the central iron core, and was partially cut (stamped) through every 7.5mm to reduce eddy currents and hence heat. This outer cylinder of iron completed the magnetic circuit (aluminium is non magnetic). The point of describing the build of the coil illustrares that the Lucas design probably made use of capacitance coupling between the HT winding and the enclosing cylinder of iron and aluminium to improve the conductivity of the HT current return path?

To summarize therefore, both systems obviously work well, but the direct connection method system 1 seems to have a slight advantage over the Lucas system. It is also unlikely that Lucas would have produced oppositely wound windings in it's ignition coils in order to employ this particular system which would then have been different to other manufacturers.

A further point of interest is that a negatively earthed battery provides a degree of cathodic protection to the frame and tinware of bikes by virtue of the frame being negatively charged, as opposed to the electron deficiency that positive earthing creates. With the advent of the zener diode a constant small leakage of electrons to the frame would have been beneficial in reducing corrosion over the long term.

5.5 Connection Polarity.

The comment that…." the central electrode of the plug needs to be negative relative to the (+'ve) earthed electrode due to the effects of thermal emission…" needs to be clarified as this could be quite misleading. i.e.

For thermionic (thermal) emission (T.E.) to occur (i.e. the emission of electrons from a material to form a cloud of electrons) it would be necessary to have the relevant electrode at a bright red heat in order for the electrons to develop energy in excess of the electrode material's potential energy barrier (P.E.B) i.e. it's work function. If this did not happen any escaping electron would be pulled back into the electrode by the positive charge it created in leaving it.

The likelihood of a red hot electrode on the compression stroke causing pre-ignition is very real. Furthermore the cooling effect of the incoming fuel/air charge would reduce the temperature of the electrode to below the critical level and at that critical time for escape to occur (refer to recent articles on spark plug grading and selection).

Thermionic emission also requires very low local pressures of the order found in discharge lamps (near vacuum levels). With high combustion chamber pressures it is unlikely that sufficient energy could be developed by the electrons to overcome the P.E.B .and to escape into a cloud.

If T.H. can occur from the fixed spark plug electrode it will similarly and certainly occur at the adjustable electrode as well, irrespective of battery polarity. If T.H. occurred at either of the electrodes, movement of these electrons would be in the direction of a more positive pole and this can depend on several factors as illustrated previously i.e. it could work against breakdown of the plug gap.

What can assist sparkplug gap breakdown is the shape of the electrodes. A pair of electrodes with a sharply defined edge would arc over at lower potentials than a nicely rounded smooth shape. This is because a sharp point or edge distorts the potential field at the point /edge, and increases the electric stress at that position relative to other positions on the face of the electrode. On the other hand deformation of either electrode to a major degree can lead to spurious arc over which could affect the ignition timing. Moral of all this is to adhere to what the manufacturers recommend.

5.6 **Distribution of HT circuit voltage**.

(This item is included in response to letters in Jampot issues no.595 and 598 among others) Until the high voltage breaks down across the spark plug gap no "HT" voltage can be distributed around the circuit. It can be shown that all of the 21000volts, or so, output from the HT winding would appear across the plug gap. Once the breakdown occurs, the original voltage collapses due to the effective short circuiting of the H.T. winding and a very small current flows around the HT circuit as previously illustrated. It can also be shown with this current flowing Ohms law determines the voltage that appears across each component i.e.

$$v = i_s \cdot r \qquad \text{(volts)}$$

where: v = to the voltage across the circuit element

i_s = to the HT current

r = to the resistance or reactance of the element

This is illustrated overleaf in fig 3 where the following typical resistances would result in the voltages shown, and which would appear across the elements;

For a lumped circuit resistance r = 1 ohm, the voltage would be V_r = 1 milli volt

For a large leakage resistance $r_c = 10000\,\Omega$ the voltage would be V_c = 10 volts.

However the capacitor would present a very low reactance due to the high frequency of the HT current and this would effectively reduce the 10 volts across the capacitor to nearly zero. This calculation also ignores the internal voltage drop of the HT winding itself. This would also reduce overall voltage levels as would the multiplicity of current paths. Thus no large voltages can affect the capacitor due to the HT ignition coil winding. Only the LV circuit can cause a rise in voltage across this element as pointed out else where in this article.

Once the spark gap arc clears, any residual voltage would be found across the plug points and no where else in the system.

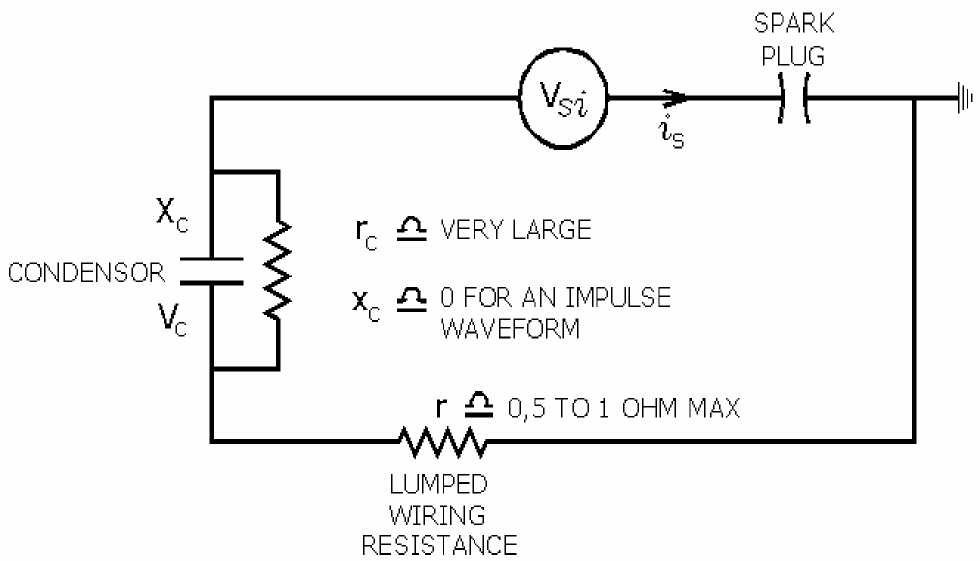


FIG.3

5.7 **A few practical aspects**

Previously the effect of the inductance of the wire to a remote capacitor was found to be very small and could be neglected. However the inductance of the system becomes a potential problem with loose or sub standard wiring connections. i.e. as explained earlier by equation (6). So a few practical tips when relocating the condenser or when altering the bikes wiring may be in order;

a) at the earth connection to the frame make sure that the joint face on the frame itself is well cleaned and thoroughly tinned with solder or plumber's metal. Rust is a poor conductor of electricity and can produce intermittent arcing faults.

b) all wiring should preferably be of the tinned copper type or the connection areas at all connector/lug ferrule crimps should be tinned. This only takes a few minutes to do and prevents a subsequent bad contact due to oxidation of the ferrule and wire interface.

c) At each connection point make sure that the copper is not nicked or cut when cutting the insulation back. This ultimately leads to wire fracture over a period of time and to intermittent faults. These will certainly cause overvoltage situations and possible damage.

d) Only clear back enough insulation to make a decent contact. Do not leave exposed copper wire open to accidental contact which can also cause overvoltage conditions.

e) Make sure the correct wire size is used, preferably 1,5 through to 4,0 mm^2.

f) Where the wire enters a lug, ferrule or other connector such as spade type use appropriately sized heat shrink sleeving over the non contact area of the connector and over the wire to a distance of about 20 mm. This mechanically braces the wire and the connector and largely prevents work hardening of the wire due to bending and vibration where it exits the connector. Work hardening eventually results in fracture and again intermittent contact and arcing.

g) Fit a suitably sized fuse in the unearthed battery lead. This must be sized to cater for the full electrical load plus about 10% but should not be too large to protect the wiring.

h) Where smaller section wire is used on the machine in various places, then sub fuse these circuits to prevent fault melt downs.

In closing, the following current ratings are given for different copper PVC insulated wire sizes for conductors operating at 70°C in an "unloaded loom" i.e. not bunched together with other wires also operating at maximum capacities. In general this situation of mutual maximum loading seldom if ever occurs. The loom and adjacent wiring does however inhibit heat dissipation from a fully loaded wire, and this affects the continuous rating of the conductor.

mm^2	RATING (amps)	RESISTANCE (milli ohms per metre at indicated temperature)					
		20	25	30	95	110	115
1,0	11	18	18,5	18,8	23,9	24,5	24,7
1,5	14	12,1	12,3	12,6	15,7	16,4	16,6
2,5	19	7,4	7,6	7,7	9,6	10	10,2
4,0	26	4,6	4,7	4,8	6,0	6,2	6,3
6,0	33	3,1	3,2	3,3	4,0	4,2	4,3

Table No. 2