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ELECTRICAL IGNITION APPARATUS USING A HIGH VOLTAGE BREAKDOWN
AND A CONDENSER FOLLOWUP THROUGH THE IGNITION GAP
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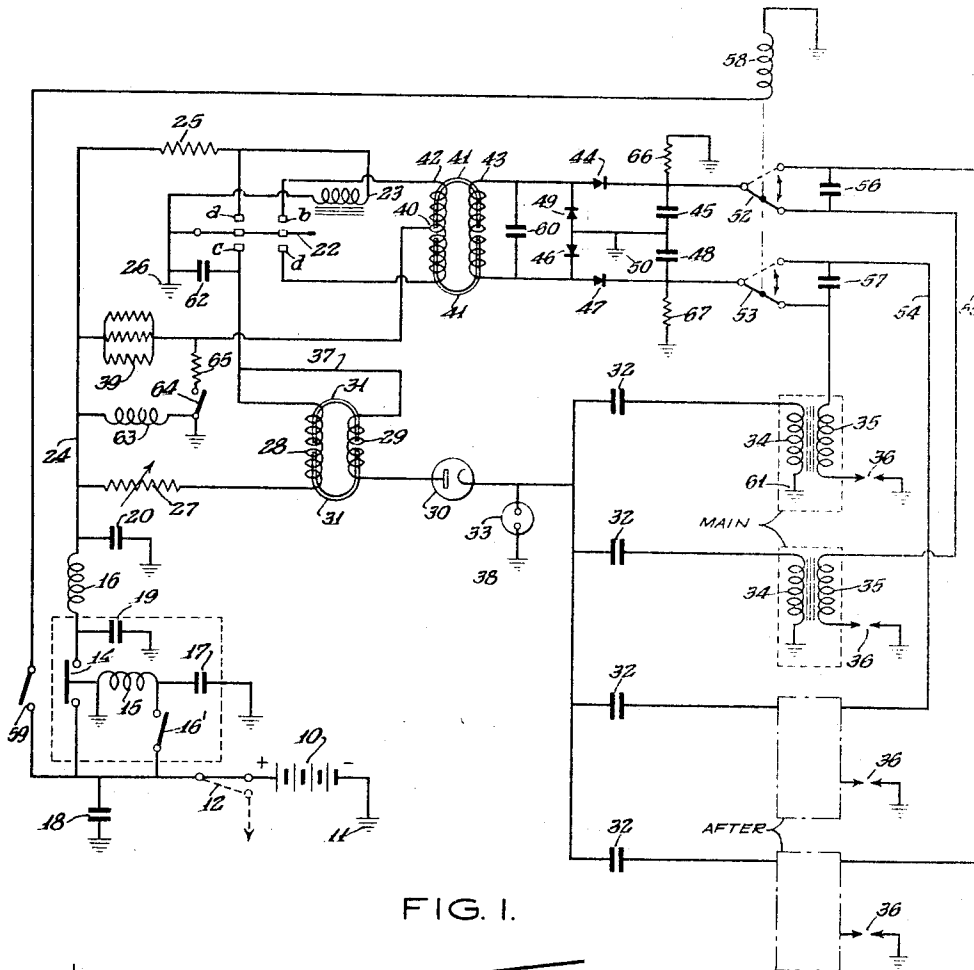


FIG. 1.

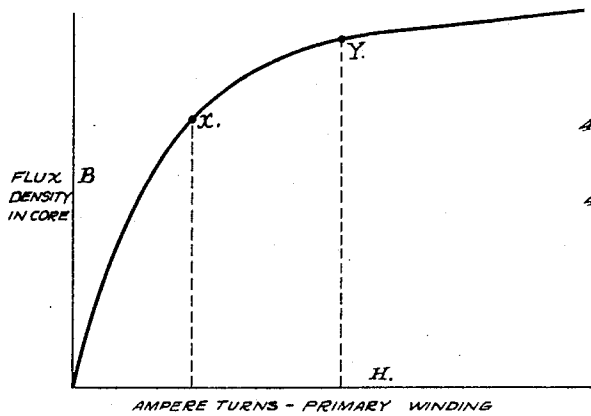


FIG. 2.

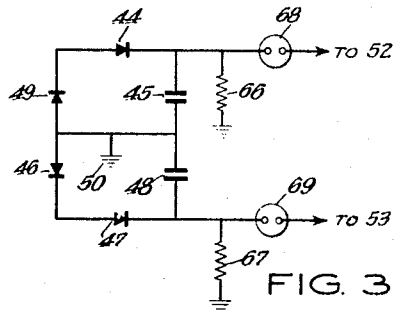


FIG. 3.

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ELECTRICAL IGNITION APPARATUS USING A HIGH VOLTAGE BREAKDOWN AND A CONDENSER FOLLOWUP THROUGH THE IGNITION GAP

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15 Claims. (Cl. 315-183)

This application is a continuation of applicant's prior filed application Serial No. 149,780, filed March 15, 1950, for Electrical Apparatus.

The present invention relates to electrical apparatus and more particularly to electrical systems adapted for generating sparks which may be utilized in many ways, such as for igniting combustible mixtures in the cylinders or combustion chambers of engines.

One of the objects of the present invention is to provide a novel electrical system which is capable of producing high-energy sparks or arcs of relatively large energy across a gap at a voltage considerably below the normal spark-over voltage of the gap.

Another object of the invention is to provide novel apparatus for generating sparks across spaced electrodes of a spark plug or igniter with little or no loss of energy resulting from a carbonized or similarly fouled gap.

Another object is to provide a novel engine ignition system or the like wherein a spark gap which is too badly fouled or short circuited to fire under normal operating conditions will be restored to operating condition by the inherent functioning of the system itself.

Still another object is to provide novel ignition means for combustion engines of all types and particularly adapted for engines of the so-called jet or turbo-jet types.

A further object is to provide a novel ignition system for producing a high-power spark of very short duration thereby minimizing gap electrode erosion and increasing the efficiency and dependability as well as the operating life of the system.

A still further object is to provide a system of the above character which weighs less and requires less space for installation than prior systems adapted for the same use.

Still another object is to provide novel apparatus for creating both a high-frequency, high-voltage spark and a low-voltage, high-energy spark across a gap by employing a low-voltage direct current source, such as a battery, generator or comparable means.

Another object is to provide novel means of the condenser discharge type for creating sparks at a spark gap, which means is so constructed as to effectively burn or blast away the substances such as carbon, lead and the like, that accumulate between the gap electrodes and tend to short circuit spark gap in combustion chambers or the like.

Another object is to provide a novel spark generating system of the above type wherein the elements are so constructed and assembled as to minimize the variation of the sparking rate resulting from variations in the voltage of the source of electrical energy.

The above and further objects and novel features of the present invention will more fully appear from the following detailed description when the same is read in connection with the accompanying drawings. It is to be expressly understood, however, that the drawings are for the purpose of illustration only and are not intended as a definition of the limits of the invention.

In the drawings, wherein like reference characters refer to like parts throughout the several views,

FIG. 1 is a circuit diagram of one form of engine ignition system embodying the invention;

FIG. 2 is a typical magnetization curve for the core of a transformer; and

FIG. 3 is a detail diagrammatic view illustrating a modification of a part of the circuit of FIG. 1.

One embodiment of the invention is diagrammatically illustrated in FIG. 1 of the drawings, by way of example, in the form of an ignition system for a so-called jet or turbo-jet engine having main and after combustion chambers or burners in each of which there are two igniter plugs. Control means are provided for effectively selectively connecting the source of power to the main burner igniters or to those in the after burners. A spark plug or igniter which is effectively connected in circuit is supplied at desired intervals with high-voltage, high frequency impulses of relatively low power or energy for the purpose of bridging and, hence, ionizing the gap between the igniter electrodes. Upon ionization of the gap in this fashion, a high-energy spark of short duration is created between the electrodes by the discharge of a large capacity condenser across the same at a relatively low voltage, that is, a voltage which is considerably below the normal sparkover voltage of the gap before the same is ionized. It is this second or high-intensity spark which is effective to ignite the combustible mixture in the engine combustion chamber or burner and to keep the gas reasonably free of carbon, lead and similar gap fouling substances.

In the system as illustrated, electrical energy is supplied by a battery 10, the negative terminal of which is connected to ground at 11, but any other suitable or equivalent source, such as a generator, for example, may be employed. If desired, the system may be selectively connected to any one of several different kinds of available sources of electrical energy, such as by a selector switch 12. In some installations, especially upon aircraft, it may be desirable to connect the operating parts of the system to the battery through a remotely controllable relay switch 14. The latter may be operated in any known manner, such as by a solenoid 15 adapted to be energized from the battery or other source through a manually operable switch 16' located in the cockpit or control room.

Inasmuch as the battery 10 may be used for supplying energy to other circuits as well as to the ignition system, it is desirable to provide means for preventing radio frequencies from feeding back into the battery circuits from the ignition circuits and hence causing interference with radio reception. This may be accomplished by means of suitable filtering means installed in the power line between the battery and the ignition and relay circuits. As shown, the filtering means comprises an inductance 16 in the main power line and for condensers 17, 18, 19, and 20, each connected to ground and to the power line from the battery. These condensers are respectively connected to the power line between the battery and relay solenoid 15, between the battery and relay switch 14, between said switch and inductance 16, and between said inductance and the ignition circuits to be hereinafter described. The inductance or choke coil 16 offers high impedance to any high-frequency currents tending to flow toward the battery, and the condensers offer paths over which radio frequency currents may leak off to ground without appreciably affecting the flow of direct current to the ignition system. The battery end of the filtering means is preferably placed in a shielded compartment and condenser 20 is connected close to the shield to insure against any jumping of the filter by high-frequency currents due to the existence of any inductive or capacitive couplings.

In mode of operation, the novel system comprehended by the invention includes simultaneously building up by increments in storage condensers both the high-voltage and the low-voltage components of energy supplied to

the igniter or spark plug gap. This function of building up said charges in unison by increments is accomplished and controlled in a novel and ingenious manner through the medium of a vibrator of any suitable known type which interrupts the flow of direct current from the battery at a relatively predetermined frequency and thus makes it possible to step-up the voltage thereof by the use of transformers. In the specific form shown, the vibrator comprises a flexible electrically conductive reed 22 which normally assumes a central position between two sets of contacts *a-b* and *c-b*. An electro-magnet or solenoid 23 is provided for moving the reed upwardly, as viewed in the drawings, into electrical engagement with contacts *a* and *b*. When switch 16 and hence relay switch 14 are closed, current flows from the positive or non-grounded terminal of the battery through power line 24, a resistance 25 which prevents excessive current flow and arcing across the vibrator points *a*, and solenoid coil 23 to ground at 26. As soon as the reed is attracted upwardly by the energized solenoid, its engagement with contact *a* short circuits the solenoid coil and it is de-energized. The reed is thus released and swings downwardly by virtue of its resiliency and across center position into engagement with contacts *c* and *d*, thus closing circuits which will be hereinafter fully described. As soon as the reed leaves contact *a*, solenoid 23 is again energized in the manner previously explained, and the cycle of vibrator operation is repeated. In one suitable embodiment employing a battery having a 24-volt rating and capable of about 25 amperes at from 12 to 30 volts potential, the vibrator is designed to operate at approximately 115 cycles per second. This will vary somewhat with variations in the voltage available at the battery or other source.

For creating the high-voltage, high-frequency component of energy which initiates the discharge across the igniter gaps, a relatively small part of the battery current, approximately 10 to 15 percent being ample, is caused to flow from power line 24 through a variable resistor 27, the primary winding 28 of a step-up transformer, vibrator contact *c*, reed 22 (only when it is in down position) and to ground at 26. This circuit is broken at contact *c* when reed 22 is in its up or raised position. The interrupted current thus passing through winding 28 induces a higher voltage in the circuit of secondary winding 29. In one satisfactory embodiment the voltage is stepped up to approximately 5,000 to 7,000 volts. The increments of electrical energy from winding 29 pass through a half-wave rectifier 30 and are stored in one or more parallel connected condensers 32 which may be of relatively small capacity, such as of the order of .002 to .003 microfarad (mfd.) each, for example. The purpose of rectifier 30 is to prevent the condensers 32 from discharging back through winding 29 and if one proves insufficient at the desired voltages, two or more small rectifiers in series or a larger one may be used. If desired, full wave rectification may be employed to speed up the charging of the condensers. When half-wave rectifiers of like polarity are used they are preferably designed to pass the initial pulse of each cycle from secondary winding 29 to thereby obtain best efficiency. Thus, the sign of the pulses to be passed by the rectifier will depend upon how the battery or other source of energy is connected in the circuit. In the form shown, the rectifier is connected to pass pulses of positive polarity since the system is connected to the positive terminal of the battery. The high voltage impulses in winding 29 are effected by an inductive kick from winding 28 each time the vibrator points *c* are opened to thereby obtain a high voltage in the secondary circuit.

Connected to ground between rectifier 30 and condenser 32 is spark gap 33 having a relatively fixed breakdown or onset voltage at which it will begin to conduct. This gap is preferably sealed so that its operation will not be affected by pressure variations at different altitudes. The other terminal of each condenser 32 is connected

to the ungrounded end of a primary winding 34 of an igniter transformer 34, 35 which steps up the voltage of the condenser discharge to a sufficient level (about 15,000 to 20,000 volts) to bridge or break down the gap 36 of an igniter plug in the engine combustion chamber without appreciably affecting the high-frequency (about 2 megacycles) characteristics of the condenser discharge. The charging circuit for the condensers 32 through winding 29 is completed through a lead 37, condenser 62, and common grounds at 26, 61. When a condenser 32 is sufficiently charged, it will discharge across sealed gap 33 and winding 34, said gap and winding being connected to common grounds 38 and 61. The secondary winding 35 of each igniter transformer is connected to the ungrounded terminal of an igniter gap 36 consisting of spaced electrodes, such as in a spark plug of known construction. The return circuit to the other end of the secondary winding 35 will appear from the description of the low-voltage, high-energy circuit which is to follow.

It will thus be seen that the normal sparking rate of the igniter gaps 36 is determined by the rate at which condensers 32 are charged to a voltage sufficiently high to jump the gap 33. The rate at which each condenser 32 is charged is in turn dependent upon the source voltage and may vary between wide limits with variations in said voltage. In most installations the source voltage does vary, particularly where a battery is used, and the present invention comprehends means whereby the variation in the sparking rate in such systems is reduced to a minimum consistent with efficient and satisfactory operation. This novel and important result is effected by properly constructing transformer 28, 29 in relation to the remainder of the circuit. In the form shown, this transformer is of the type comprising a core made of two horse shoe shaped parts 31, 31 which may have air gaps between the adjacent ends thereof within the windings 28 and 29. Knowing the range of the variation in the source voltage—which in most battery systems in aircraft installations today is from about 12 to 30 volts—and the variations caused thereby in other parts of the system to be hereinafter described, the transformer 28, 29 is constructed so that when connected in the circuit in the manner illustrated, it will operate within the predetermined voltage range on a predetermined portion of the magnetization curve of its core 31, 31 which will give good energy transfer without excessive variation. This is done by properly adjusting the reluctance of the core 31, 31 by providing suitable air gaps between the ends of the core halves. These gaps will vary with each coil and core because of the differences in electrical constants and the inherent and manufacturing differences in physical characteristics of the assemblies and the parts thereof. The adjustment should be such as to cause the transformer to operate along the knee of the magnetization curve of the core, such as approximately between the points X and Y on the typical BH curve illustrated in FIG. 2. In a typical ignition system constructed in this manner, a source voltage variation from 12 to 30 volts will effect only a reasonably small variation in the sparking rate at gaps 36, such as from about 10 to 20 sparks per second. The high-voltage, high-frequency portion of the system is thus tuned during production to insure a desired sparking rate at the available voltages and as will be hereinafter explained, to operate in unison with the low-voltage, high-energy portion of the system.

The major portion of the current from battery 10 is used for building up low voltage charges on one or a pair of condensers of relatively large capacity for supplying the high power arc at the gaps of one or more igniter plugs in either the main burner, the after burner or both of the engine. In the illustrated embodiment this current flows from the positive terminal of the battery through power line 24 and a resistance 39, which may consist of one resistor, several resistances in parallel as shown or in any other suitable combination to the center tap 40 of the primary winding 48 of a step-up transformer,

When the vibrator reed 22 is in its up position (as viewed in the drawings), current flows through the upper half of primary winding 42 to vibrator contact *b* and thence through the reed to ground at 26. During the intermittent intervals that reed 22 engages the contact *d*, current flows from center tap 40 through the lower half of winding 42 and thence through the reed to ground.

The interrupted direct current flowing alternately in opposite directions through different halves of primary winding 42 induces an increased voltage of alternating polarity in a circuit which includes secondary winding 43. When the voltage is of one polarity the circuit of the winding 43 is effectively completed through a half-wave selenium rectifier 44, high-capacity condenser 45, and a similar half-wave rectifier 46. When the voltage is of the other polarity the circuit is effectively completed through rectifier 47, condenser 48 and rectifier 49. These rectifiers are arranged to permit the flow of current in the circuits described but effectively prevent the condensers from discharging back through the transformer winding. In this manner condensers 45, 48 may be alternately charged with successive small increments of energy to full capacity at a relatively low voltage, such as from 600 to 1,000 volts which is far below the normal spark-over voltage of the igniter gaps 36 when there is no fouling thereof. In order to complete the circuits through secondary windings 35 of the igniter transformer, as mentioned above, the low potential terminals of condensers 43 and 48 are connected to ground at 50 and the positive or high-potential terminals thereof may be connected through switches 52 and 53 to the secondary windings 35 of the two main burner igniter transformers. For a purpose to be more fully explained, a spark gap may be interposed between each condenser 45 and 48 and the secondary windings 35 as illustrated in FIG. 3.

It will thus be seen that whenever these gaps 36, which are directly connected to condensers 45 and 48 through switches 52 and 53, are ionized by a high-frequency, high-voltage impulse from condensers 32, thereby reducing the spark-over voltage of such gaps to a value at or below the voltage across condensers 45 and 48, the latter will discharge across said ionized gaps thereby producing very high-energy arcs, each having a power level of several thousand watts which will cause the temperature of the mixture in the vicinity of the gap to rise rapidly to the kindling point. The initial high-frequency voltage impressed across gaps 36 by condensers 32 through transformers 34, 35 rises on such a steep wave front that the gaps break down before any appreciable loss of energy can occur as a result of any fouling of the gap, or the like. The high-energy spark which follows the high-frequency pilot or ionization spark is of very short duration—about 100 microseconds and hence from $\frac{1}{10}$ to $\frac{1}{30}$ that of conventional ignition sparks—so that gap electrode erosion is held to a minimum in spite of the intensity of the sparks.

For best and most efficient operation, it is desirable that condensers 45 and 48 be fully charged during the intervals between successive discharges of the high-voltage condensers 32. To obtain this result transformer 42, 43 which supplies energy to condensers 45 and 48 must be properly constructed or tuned to operate in unison or harmony with transformer 28, 29 which, as heretofore pointed out, determines the rate at which condensers 32 are charged and, hence, the sparking rate. As a practical matter, the low-voltage portion of the system is first designed to give reasonably efficient power transformation and such maximum and minimum charging rates within the range of available voltage as will provide a suitable rate. This is done by constructing transformer 42, 43 with suitable air gaps between the parts of the core 41, 41 thereof to cause the same to operate along the bend or knee X-Y of the magnetization curve so that there will be relatively small change in the charging rate within the voltage range during normal

operation. The transformer 28, 29 is then constructed in the manner heretofore described to provide a sparking rate which is comparable to the rate at which condensers 45 and 48 are charged to substantially their full capacity. When transformer 42, 43 is thus designed to operate in the system near the saturation portion of the magnetization curve of its core, and resistance 39 is sufficiently large to suitably limit the current at the vibrator points *b* and *d*, a greater magnetization current is drawn by coil winding 42 and there is hence an increased voltage drop across said resistance as the source voltage rises from minimum to maximum, thereby decreasing the voltage drop which might otherwise be expected across the coil winding, by reason of this characteristic of the system, the narrow limits through a relatively wide range of source voltage.

Small variations in the sparking rate may be effected by adjusting variable resistor 27 to vary the current flowing through and the voltage drop across coil winding 28. A small change thus made in the low energy circuit, which draws only a small portion of the current from the source, may effect a material change in the sparking rate without effecting any appreciable change in the charging rate of the high-energy condensers which utilize a much larger percentage of the energy supplied by the source. Adjustments of resistance 27 may thus be used within reasonable limits to bring the high and low voltage portions of the system into operating harmony after the system is completely assembled, that is, to harmonize the sparking rate of the low energy circuit with the charging rate of the high-energy condensers 45, 48.

Although a separate low-voltage, high-energy circuit identical with that heretofore described for the main burners may be provided for the after burners without duplicating the high-voltage, high-frequency circuit, the same low voltage circuit may be utilized when the after burner transformers 34, 35 are connected in circuit in the novel manner hereby contemplated. As shown, the secondary windings of either or both of the after burner transformers may be directly connected in circuit with condensers 45 and 48 through leads 54, 55 by throwing either or both of the switches 52 and 53, respectively, thereby at the same time interrupting the direct connection between one or both of said condensers and the secondary windings 35 of the main burner transformers. It is important, however, that the terminals of these switches or the leads thereto be bridged by condensers 56 and 57, respectively. This is necessary in order to complete the 35 which are not at the moment connected in circuit directly through one or the other of switches 52 and 53. It will be noted that the high-frequency circuits to all of the igniter plugs 36 are always complete, except during the igniter plugs 36 are always complete, except during frequency pilot spark will occur at each of the igniter plugs whenever sealed gap 33 becomes conductive. This pilot spark, however, possesses insufficient energy to ignite the mixture under normal conditions of operation and is accordingly ineffective unless followed by a high-energy discharge from one of the condensers 45 or 48. The condensers 56 and 57 are of relatively small capacity—of the order of .01 microfarad—and hence offer high impedance to the discharges from the relatively large capacity condensers 45 and 48 which may be of the order of 6 microfarads each. The initial and important impulse in the discharge from each of the latter condensers is for all practical purposes essentially direct current and hence by-passes the smaller condensers 56 and 57.

Remote control means are preferably provided for actuating switches 52 and 53. In the illustrated embodiment said switches are electro-magnetically actuated by a solenoid 58. One end of the solenoid coil is connected to ground and the other end is connected through a switch 59 to the positive terminal of battery 10. If only two igniter gaps 36 are used, these switches are not required. If there is only one gap 36 to be fired, only one

of the condensers 45 and 48 will be necessary, in which event it could be connected with secondary winding 43 through a full wave bridge rectifier. Also, a single high energy condenser could be selectively connected through selector switch means to more than one gap 36.

In order to prevent arcing at, and hence deterioration of, vibrator contacts *b* and *d*, a buffer condenser 60 is connected across transformer winding 43. A condenser 62 is connected in shunt with contact *c* and reed 22 for eliminating arcing at that contact. This latter condenser also serves as a part of the charging circuit for condensers 32 as heretofore pointed out.

In some installations supplied by a battery or similar source of variable voltage the supply voltage may vary between limits which may have certain undesirable effects on the operation of the system. The present invention contemplates novel control means which may be automatically operable to substantially avoid these effects and may be used when necessary or desirable. Said means, in the form illustrated, comprises what may be termed a voltage control relay which includes a solenoid 63, the coil of which is connected in circuit with battery 10 whenever the ignition circuit is operated, but a cut-out switch may be conveniently supplied. A normally open switch 64 is adapted to be actuated to closed position by said solenoid whenever a predetermined voltage at about the center of the normal or most prevalent voltage range, such as approximately 19 to 20.5 volts in a 24 volt battery system, appears across the coil thereof. In closed position switch 64 connects a resistor 65 between ground and a point in the lead between resistor 39 and center tap 40 of winding 42. This increases the current flow through, and hence the voltage drop across, resistor 39, thereby reducing the voltage available at the center tap 40 to a value within the range of the lower battery voltages at which the system may be primarily designed to operate. At the same time, a sufficient portion of the increased current is drained off through resistor 65 to maintain within relatively narrow limits the increase of current flow through coil 42 and hence, across the vibrator contacts. The current through winding 42 is thus kept within a predetermined range so that the voltage attained by condensers 45 and 48 during the interval between successive discharges thereof does not vary materially throughout the voltage range of the battery or other source during operation of the ignition system.

When the operation of the system is discontinued by opening switch 16' there is usually a residual charge on condensers 45 and 48 which it is desirable to remove. Accordingly, the high potential terminals of these condensers are preferably connected to ground through resistors 66 and 67, respectively. Each resistance may be of the order of .25 to .50 megohm so that any energy leakage therethrough during normal operation will be negligible, but any charge remaining on the condensers when operation of the system is terminated will leak off slowly to ground within a few seconds. These resistances are not essential to the operation of the system but are used in the interest of safety.

It is a known characteristic of a high-voltage, high-frequency discharge, such as that from a condenser 32 through a transformer 34, 35, that it will create a spark at or ionize a spark gap even though the latter may be badly fouled, and hence shunted by a resistance path. Accordingly, as long as the resistance of the path in shunt with or across the gap is sufficiently high to prevent leakage of current therethrough and hence dissipation of energy from condensers 45 and 48, as the latter are being charged in increments, the high energy arcs or impulses created across the gaps 36 by the discharges from said fully charged condensers will burn or virtually explode out of the gap the carbon, lead or other substance constituting the high-resistance shunt or short-circuiting path.

If the igniter gap 36 becomes very badly fouled, either

during or between operating intervals, the resistance shunted across the gap may be insufficient to prevent leakage of energy from condensers 45 and 48 at a relatively high rate during the charging thereof, thereby preventing the storage of adequate charges on the condensers to create an impulse or arc at the gap of sufficiently high energy to displace or burn out the substance causing the fouling or to ignite the combustible mixture in the combustion chamber. Although this contingency is not a common one in most present day engine installations, this invention comprehends novel means for preventing failures of this kind during operation and for automatically restoring the system to operating condition if such fouling is created between operating intervals. In the form shown, this novel result is obtained by inserting suitable spark gaps 68 and 69 (FIG. 3) between the high potential terminals of condensers 45 and 48, respectively, and the secondary windings 35 connected therewith. These gaps are preferably of the sealed type and set to break down at a voltage which is preferably approximately equal to or slightly greater than the voltage of the maximum charge attainable by condensers 45 and 48. If the condensers 45 and 48 are sufficiently large and partial charging thereof will effect the desired results at the igniter gaps, the gaps 68 and 69 may be set to break down at some suitable lower voltage if desired. The minimum spark-over or onset voltage of gaps 68 and 69 will be determined by the requirements of the system and may in some instances be considerably below the full voltage attainable by said condensers. In operation, ionization of gaps 68 and 69 is ordinarily caused by the high frequency, high voltage discharges induced in windings 35, since each of said gaps is in series with one of said windings, an igniter plug 36 and one of the condensers 45 or 48.

The spark gaps 68 and 69 do not effect breaks in the circuits heretofore described containing secondary windings 35, insofar as the high frequency currents and high voltage induced therein through primary windings 34 are concerned. These stepped-up high frequency, high voltage discharges from condenser 32 are not appreciably effected by the low voltage gaps 68 and 69 and hence, the normal operation of the system as heretofore described is not disturbed. These gaps do, however, prevent any discharge or leakage of energy from condensers 45 and 48 across a gap 36 that may be badly fouled until said gaps are ionized by the discharge of condensers 32 or the charge on the condensers 45 and 48 exceeds the spark-over voltage of the gaps 68 and 69. Thus, a full or at least a pre-determined charge on condensers 45 and 48 and hence a high-energy discharge through or across the gaps 36 is assured independently of the condition thereof. One or several such discharges will almost certainly destroy shunt paths of the character which customarily form at the igniter gaps and thereby restore the latter to such a condition that mixture-igniting arcs or sparks will occur.

An important characteristic and feature of the system herein disclosed is that the fouling or short-circuiting of one of the igniter gaps 36 by the flame in a combustion chamber or by other foreign substances, or the short-circuiting of a transformer coil 34, 35 will not appreciably affect the operation of the system with respect to the remaining igniter gaps. The present system accordingly provides a genuine factor of safety against engine failure caused by ignition failures.

In a satisfactorily operable system constructed in accordance with the present disclosure and used in jet type engines, the various elements of the circuits have the following electrical values: each branch of resistance 39 and resistance 65, 2.2 ohms; each resistance 66 and 67, .22 megohm; resistance 25, 10 ohms; resistance 27, 7.5 ohms; each condenser 32, .0024 microfarad (mfd.); each condenser 45 and 48, 6 mfd.; condenser 62, .5 mfd.; each condenser 19 and 20, 2 mfd.; each condenser 17, 18,

56 and 57, .01 mfd.; condenser 60, .05 mfd.; winding 28, .44 ohm; winding 29, 3725 ohms; inductance 34, .004 millihenry; inductance 35, 12 millihenry; winding 42, .42 ohm and 20 millihenries; winding 43, 156 ohms and 13,500 millihenries, windings 15 and 63, 158 ohms each; inductance 16, .03 millihenry and winding 58, 31 ohms. These are merely nominal electrical values and may vary in different systems according to the operational requirements. In such a system having a 12 to 30 volt source of direct current, such as a storage battery, the high-voltage circuit will draw approximately 2 to 3 amperes and the low-voltage circuit will draw up to approximately 15 amperes at maximum source voltage. Condensers 32 are charged to about 5,000 volts before each discharge and condensers 45 and 48 are charged to about 600 volts in normal operation.

There is thus provided a novel electrical system capable of generating high-energy, low-voltage arcs or sparks of very short duration across a gap having a normal spark-over voltage many times greater than the voltage at which the energy is supplied—a system which is admirably adapted for use in igniting combustible mixtures in the combustion chambers of engines and particularly engines of the jet or turbo-jet type. The system may be readily adapted without excessive duplication of parts for firing a plurality of igniter gaps either singly, simultaneously or in selected groups. Additionally, the system provided is novelly constructed to require but a single source of electrical energy, the available voltage of which may vary between rather wide limits without effecting a material variation in the sparking rate or any loss of efficiency, this result being accomplished without the necessity for using any mechanically operable control mechanisms. By reason of its ability to fire or restore to firing conditions badly fouled spark gaps, the system comprehended is exceedingly dependable thereby increasing the safety of aircraft and of the persons who fly therein. The elements required for the system may be readily and inexpensively assembled into a light-weight compact unit or units which may be easily installed on or adjacent to an engine.

Although only a limited number of embodiments of the invention are illustrated in the drawing and described in detail in the foregoing specification, it is to be expressly understood that the invention is not limited thereto. For example, the illustrated cold cathode and selenium type rectifiers may be replaced by hot cathode types and the spark gaps which control the discharging of the condensers may be replaced by mechanical circuit breakers or by other types of electronic tubes in conjunction with triggering means for rendering the same conductive at desired intervals or voltages. The filtering means may, of course, be eliminated where interference with radio reception is not an important factor and the remote control means are not essential parts of the basic circuit. Although the invention comprehends a system which will function with only a single source of electrical energy, the voltage of which may vary, the source voltage may be constant and if desired, different sources of energy may be utilized for different parts of the circuit. Other known types of transformers may be used and the reluctance of the cores thereof may be adjusted in any other known manner. Various other changes may also be made in the structures of the various elements and in the electrical constants of the circuit, as will now be apparent to those skilled in the art, without departing from the spirit and scope of the invention.

What is claimed is:

1. In apparatus of the class described, a direct current source of electrical energy, first and second step-up transformers having primary windings in parallel circuits connected to said source, a vibrator operatively connected to said source and operable to intermittently interrupt the circuits through said primary windings, a condenser con-

nected to the secondary winding of said first transformer and chargeable thereby in increments to a voltage in excess of the source voltage, a third transformer having its primary winding connected to said condenser, a spark gap for controlling the discharge of said condenser through said last-named primary winding, an igniter gap connected with the secondary winding of said third transformer which steps up the voltage of said condenser discharge to a value greater than the normal breakdown voltage of the igniter gap, a second condenser in circuit with the secondary winding of said second transformer and chargeable thereby in increments to a voltage below the normal spark-over voltage of the igniter gap, and means connecting said second condenser to the igniter gap through said secondary winding of the third transformer whereby said second condenser discharges across the igniter gap when the latter is ionized by the discharge of said first-named condenser.

2. Apparatus as defined in claim 1 wherein said first and second transformers are regulated to operate along the knees of the magnetization curves of the cores thereof when the voltage of said source in normal operation varies between predetermined limits.

3. In apparatus of the class described, a direct current source of electrical energy, first and second transformers, the primary windings of which are in parallel circuits connected to said source and the connection from the source to the primary winding of said first transformer being intermediate the ends thereof, vibrator means operatively connected with said source and operable to intermittently interrupt the circuit through the primary winding of said second transformer and to alternately open and close circuits through opposite halves of the primary winding of said first transformer, a condenser chargeable in increments by the secondary winding of said second transformer, said condenser being connected to said secondary winding by means including a rectifier, a high-frequency transformer, an igniter gap connected in series with the secondary winding of said high-frequency transformer, means for causing said condenser to discharge intermittently through the primary winding of said high-frequency transformer to energize the secondary winding thereof and ionize said igniter gap, a second condenser in series with said last-named secondary winding and the igniter gap, and means including a rectifier for connecting said second condenser to the secondary winding of said first transformer whereby said second condenser is charged in increments to a voltage below the normal breakdown voltage of the igniter gap to discharge across said gap when it is ionized.

4. In apparatus of the class described, a source of electrical energy, the voltage of which varies between predetermined limits, a first condenser, means including a first transformer energized by said source for incrementally charging said first condenser, a second condenser of considerably less capacity than said first condenser, means including a second transformer energized by said source for incrementally charging said second condenser to a voltage considerably higher than the voltage of the charge on said first condenser, the electrical constants of the circuits being such that during the same intervals of operation said first condenser is charged to approximately a predetermined voltage and said second condenser is charged to approximately a predetermined higher voltage independently of the voltage of said source, the length of said intervals being dependent upon said source voltage, means comprising a fixed spark gap for causing said second condenser to discharge whenever it attains said predetermined higher voltage, and gap means ionizable by said discharge to cause said first condenser to discharge across said gap means.

5. Apparatus as defined in claim 4 comprising means automatically operable in response to the voltage of said source for connecting the high potential terminal of the

primary winding of said first transformer to ground through a resistor.

6. In apparatus of the class described, at least two igniter gaps, high-frequency transformers each having the secondary winding thereof in series with one of said gaps, a circuit including parallel branches each of which includes a condenser and the primary winding of one of said transformers, common means for simultaneously charging said condensers in increments, rectifier means for preventing said condensers from discharging back through said charging means, and common means for causing said condensers to discharge simultaneously through the primary windings connected therewith to energize said secondary windings and initiate a spark at each of said gaps to ionize the latter.

7. Apparatus as defined in claim 6 comprising a second condenser, means for charging said second condenser to a voltage below the normal break-down voltage of said gaps simultaneously with the charging of said first-named condensers, and means for selectively connecting said second condenser to any of said igniter gaps to discharge thereacross when the same are ionized.

8. Apparatus comprising a direct current source of electrical energy, an igniter gap having a normal break-down voltage greatly in excess of the voltage of said source, a condenser, means including a vibrator and a transformer for charging said condenser in increments from said source, a high-frequency transformer having the secondary winding thereof in series with said gap and the primary winding thereof in circuit with said condenser, means comprising a fixed spark gap responsive to the charge on said condenser for intermittently causing said condenser to discharge through said transformer to ionize said igniter gap at the time when said charge attains a predetermined voltage, a second condenser, means including said vibrator and a transformer for charging said second condenser in increments from said source to a voltage between the voltage of the source and the normal break-down voltage of said igniter gap, and means including the secondary winding of said high-frequency transformer for connecting said igniter gap to said second condenser whereby the latter will discharge across said igniter gap when it is ionized by the discharge of said first-named condenser.

9. Apparatus as defined in claim 8 comprising a spark gap in the connection between said second condenser and said igniter gap.

10. A spark ignition system for initiating combustion of fuel in an engine comprising a spark type ignition device having spaced electrodes forming a gap across which an ignition spark passes, a sparking circuit including said electrodes, a condenser in said sparking circuit, a charging circuit connected to said sparking circuit for charging said condenser, a voltage supply in said charging circuit for progressively charging said condenser through a series of high potential pulses, means in said charging circuit to prevent said condenser from discharging back through said charging circuit, means for rendering said gap conductive to the charge on said condenser to generate said ignition spark, said last-named means comprising a step-up transformer, the secondary winding of the latter being connected in series relation with said condenser and said electrodes in said sparking circuit, and a control spark gap connected in the sparking circuit between said condenser and said secondary winding.

11. A spark ignition system for initiating combustion of fuel in an engine comprising a spark type ignition device having spaced electrodes forming a gap across which a spark passes; an electrical sparking circuit consisting only of the said electrodes and in series therewith an inductive choke and an accumulator condenser of large capacitance; a source of high potential electrical impulses; and electrical charging circuit means connecting said source with said condenser to charge the condenser by a

plurality of successive high potential impulses step by step to the break-down potential of the sparking circuit to produce successive sparks across said electrodes in untimed intervals and further including a rectifier device to prevent discharge of the condenser through the charging circuit means.

12. In an electrical ignition system including a plurality of spark ignition devices, a plurality of energy storage capacitors, a capacitor charging circuit adapted when energized to provide a high voltage substantially unidirectional charge current output to said energy storage capacitors, said capacitors being so connected with each other in said charging circuit that all are charged to like polarity and to substantially the same potential, a plurality of discharge circuits each connecting one of said capacitors to a respective one of said spark ignition devices for recurrent discharge of the capacitor there-through, and inductor means including windings connected in said discharge circuits to effect substantially simultaneous discharge of said capacitors each through its respective ignition device.

13. An electrical ignition system as defined in claim 12 wherein said inductor means includes a plurality of secondary windings each connected in a respective one of said discharge circuits and primary winding means inductively coupled to said secondary windings, and said system comprises means for recurrently impressing on said inductor primary winding means a high impulse voltage thereby to induce in each of said secondary windings an impulse voltage effective to initiate simultaneous discharge of said capacitors each through its respective ignition device.

14. In an electrical ignition system for firing a plurality of spark ignition devices simultaneously, a plurality of energy storage capacitors, a capacitor charging circuit adapted to provide a high voltage substantially unidirectional charge current output to said energy storage capacitors, said capacitors being so connected with each other in said charging circuit that all are charged to like polarity, a plurality of discharge circuits each connecting one of said capacitors to a respective one of said spark ignition devices for recurrent discharge of the capacitor there-through, inductor means including a plurality of secondary windings each connected in a respective one of said discharge circuits and primary winding means inductively coupled to said secondary windings, triggering capacitor means connected to be charged through said capacitor charging circuit, and a trigger gap connecting said triggering capacitor means for discharge through said inductor primary winding on break-down of said trigger gap, whereby discharge of said triggering capacitor means through said trigger gap recurrently impresses on said inductor primary winding means a high impulse voltage thereby to induce in each of said secondary windings an impulse voltage effective to initiate simultaneous discharge of said energy storage capacitors, each through its respective ignition device.

15. In an electrical ignition system a plurality of spark ignition devices, a plurality of energy storage capacitors, a capacitor charging circuit adapted to provide a substantially unidirectional charge current output to said energy storage capacitors, said capacitors being so connected with each other in said charging circuit that all are charged to like polarity, a plurality of discharge circuits each connecting one of said capacitors to a respective one of said spark ignition devices for recurrent discharge of the capacitor there-through, inductor means including a plurality of secondary windings each connected in one of said discharge circuits and primary winding means inductively coupled to said secondary windings, a control gap connected between the capacitor and inductor winding in each of said discharge circuits, triggering capacitor means connected to be charged through said capacitor charging circuit, and a trigger gap connecting said triggering capacitor means for discharge through said inductor primary

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winding means on break-down of said trigger gap, whereby discharge of said triggering capacitor means through said trigger gap recurrently impresses on said inductor primary winding means a high impulse voltage thereby to induce in each of said secondary windings an impulse voltage effective to initiate substantially simultaneous discharge of said capacitors each through its respective control gap and ignition device.

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