April 9, 1935. G. I. FINCH ET AL 1,997,515

ELECTRIC SPARK DISCHARGE SYSTEM

Filed March 10, 1932 2 Sheets-Sheet 1

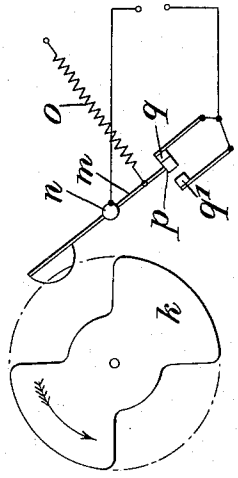


Fig. 5.

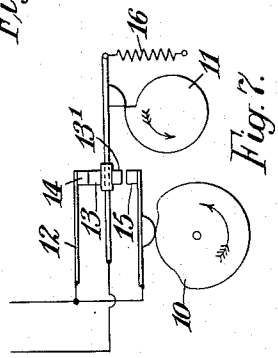


Fig. 7.

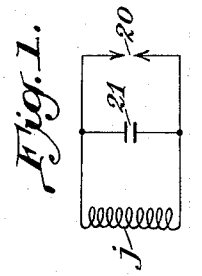


Fig. 1.

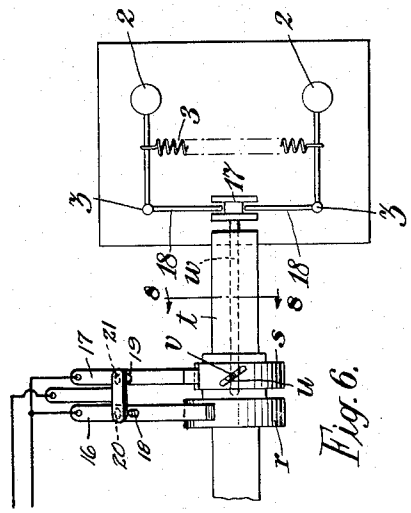


Fig. 6.

Fig. 2.

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ELECTRIC SPARK DISCHARGE SYSTEM

Filed March 10, 1932 2 Sheets-Sheet 2

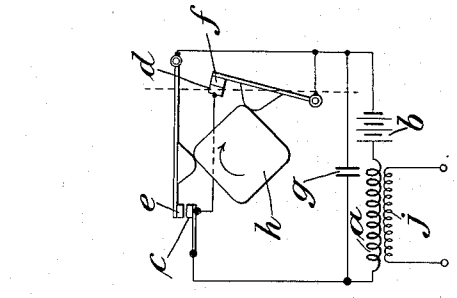


Fig.4.

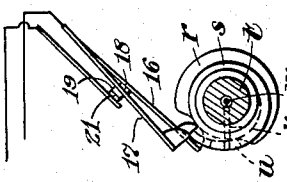


Fig.8.

Fig.3.

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1,997,515

ELECTRIC SPARK DISCHARGE SYSTEM

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Application March 10, 1932, Serial No. 598,052
In Great Britain March 31, 1931

8 Claims. (Cl. 123—148)

This invention relates to electric spark discharge systems.

In ordinary high tension coil ignition systems a high tension discharge is brought about by interrupting the circuit of the primary coil at a point corresponding to the peak value of the primary current in which a current is flowing and maintaining the interruption until after all the energy due to the collapsing magnetic field has been dissipated in the discharge from the secondary at the sparking plug points.

The primary current rises steadily until the interruption point is reached whereupon the current drops rapidly to zero at which value it remains until, after completed dissipation in the secondary discharge of all available energy, the next cycle of operations commences with the closing of the primary circuit.

As the speed or frequency of operation is increased the peak value of the secondary current generated becomes smaller and smaller because the time available between make and break for the building up of the primary current, and hence also the value of the primary current at break, to which the peak value of the secondary current is proportional, decreases.

It has thus been recognized that the time during which the interrupter remains open should not greatly exceed the life of the spark discharge in order to provide as long a time as possible for the build up of the primary current.

Under these circumstances, i. e. when the primary circuit is closed at any time after cessation of the discharge, the rate of build up of the primary current occurs in accordance with the well-known law:—

$$i=\frac{E}{R}\left(1-e^{-\frac{R}{L_1}\cdot t}\right)$$

Numerous methods have been suggested and employed in order to bring about this result, i. e. to lengthen the time of make as much as possible by closing the circuit as soon as possible after cessation of the discharge. Examples of such methods are:—

1. Specially designed cam surface slopes.

2. Two contact breakers, also provided with special cams, operating in such phase relationship with each other, and each one breaking the circuit independently of the other in such a manner that the resulting discharges are brought about by the two contact breakers alternately. Such a device enables the contact breaker cam to be driven at half the ordinary speed required with one contact breaker.

3. A device incorporating two contact breakers connected in parallel, one of which is set with reference to a given cam angle to such an extent out of phase with the other contact breaker, that one contact breaker on opening still leaves the primary circuit closed through the other contact breaker. When in due course on further rotation of the cam, the second contact breaker opens, and thus effectually breaks the circuit, the first contact breaker is beginning to close.

The main object of the invention is to provide electric spark discharge systems wherein the waste of energy from the point of view of efficient ignition is eliminated or reduced as desired.

Referring to the accompanying diagrammatic drawings:—

Figure 1 is a diagram representing a typical secondary circuit of an ignition coil.

Figures 2 and 3 are explanatory diagrams illustrating the growth of voltage across the spark gap and current flowing therein respectively.

Figure 4 is an end view of a form of double contact breaker suitable for use in accordance with the present invention.

Figure 5 is a similar view of a suitable form of cam mechanism.

Figure 6 is a side view of a convenient form of automatic mechanism for operation in conjunction with the mechanism of Figure 5.

Figure 7 is an end view of a modified form of contact mechanism.

Figure 8 is an end view of the contact mechanism shown in Figure 6.

In order to explain clearly the nature of the present invention it is desirable to consider the main phenomena accompanying the spark discharge of high tension ignition coils in conjunction with Figures 1 to 3 of the accompanying diagrammatic drawings.

In Figure 1 *j* represents the secondary winding of a typical ignition coil and **20** the spark gap in circuit therewith. Now the winding *j* has unavoidably associated with it a certain self capacity, represented by a condenser **21**, usually of the order of about 20 micromicrofarads. Suppose now the closed primary circuit (not shown) which is magnetically coupled with the secondary winding *j* and in which a current is flowing be broken (opened) then the lines of force in collapsing commence to cut the secondary winding in which in consequence a current commences to flow. This current cannot flow across the spark gap the resistance of which at the moment is almost infinite. The current, therefore, flows into the condenser **21** and charges this up. It will be realized that since the condenser **21** is so exceedingly small it will rapidly be charged to a high voltage equal to the breakdown potential of the spark gap after the secondary winding has been cut by only a few of the great many lines of force available. In other words, of the electromagnetic energy originally stored in the primary and rendered available for transfer as electromagnetic energy to the secondary circuit

only a minute fraction is required to charge the condenser 21 to the breakdown potential of the spark gap.

The gap now breaks down and its resistance falls from a nearly infinitely high value to only a few ohms. In other words, the spark across the spark gap is virtually equivalent to a short circuiting of the secondary winding bearing in mind that the resistance of the secondary winding is usually of the order of about 1,000 to 4,000 ohms. Thus once a spark occurs the electromagnetic energy which continues to be transferred from the primary to the secondary circuit no longer is employed in charging up or flowing into the condenser 21 but instead discharges straight across the gap.

That portion of the spark in which energy stored in the self capacity is dissipated may be termed the "capacity component" which term usefully serves to indicate its electrostatic nature. Its life is clearly short, since the self capacity is of the order of, say, 20 micromicrofarads, the inductance of the circuit comprising self capacity and spark gap is clearly exceedingly small and the resistance comprises the resistance, in effect, of some of the secondary winding as well as of the spark gap and associated leads.

That portion of the discharge in which the electromagnetic energy transferred from the primary into and accepted and dissipated as such by the secondary may conveniently be termed the "inductance component", the term serving the useful purpose of indicating the electromagnetic nature of this energy.

From the above it will be seen that the capacity and inductance components of the discharge differ in amongst others the following important respects:—

Regarding the capacity component—

(1) The maximum voltage is very high corresponding to the breakdown potential of the spark gap which amounts to a figure of the order of 15,000 volts.

(2) The maximum current is of the order of from 100 to 1,000 amperes or more.

(3) The duration of the current is exceedingly short, probably less than 10^{-6} second.

(4) The natural frequency of the current is very high of the order of 10^7 cycles per second.

As regards the inductance component—

(1) There is no peak voltage (we having found that once the spark is established the potential difference across the gap is of the order of 200 to 300 volts only and is constant and nearly independent of the current flowing).

(2) The maximum current is of the order of 120 milliamperes or less.

(3) The duration is relatively long, i. e., of the order of 10^{-3} second.

(4) The frequency of the current is of the order of between 10^4 and 2×10^4 cycles per second.

It is not practicable, in view of the above, to show the capacity component and inductance component on one drawing to the same scale; thus, in Figures 2 and 3 in which abscissae represent time elapsing after interruption of the primary circuit the length ox_1 is intended to indicate a period of 10^{-6} second and $x_1 x_2$ to indicate 10^{-3} second. Again, of the ordinates in Figure 2 which represent voltage across the spark gap the length oy_1 indicates about 200 to 300 volts whilst oy_2 indicates about 15,000 volts whilst in Figure 3 of the ordinates which represent current traversing the spark gap oy_3 indicates about 1,000 amperes whilst oy_4 indicates about 100 milliamperes.

It will be noted from Figure 2 that the voltage across the gap rises exceedingly rapidly until the breakdown voltage is reached at y_2, x_3 whereupon it falls instantly to a value oy_1 at which it remains substantially constant but with alternate change of sign until the completion of the capacity component at point x_1 after which it remains substantially constant for the remainder of the discharge, i. e. throughout the life of the inductance component. Also from Figure 3 it will be noted that the spark gap current commences at point x_3 and after rising extremely rapidly to a peak value oy_3 oscillates about a mean value of about 100 milliamperes and continues to execute a series of damped oscillations about a mean falling value indicated by the dotted line, the scale of the ordinates changing at the point x_1. In Figure 3 the curve extending as far as the point x_1 represents the capacity component of the discharge whilst that portion of the curve from x_1 to x_2 represents the inductance component.

We have found that the usefulness of the discharge depends on the peak value of the first oscillation of the inductance component, i. e. upon the value oy_4 attained during the complete oscillation occurring between points of time x_1 and x_5 (Figure 3). It is this value which determines the incendivity of the spark, and also the ability of the discharge to pass in spite of comparatively low values of plug insulation and resistance. Our experiments have shown further that no advantage is to be gained from the point of view of power output of an internal combustion engine by the use of a line source of ignition such as results from a combination of turbulence of combustible mixture and long life of the spark discharge at the plug points. Consequently, of the whole induction coil secondary discharge, it is only the first half of the first oscillation of the inductance component which is actually required. The remaining portion of the inductance component of the discharge not only serves no useful purpose but involves a waste of energy. This in its turn causes unnecessary burning away of the plug points, and gives rise to unnecessary heating of the plug points, which is apt to produce pre-ignition.

According to the present invention, therefore, we open the primary circuit at a point when the current flowing therein is as large as possible and reclose it at a point during the life of the secondary discharge at or shortly after the first half of the first cycle of the inductance component.

When this is done the build up of the primary current on reclosing of the primary circuit occurs in two stages, of which the second stage only follows the law set forth above. It can be shown, however, that the initial portion of the build up, i. e. until the secondary current has fallen to zero, takes place in accordance with the law:—

$$i=\frac{E+ne_2}{R}\left(1-e^{-\frac{R}{L_1(1-k^2)}\cdot t}\right)$$

This is at an exceedingly high rate, because at the moment of make the secondary circuit is still short-circuited by the discharge and thus on remaking of the primary circuit an almost complete transfer into the primary circuit of the electromagnetic energy still remaining is in effect obtained.

In the above formulæ the following symbols have been used:—

L_1=primary inductance.

L_2=secondary inductance.

k=coefficient of coupling.

$n=k\sqrt{\frac{L_1}{L_2}}$

R=resistance of primary circuit.

i=primary current.

E=voltage of primary battery.

e_2=steady voltage across the discharge, after breakdown has taken place.

e=base of Napierian logarithms.

The invention thus consists in a method of or means for obtaining an electric spark discharge wherein the primary circuit is opened at a point when the primary current is as large as possible and is reestablished during the life of the secondary discharge at or shortly after the peak of the first half of the first cycle of the inductance component is reached.

The invention also consists in a spark discharge system as set forth above embodying a make and break device for controlling the opening and closing of the primary circuit wherein the moment of re-establishment of the primary circuit can be controlled or varied preferably while the device is in operation to enable the total duration of the secondary discharge to be varied, as desired.

The invention also consists in an electric spark discharge system as set forth above wherein the period of interruption of the primary circuit is automatically rendered substantially constant irrespective of changes in speed or frequency of operation.

The invention also consists in an electric spark discharge system as set forth above wherein the duration of interruption of the primary circuit is so chosen that a predetermined duration of the secondary current is obtained at a high or other predetermined speed.

The invention also consists in methods of and means for obtaining electric spark discharges as set forth above applied in connection with stroboscopic observations.

In carrying the invention into effect in one form illustrated in Figure 4 by way of example as applied to a coil-ignition system fed with direct current and furnished with a contact breaking device, we provide two make and break devices connected in parallel in the primary circuit formed by a coil primary *a* and direct current source *b*. The make and break devices consist of fixed contacts *c*, *d* and moving contacts *e*, *f* and are shunted in the usual way by a suitable capacity *g*. The fixed and the moving contacts are respectively electrically connected together. The moving contacts are operated in succession by a cam *h* driven from, say, an internal combustion engine whose ignition is to be effected by the spark discharges of the secondary coil *j*. The cam and contacts are disposed relatively to each other in such a manner that both pairs of contacts do not open simultaneously, but first the pair *c*, *e* opens (the primary circuit still being completed through the second pair *d*, *f*) and then shortly afterwards the pair *d*, *f* opens (thus effectively breaking the primary circuit). The primary circuit is once more completed by the closing of the first pair of contacts *c*, *e*.

In an alternative arrangement (not shown) the moving contacts are mounted upon blades or arms disposed nearly 180° apart in relation to a double cam, the two raised surfaces of which lie 180° apart round the common axis of rotation. The angle of displacement of the contact blades is not exactly 180° so that as the cam rotates first one pair of contacts is operated and then immediately afterwards the other pair of contacts is operated. The result of this arrangement, as in that described above, is that the circuit from the source of direct current through the primary winding of the ignition coil is interrupted for a very brief period of time. Conveniently the actual period of time of interruption is regulable, for example, by mounting one pair of contacts upon a member which is capable of silght rotational adjustment about the axis of the cam in relation to the other pair of contacts.

The movable contact arms are so timed in relation to the cam that after the circuit of the current source is interrupted it becomes re-established immediately the primary current in the ignition coil has fallen to zero. By this arrangement the secondary current rises rapidly to its peak value and then immediately drops again to zero instead of falling slowly with a number of decreasing oscillations as would be the case were the primary circuit interruption itself sustained.

Consequently only energy which is useful in effecting ignition is dissipated at the spark gap; the remaining energy reappears upon re-establishment of the primary circuit instead of being dissipated in the secondary discharge and causing the usual wasteful burning of the plug points.

It will be appreciated that it is not essential to re-establish the primary circuit immediately the secondary current has attained its peak value but any delay beyond this point tends to cause burning of the plug points without any observable advantage from the ignition point of view.

Re-establishment of the primary circuit before the secondary current has attained its peak value however arrests the rise of the secondary current and causes it to drop rapidly to zero.

In the alternative arrangement illustrated in Figure 5 a double sector member *k* acting upon a lever *m* pivoted at *n* and biased by a compression spring *o* tends always to occupy the position depicted in Figure 5.

The end of the lever remote from that actuated by the member *k* carries a contact *p* which can play between resiliently mounted fixed contacts *q*, *q'*.

In the examples described above variation of speed or frequency of operation will obviously vary the time elapsing between break and make of the primary circuit. For example at very slow speed (the device being set to achieve the highest ignition efficiency at normal and therefore a higher running speed) re-establishment of the primary circuit may not take place until a short time after the primary current has fallen to zero. It is therefore preferred that automatic means be provided whereby the actual duration of break in the primary circuit be maintained constant irrespective of variations in speed or frequency of operation.

One convenient means for achieving this end is illustrated is Figure 6 wherein *r* and *s* represent two cams, *r* being rigid on the shaft *t*, while *s* is connected rotationally thereto by a slot *u* engaging a pin *v* on a shaft *w* carrying a collar *x*. The collar is moved axially by the bell crank levers pivoted at *z* as they are operated by centrifugal force applied to the balls 2 which is opposed by the spring 3.

The cams *r*, *s* coact with movable blades 16 and

17 respectively, these blades carrying moving contacts 18 and 19 co-operating respectively with fixed contacts 20 and 21, the pairs of contacts being connected in parallel as shown in Figures 6 and 8.

In a modification illustrated in Figure 7 two cams 10 and 11 are provided geared together so as to rotate at the same speed of rotation and a movable blade 12 actuated by the cam 11 carries contacts 13, 13' playing between fixed contacts 14, 15 which are connected together electrically.

In the position illustrated, the circuit is made through contacts 14 and 13. As the undercut cam 11 rotates, contact 13 is released and 13' falls on to contact 15 under the action of a spring 16, thus allowing the circuit to be broken for a very short period of time. On further rotation, contacts 15 and 13' are together pressed upwards by cam 10 until the contact 13 is brought into contact with 14, the circuit meanwhile remaining closed. Contact 15 is then allowed to fall by cam 10 but contact 13 remains in contact with 14 due to the action of cam 11.

With this arrangement the rapidity of the opening of the circuit is rendered independent of the speed of rotation of the cams owing to the form of the cam 11.

In coil ignition systems according to the present invention the peak value of the secondary current remains substantially constant irrespective of the speed or frequency of operation because with this device, as is pointed out in detail below, the primary current at the moment of break is substantially constant at, or nearly at, its maximum possible value irrespective of the break frequency. Consequently failure of ignition due to a sooty sparking plug (involving a shunt resistance leakage path) is no greater at high speeds than at low. This characteristic is in marked distinction from existing coil ignition systems wherein a falling off of secondary current peak value occurs with rise of speed.

An important characteristic which we have observed concerns the curve of primary current. In existing systems this curve drops rapidly to zero at interruption of the circuit and remains at zero until re-establishment of the circuit whereupon it rises gradually from zero to the point at which next interruption occurs, in which case, however, at all but the lowest frequency of interruptions opening of the primary circuit occurs well before the primary current has been built up to its maximum value. In systems according to the present invention, however, the period of interruption may be made so short that when the primary circuit is re-established the secondary circuit is still completed by way of the spark discharge. Consequently, since in these circumstances the primary inductance is extremely small, the primary current is able to rise rapidly to a point not very much below the value it had attained at the moment of interruption. Thereupon the primary current rises again until the point of the next interruption is reached. In this way the primary current builds up to a considerably higher value at the moment of break than is the case in existing systems.

Any convenient means may be adopted in order to enable the period of completion of the primary circuit necessary to secure the desired curtailment of secondary spark discharge to be determined.

For example, an electromagnetic oscillograph may be employed to observe the secondary current, the contact mechanism being adjusted until the desired point of cessation of the discharge is reached.

Observations of this nature, however, are more effective if recourse is had to the cathode ray oscillograph.

It is to be understood that the examples described above are given by way of illustration only and may be modified in a variety of ways.

If existing forms of contact mechanism using a single pair of contacts or two such pairs of contacts operating synchronously as used ordinarily for ignition purposes be adapted in order to give the short period of interruption which we require, according to the present invention it is found that there is a liability to failure due to arcing and to the fact that the gap or gaps close in an ionized atmosphere; and for this reason we prefer, as in the examples described above, to use two pairs of contacts, one for opening and the other for closing the circuit.

The present invention may be applied advantageously in connection with stroboscopic observations. For example in the observation of the speed of rotation of a shaft or other rotating body a cam-actuated contact maker driven thereby may be employed to control the primary circuit of a transformer, the secondary circuit of which is connected to a neon lamp serving to illuminate the shaft or body. By this means illumination of the shaft results once per revolution, and by reducing as desired the period of each flash the definition may be rendered extremely sharp. By slowly rotating the contact breaker observation of the various portions of the shaft may be made.

Having now described our invention, what we claim as new and desire to secure by Letters Patent is:—

1. An electric spark discharge system comprising a secondary circuit having a spark discharge gap, a primary circuit electromagnetically coupled to said secondary circuit, said primary circuit including a direct current source and means effecting opening of said primary circuit to produce a spark discharge at the discharge gap, and re-establishing of said circuit during the life of said discharge at a time within the region immediately following the time at which the first half of the first cycle of the inductance component reaches its peak value.

2. A method of obtaining an electric spark discharge from a coil ignition system operated by a direct current source comprising the opening of the primary circuit of the coil whilst the primary current is as large as possible and the re-establishment of said circuit during the life of the secondary discharge at a time within the region immediately following the time at which the first half of the first cycle of the inductance component reaches its peak value.

3. An electric spark discharge system comprising a secondary circuit having a spark discharge gap, a primary circuit electromagnetically coupled to said secondary circuit, said primary circuit including a direct current source and means effecting opening of said primary circuit to produce a spark discharge at the discharge gap, and re-establishing of said circuit at the moment when the first half of the first cycle of the inductance component of the secondary current reaches its peak value.

4. An electric spark discharge system comprising a secondary circuit having a spark discharge gap, a primary circuit electromagnetically coupled to said secondary circuit, said primary cir-

cuit including a direct current source and means effecting opening of said primary circuit to produce a spark discharge at the discharge gap, and re-establishing of said circuit shortly after the first half of the first cycle of the inductance component of the secondary current has reached its peak value.

5. An electric spark discharge system as claimed in claim 1 including means for varying the duration of the break in the primary circuit.

6. An electric spark discharge system as claimed in claim 1 including means for varying the duration of the break in the primary circuit during operation of the system.

7. An electric spark discharge system as claimed in claim 1 including means for maintaining constant the duration of the primary circuit break notwithstanding changes in the frequency of operation of the primary circuit opening and re-establishing means.

8. An electric spark discharge system as claimed in claim 1 including a spark discharge lamp connecting across said spark discharge gap for stroboscopic purposes.

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