United States Patent

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[54] **CAPACITOR DISCHARGE IGNITION SYSTEM**
9 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** ..... **315/209 CD,** 315/209 SC, 315/241
[51] **Int. Cl.** **F02p 3/06,** H01t 15/02
[50] **Field of Search** ..... 315/209 CD, 209, 241, 209 SC; 331/113.1

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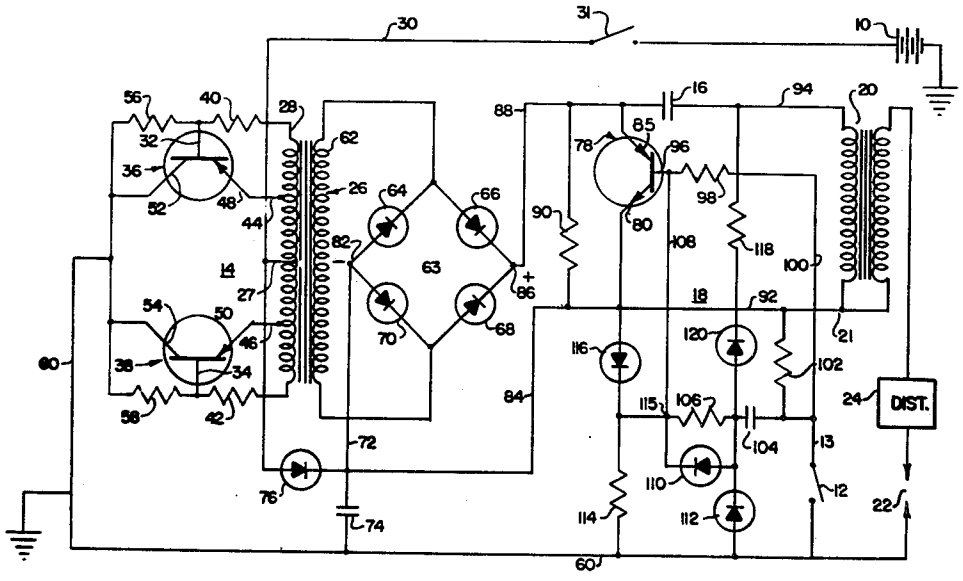
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ABSTRACT: A capacitor discharge ignition system which includes a storage capacitor, a charging circuit for charging the capacitor, a switch effectively directly connected across the output of the charging circuit and adapted to be actuated in timed relation with respect to an engine, wherein the charging circuit comprises a converter which stalls on actuation of the switch means which is connected to provide a low impedance short across the output of the converter to reset the converter and switch means in timed relation as a function of the engine speed. The switch includes a trigger circuit and a feedback circuit is provided to feed back a portion of the energy stored in the storage capacitor to effectively completely discharge the trigger circuit of the switch when actuated. There may further be provided means for supplying a reverse gate voltage to the switch means to prevent spurious signals from actuating same.



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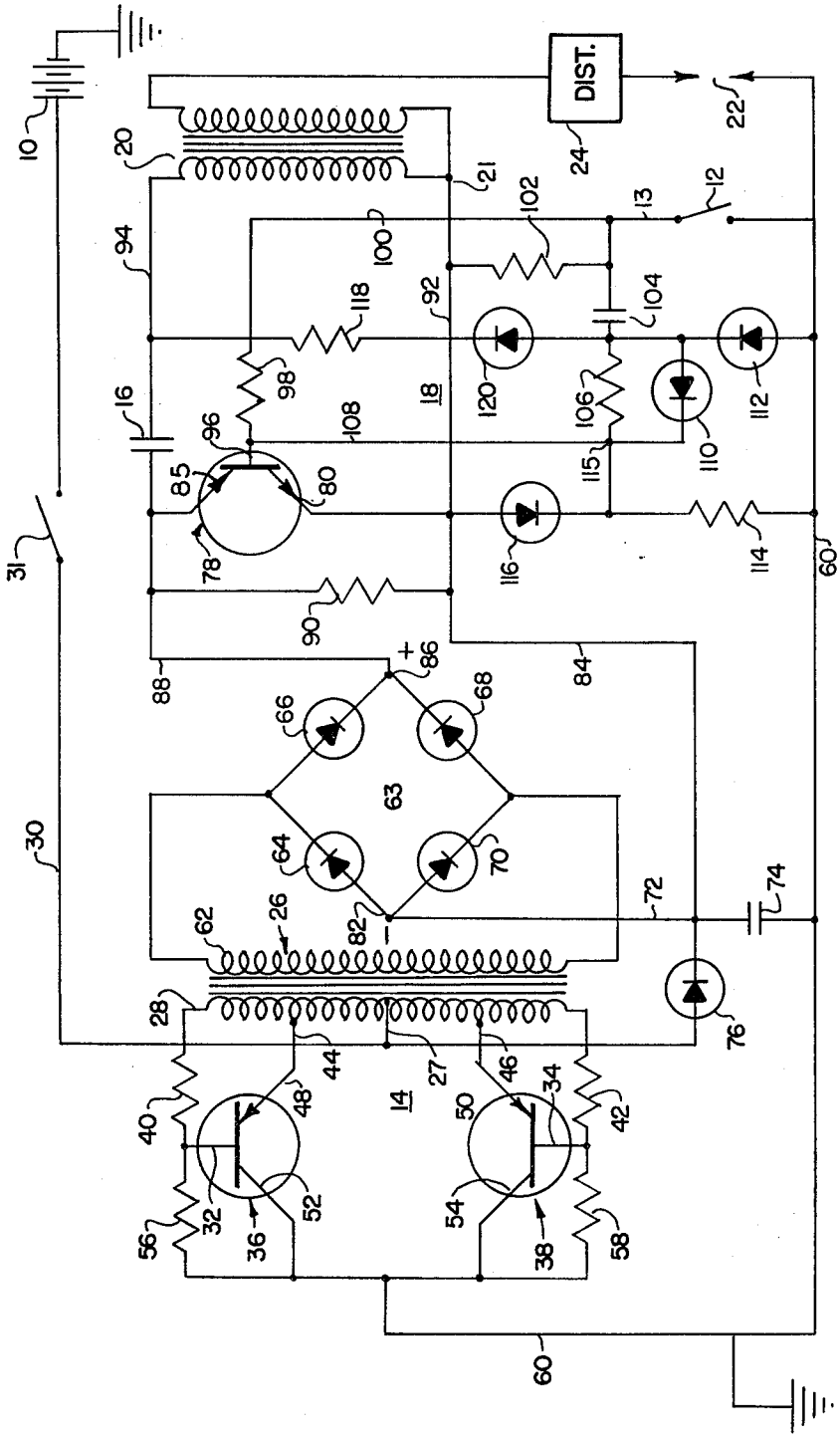


FIG. 1

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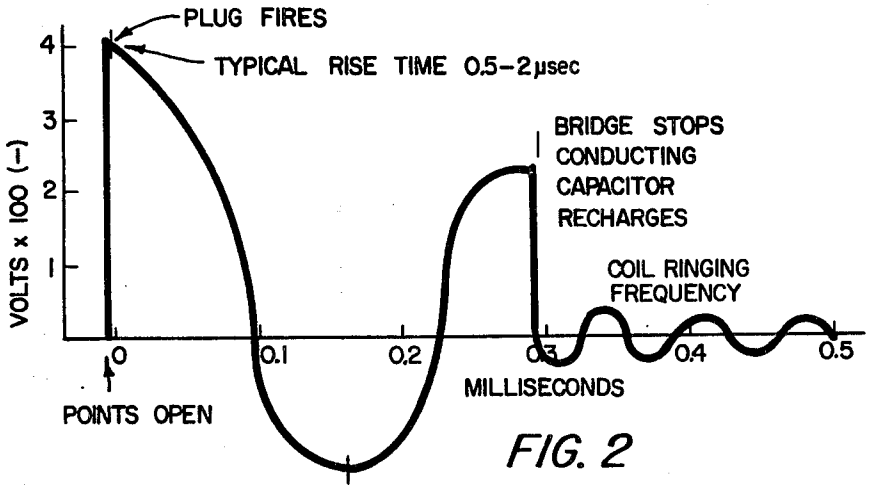


FIG. 2

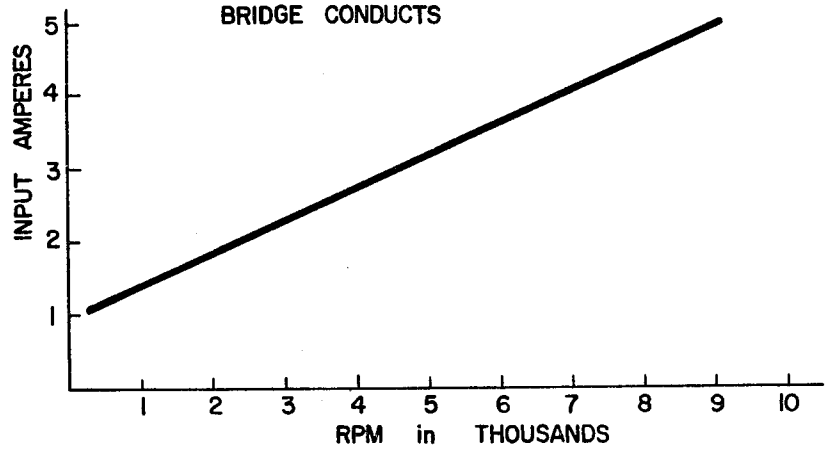


FIG. 3

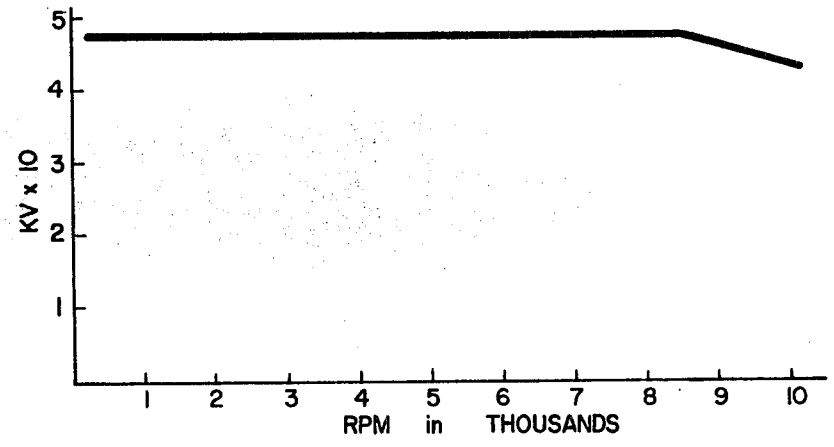


FIG. 4

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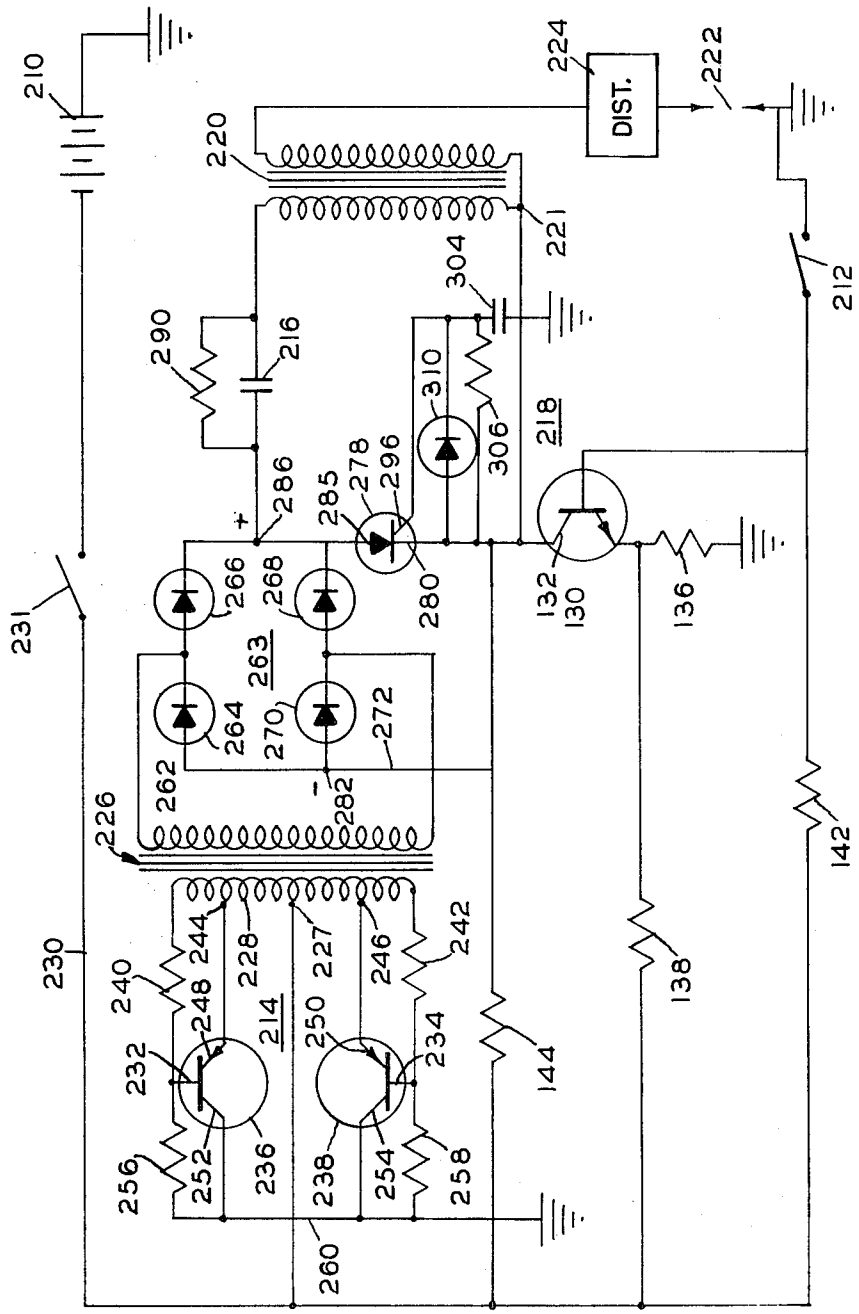


FIG. 5

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CAPACITOR DISCHARGE IGNITION SYSTEM

The use of higher compression ratios in the modern automobile and truck engines requires a higher voltage at the points of the spark plugs and greater dependability of the remaining circuit components. Several attempts have been made to achieve the required results by combining transistor amplifiers with gaseous discharge tubes and storage capacitors but these circuits have been expensive, bulky, and sometimes refuse to operate when one spark plug is short circuited or refuses to fire because of too widely separated points. The circuit of the present invention utilizes relatively few elements, insures a strongly peaked sparking voltage pulse that causes a discharge at some of the spark plugs even though other plugs are disconnected or shorted.

The new ignition circuit for high compression engines is relatively inexpensive as compared with those heretofore proposed. It increases the life of spark plugs and reduces, if not eliminates, misfiring due to fouled plugs by providing a single high voltage pulse across the spark plug terminals. The circuit effectively reduces the required current through the breaker contacts, thus insuring longer contact life.

It is the principal object of the present invention to provide an ignition circuit which will develop, in a simple controllable manner, high voltages and relatively high energies for delivery to a spark plug or spark gap to ignite combustible fuel mixtures.

A further important object of the present invention is the provision of an improved ignition system having a variable spark repetition rate responsive to engine speed.

It is a further object of the present invention to provide an ignition circuit which is efficient and will provide dependable operation over a wide range of ambient temperatures, voltages, and energies in predictable manner.

A further object of the present invention is the provision of an improved ignition system which provides for delivery of only one complete cycle to the ignition coil each time the points open.

A still further object of the present invention is to provide an improved ignition circuit which displays a rapid rise time and avoids most of the disadvantages of prior art ignition systems.

Another object of the present invention is to provide an improved ignition system which avoids refiring due to point bounce in high-speed engines.

Another important object of the present invention is to provide an improved ignition circuit which is capable of impressing a voltage and current, with a minimum electrical loss, across the primary windings of a high ratio step-up transformer or ignition coil, the output of which is delivered to spark plugs or spark gaps.

In accordance with the present invention a relatively low DC voltage is transformed to an intermediate DC voltage by means of a DC to DC converter and stored in a storage capacitor. Breaker contacts or other suitable means are controlled to open and close in synchronism with the movements of the engine's pistons to provide a signal or condition representative of such movement. The signal or condition thus produced is used to control the discharge of the capacitor into a high ratio step-up transformer having the output thereof connected to deliver the developed potential to spark plugs or spark gaps in timed sequence and in proper order to ignite a combustible fuel serving to drive an engine.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following detailed description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

In the drawings:

FIG. 1 is a schematic diagram of connections of the preferred form of the ignition circuit of the invention;

FIG. 2 is a graph showing the voltages developed across the ignition coil primary windings during the operation of the circuit of this invention as a function of time;

FIG. 3 is a graph showing power supplied to the ignition circuit of this invention as a function of engine speed;

FIG. 4 is a graph showing the high tension voltage developed at the spark plugs by the ignition circuit of this invention as a function of engine speed; and

FIG. 5 is a schematic diagram of connections similar to FIG. 1 but employing a modified control arrangement.

Referring now to FIG. 1, the circuit includes the usual battery 10 and breaker points 12 which are operated by a portion of the mechanical gearing coupled to a drive shaft. Although the circuit is illustrated as using breaker points as the means of synchronizing operation of the circuit with the movement of the engine, it will be readily understood by those skilled in the art that other control means and methods may be used with equal success that make use of magnetic, photoelectrical or Hall effect characteristics to sense the appropriate moment for firing and develop a control signal suitable to control the ignition circuit of the present invention.

The ignition circuit includes a DC to DC converter 14 to convert the relatively low voltage from battery 10 to a higher voltage for storage, a storage element or capacitor 16, a switching circuit 18 to control the discharge of the storage element 16, a sensing means such as breaker points 12 to sense the relative position of engine parts, and actuate switch 18 and a high voltage output transformer or coil 20 to transform the voltage stored in capacitor 16 to a high tension voltage which will fire a spark plug. The output circuit includes the usual plurality of spark plugs represented by a single gap 22 and a distributor 24 which may be operated by a mechanical gear means coupled to the drive shaft of the engine. The operation of the distributor and the spark plugs are well known and need not be described here in detail.

The converter 14 includes transformer 26 having a center tapped 27 primary winding 28 connected to the positive terminal of battery 10 via conductor 30 and ignition switch 31. Each end of the primary winding is connected to the base electrode 32 and 34 respectively of transistors 36 and 38 serially through base-current-limiting resistors 40 and 42. Intermediate taps 44 and 46 to either side of the center of the primary winding 28 are connected respectively to the emitter electrodes 48 and 50 of transistors 36 and 38. The collector electrodes 52 and 54 are connected serially through forward bias resistors 56 and 58 to base electrodes 32 and 34 respectively and are further connected to ground potential via conductor 60. The secondary winding 62 of transformer 26 is connected to a diode rectifier bridge 63 comprising diodes 64, 66, 68 and 70. The negative terminal of rectified output of bridge 63 is connected via conductor 72 to one lead of filter condenser 74 with the other lead being connected to ground potential. A diode 76 is connected between the center tap 27 of the primary winding of transformer 26 and the positive lead of condenser 74 which acts as a filter to reduce any voltage ripple present on the battery supply as it is passed through diode 76 to the switching circuit 18. Resistors 56 and 58 of the oscillator converter 14 serve as forward bias resistors enabling the oscillator to start at low temperatures and resistors 40 and 42 set the drive level of the feedback signal to transistors 36 and 38.

The switching circuit 18 contains the silicon-controlled rectifier control circuit and associated protective circuits. The silicon-controlled rectifier 78 has the cathode 80 thereof connected to the negative terminal 82 of bridge 63 via conductors 84 and 72. The anode 85 of rectifier 78 is connected to the positive terminal 86 of the bridge 63 via conductor 88. A high resistance bleeder resistor 90 is connected between the anode 85 and the cathode 80 of the rectifier 78. The cathode 80 of rectifier 78 is connected to the common connection 21 of the primary and secondary windings of coil 20 via conductor 92. The anode 85 of rectifier 78 is connected to the other end of the primary winding of coil 20 serially through storage capaci-

tor **16** via conductor **94**. The gate electrode **96** of rectifier **78** is connected serially through a resistance **98** to the ungrounded contact **13** of the breaker points **12** via conductor **100**. A resistance **102** is connected between contact **13** of the points and conductor **92** to receive current from the junction of diode **76** and condenser **74** via conductor **84**. The contact **13** of the points is also connected to the gate electrode of rectifier **78** serially through condenser **104**, resistor **106**, and conductor **108**. A diode **110** is connected in shunt with resistor **106** and diode **112** is connected between the junction of condenser **104** and resistor **106** and ground potential existing on conductor **60**. A resistor **114** is connected between ground potential on conductor **60** and the juncture **115** of gate electrode **96**, resistor **106** and diode **110**. A further diode **116** is connected between juncture **115** and cathode electrode **80**. The coil side of storage capacitor **16** is connected to the juncture of condenser **104**, diodes **110** and **112**, and resistor **106** serially through resistor **118** and diode **120**.

The operation of the ignition circuit is as follows: On closure of the ignition switch **31** battery voltage is supplied from battery **10** to the center tap **27** of transformer **26** and to diode **76**. The application of voltage to the transformer causes to flow through resistors **40**, **42**, **56** and **58** and simultaneously through transistors **36** and **38** to ground. Since these paths have a different resistance value, one-half of the primary winding will have a higher current flow.

Assuming that the upper half of the primary winding **28** carries slightly higher current than the lower, the voltages developed, in the two feedback windings connecting resistors **40** and **42**, tend to turn transistors **36** on and **38** off. This increases the current through the upper half of the transformer winding. The increase in current further drives transistors **36** into conduction and transistors **38** into cutoff, simultaneously transferring energy to the secondary of transformer **26** that is rectified by the diode bridge **63**.

When the current through the upper half of the primary of transformer **26** reaches a point where it can no longer increase, due to resistance in the primary circuit and/or transformer core saturation, the signal applied to the transistor **36** from the feedback winding decreases. Since transistor **36** immediately turns off, the current in the upper winding decreases. The magnetic field developed by the current flow starts to collapse. This collapsing field, cutting across all the windings in the transformer, develops voltages in the transformer opposite in polarity to the voltage developed by the expanding field. This voltage now drives transistor **36** into cutoff and transistor **38** into conduction and simultaneously delivers power to the diode bridge **63**. Once started, this action alternates, without load, at approximately 50 cycles per second.

The voltage applied to the diode bridge is rectified to a DC potential of about 400 volts, charging capacitor **16** through the coil **20**, connected through the minus and plus coil terminals to the negative terminal of the diode bridge. This action takes place as soon as power is applied by turning on the ignition key. Simultaneously, voltage is applied from the battery through diode **76** to capacitor **74** (serving as a filter to reduce any voltage ripple present on the battery supply). This filtered voltage then flows through resister **102** to ground, if the distributor point **12** is closed, or through condenser **104** and the silicon-controlled rectifier gate electrode **96** if the point is open.

Assume that the point is closed and the ignition switch **31** is closed as the first cylinder comes up on compression and reaches the position where the spark plug should be fired, the point **12** opens. The current available at the junction of diode **76** and condenser **74** now flows through resistor **102**, condenser **104** and diode **110** to the gate of the silicon-controlled rectifier **78**. This current switches the rectifier on.

When the rectifier turns on, two things happen simultaneously. The silicon-controlled rectifier short circuits the power supply (the energy is absorbed in the transformer **26**) and the effect of the short reflected to the primary of transformer **26** removes the drive from transistors **36** and **38** stopping converter operation. The rectifier **78** also connects the positive side of capacitor **16** to the plus coil terminal. This forms a closed circuit consisting of the capacitor **16**, silicon-controlled rectifier **78**, and coil **20** primary winding. The energy stored in the capacitor **16** is now delivered to the ignition coil **20**. The coil primary voltage rises from 0 to 400 volts in approximately 2 microseconds, FIG. 2.

The rise time of a standard ignition coil secondary is slower than the rise time of its primary because of reflected secondary capacitance and primary leakage inductances. A typical secondary rise time is approximately 15 microseconds.

In the circuit made up of the silicon-controlled rectifier **78**, capacitor **16**, and coil **20**, a resonant circuit is formed between the primary coil inductance and capacitor **16**. The flywheel effect of this circuit restores unused energy to the capacitor **16**, the capacitor discharge current flows through the rectifier **78** and coil primary creating a magnetic field in the coil **20**. Current produced by the coil's magnetic field continues to flow in the circuit until the capacitor **16** is charged in a reverse direction to approximately 300 volts.

At this point the current attempts to reverse through the rectifier **78** causing the same to return to its off condition. The direction of current and voltages causes the diode bridge **63** to conduct as a short circuit (all diodes simultaneously in a conduction mode). This current flow discharges the capacitor **16** to zero from its reverse direction and recharges the capacitor **16** toward its normal state. The remaining energy is stored in the circuit. When the current supplied by the coil inductance drops to zero, the bridge returns to a normal state, the load is removed from transformer **26** and normal converter operation resumes.

As designed, the power supply of the present ignition system meets two important requirements: it is stable when short circuited by the rectifier, and it is resistant to parasitic oscillations under those conditions. High frequency or parasitic oscillations could destroy the inverter transistors by feeding power to the diode bridge **63**. The rectifier **78** would continue to conduct, causing losses in the transformer and associated circuitry. The inverter transistors **36** and **38** are rated at 7 amperes each. They normally carry a maximum of 2 amperes. Parasitic oscillations would cause the power supply to draw currents of 15 to 20 amperes causing their destruction or require more expensive units.

The normal operating frequency of the power supply, without spark load, is in the 50 to 60 c.p.s. range. Since the spark repetition rate of an eight-cylinder engine a 6,000 r.p.m. is 400 pulses per second, a frequency of 50 cycles will not supply the energy needed. As a result, the power supply changes its repetition rate, as the transformer is reset to a zero flux condition, by the signal coupled back through the diode bridge during the spark cycle. This restarting of the oscillator to follow its load frequency causes the input power to the unit to increase in direct ratio to engine speed. See FIG. 3.

The power supply will deliver full energy to the capacitor at engine speeds over 8,000 r.p.m. Between spark pulses the converter has plenty of time to recharge the capacitor. Since its current drain is low, the ignition circuit operates normally using the ballast-dropping resistor already in most vehicles. This eliminates, in contrast to transistor systems, rewiring the vehicle and/or adding an ignition relay.

As the engine continues to turn off compression, the converter recharges the capacitor for the next compression cycle. This enables the SCR ignition system to deliver much higher energies during the starting cycle than would be possible if the energy were to be stored during the compression cycle when battery voltage is lowest.

This removes the major handicap of SCR capacitive discharge systems—the inability of the silicon-controlled rectifier to turn off. Since the SCR **78** will always turn off when voltages are removed, and the converter **14** cannot restart due to the reflected load until the SCR is off, it is impossible for this system to refuse to reset between spark pulses. Thus a primary problem in previous designs of SCR ignitions has been solved.

Since silicon-controlled rectifiers radically change gate sensitivity with temperature, something must be done to supply trigger, or gate, current to fire the SCR over a low temperature range of −50° to 65° F. Resistor **102** and capacitor **104** deliberately overdrive the SCR **78** (in current) at the lowest operating temperature and voltage. High temperatures could cause multiple firing of the SCR—this is detrimental to a spark plug life and engine operation. Resistor **118** and diode **120** couple a negative pulse from the ignition coil **20**, completely reverse charging condenser **104**, as soon as the silicon-controlled rectifier **78** switches on. Diode **112** serves to clamp the potential on condenser **104** at ground potential. This removes the gate pulse and assures that only one complete cycle will be delivered to the coil each time the points open. Diode **116** and resistors **114** and **118** apply a normal reverse-gate voltage to the SCR **78** so that any ripple voltage still in the gate circuit will not cause the SCR to fire except from a definite breaker point signal.

Silicon-controlled rectifiers have another important characteristic in electronic ignition systems. The gate-firing characteristic of the scr is primarily a function of time, as long as the supplied current is above the minimum required to fire same. The modulation characteristic of the transistor is not present. Dirty or contaminated points do not degrade the spark energy. The system of this invention will operate excellently with points that could not be used in either a Kettering or a transistor ignition.

Since silicon-controlled rectifiers may be triggered by a current pulse of very short duration, it is necessary to prevent point bounce on closure. Point bounce problems are one of the inherent limitations to a high-speed point operation. To remove the possibility of refiring by point bounce, diode **110** and resistor **106** introduce a predetermined delay of approximately 1 millisecond in recharging capacitor **104** when the points **12** close. The spark plugs are properly fired in speed ranges much in excess of those of either a standard ignition system or transistor system. Analysis of high-speed operation of the SCR ignition circuit of this invention shows that accurate ignition control of timing may be obtained in excess of 10,000 r.p.m. with only minor care being used in point of adjustment as shown in the graph of FIG. **4**.

Resistor **90** is present to discharge capacitor **16** when the ignition switch is opened. This prevents any shock hazard during servicing of the ignition system. Resistors **40** and **42** are base-current-limiting resistors controlling the drive currents supplied, and resistors **56** and **58** forward-bias transistors **36** and **38** to assure starting at low temperatures.

Transistor ignition systems, in general, require the removal of the capacitor installed in the distributor. The SCR system of this invention operates either with or without this distributor capacitor. The only effect of the distributor capacitor is to reduce the SCR firing current, since resistor **102** must supply charge current to it as well as condenser **104**. Resister **102**, however, is sufficiently low in value to supply over two times the maximum required current to the SCR even with the distributor capacitor installed.

Ignition systems with rapid rise time provide better performance in firing fouled plugs—as less total energy is wasted in the fouling resistance. If the secondary of the ignition coil is considered to consist of an airgap shunted by resistance, then the energy dissipated in the shunting resistance is directly dependent upon the time required to reach the ionization potential of the airgap. Silicon-controlled rectifier systems are capable of very rapid rise times and have the ability to fire spark plugs with low shunting resistance.

The rise time of the SCR system is dependent, to a large extent, on coil characteristics. However, its rise time to fire is more rapid than a Kettering system with the same coil. The SCR ignition unit has been designed to fit existing vehicles without modification but even more rapid rise times—in the 2 microsecond range—could be supplied with a special coil.

The energies delivered by this SCR system to the spark plug are easily controlled by the capacitance value of capacitor **16**, but may be raised by increasing the value of this capacitor. As designed, it is capable of delivering 80 milliwatt-seconds of energy to the coil primary. Assuming a coil efficiency of 50 percent, total spark energy delivered would be 40 milliwatt-seconds or a substantial increase over the energy of standard systems.

If much higher energies should be needed in the future, system redesign would consist of either increasing the value of capacitor **16** or increasing the voltage supplied by the power supply. The new energy level increases directly with the capacitance or with the square of the voltage.

Thus it will be seen that the energy transfer ignition system of this invention provides energy levels substantially in excess of any present ignition system and ease of control thereof. Further the circuit provides a much more rapid rise time than the known Kettering system using the same coil. Further point life is limited inly by mechanical wear and point condition is relatively unimportant, as is dwell time, providing a system having higher reliability than others now being used. The current load on the battery using this circuit is substantially less than in the Kettering system and only about 20 percent that of most transistor systems.

Referring now to the embodiment of FIG. **5** the circuit includes the usual battery **210** and breaker points **212** which are operated by a portion of the mechanical gearing coupled to a drive shaft. Although the circuit is illustrated as using breaker points as the means of synchronizing operation of the circuit with the movement of the engine, it will be readily understood by those skilled in the art that other control means and methods may be used with equal success that make use of magnetic, photoelectrical or Hall effect characteristics to sense the appropriate moment for firing and develop a control signal suitable to control the ignition circuit of the present invention.

The ignition circuit includes a DC to DC converter **214** to convert the relatively low voltage from battery **210** to a higher voltage for storage, a storage element or capacitor **216**, a switching circuit **218** to control the discharge of the storage element **216**, a sensing means such as breaker points **212** to sense the relative position of engine parts and actuate switch **218** and a high voltage output transformer or coil **220** to transform the voltage stored in capacitor **216** to a high tension voltage which will fire a spark plug. The output circuit includes the usual plurality of spark plugs represented by a single gap **222** and a distributor **224** which may be operated by a mechanical gear means coupled to the drive shaft of the engine. The operation of the distributor and the spark plugs are well known and need not be described here in detail.

The converter **214** includes transformer **226** having a center tapped **227** primary winding **228** connected to the positive terminal of battery **210** via conductor **230** and ignition switch **231**. Each end of the primary winding is connected to the base electrode **232** and **234** respectively of transistors **236** and **238** serially through base-current-limiting resistors **240** and **242**. Intermediate taps **244** and **246** to either side of the center of the primary winding **228** are connected respectively to the emitter electrodes **248** and **250** of transistors **236** and **238**. The collector electrodes **252** and **254** are connected serially through forward bias resistors **256** and **258** to base electrodes **232** and **234** respectively and are further connected to ground potential via conductor **260**. The secondary winding **262** of transformer **226** is connected to a diode rectifier bridge **263** comprising diodes **264**, **266**, **268** and **270**. Resistors **256** and **258** of the oscillator converter **214** serve as forward bias resistors enabling the oscillator to start at low temperatures and resistors **240** and **242** set the drive level of the feedback signal to transistors **236** and **238**. The negative terminal **282** of the rectified output of bridge **263** is connected via conductor **272** to one end **221** of the primary winding of ignition coil **220**, the other end of which is connected serially through storage condenser **216**, shunted by resistor **290**, to the positive terminal **286** of the bridge rectifier **263**. The diodes **264**, **266**, **268** and **270** of rectifier **263** rectify the output of transformer **226**, and in the process due to the filtering action of condenser **216**

reduces the "spiking" which would otherwise require much higher voltage rated transistors for **236** and **238**.

The control circuit **218** comprises a silicon-controlled rectifier or SCR **278** having the anode **285** thereof connected to the positive terminal **286** of bridge **263** and the cathode **280** also connected to end **221** of ignition coil **220**. The gate electrode **296** thereof is connected serially through condenser **304** to ground. Diode **310** shunted by resistor **306** connects gate **296** and cathode **280**. Diode prevents excess reverse voltage from being applied between gate **296** and cathode **280** between firing intervals and during the charging of condenser **304**. Resistor **306** serves to reduce the possibility of circuit leakages which might trigger SCR **278**. Condenser **304** is an energy storage capacitor which is discharged through SCR **278** to turn on same and energize coil **220** for firing.

The control circuit further includes transistor **130** having the collector **132** thereof connected to cathode **280** of SCR **278** and the emitter **134** thereof is connected through resistor **136** to ground potential and also connected through resistor **138** to battery **210** through switch **231** via conductor **230**. The base **140** of transistor **130** is also connected to the battery **210** in similar manner through resistor **142**. Resistor **142** is a base bias resistor used to turn transistor **130** on when the points **212** open while resistors **136** and **138** act as a voltage divider to provide a bias during the time the transistor is not conducting in order to prevent false triggering die to primary ripple or noise. The cathode of transistor **130** is connected to battery **210** through resistor **144**.

The circuit of FIG. **5** operates as follows: On closure of switch **231**, power from battery **210** is applied to the center tap **227** of transformer **226**. Since the resistances across transistors **236** and **238** will not be equal, one or the other will draw more current through the transformer primary to ground. The initial current surge produces an induced current to the feedback winding (the end turns of the transformer primary) driving this transistor towards conduction and simultaneously driving the opposite transistor towards cutoff. As the current rises and reaches the point of transformer core saturation (or where the current can no longer rise due to primary resistance, i.e., ballast resistor) the collapsing magnetic field drives this conducting transistor towards cutoff and switches the opposite transistor on. This occurs with no load or at engine idle at approximately 50 cycles per second. Due to the developed cutoff bias produced by the transformer feedback windings the transistors will operate at much higher temperatures than is possible in a transistor ignition system. The alternating current field induced by this action generates a stepped up voltage in the secondary windings, multiplied by the ratio of the transformer (approximately 25 times the battery voltage), or at nominal battery voltage of 14 volts, approximately 400 volts. This 400-volt output square wave is rectified in the diode bridge **263** and charges capacitor **216** to the peak voltage of 400 volts. Simultaneously with this action, the battery potential applied to the transformer primary also flows through resistor **144** and diode **310** and charges capacitor **304** to the battery potential, points being closed. The system is now ready to fire the coil.

The points, opening, remove the ground from the distributor terminal, causing the battery voltage, which has been flowing through **142** to ground, to raise the base voltage of transistor **130** to nominal battery voltage, causing it to conduct. The energy stored in capacitor **304** and the current through resistor **144** now discharge through transistor **130** to ground. Since the silicon-controlled rectifier **278** becomes an extremely low resistance when fired, capacitor **216** discharges through SCR **278** and the coil **220**, thus developing an applied voltage peak of 400 volts across the coil with a peak surge current of approximately 400 times the coil ratio or with a 200 to 1 ratio coil, 80,000 volts. Since a silicon-controlled rectifier is an extremely rapid switch, the time for the secondary voltage to rise is approximately equal to the turn on time of the silicon-controlled rectifier, or one- or two-millionths of a second.

Due to the inherent inductance of the ignition coil an oscillatory response or flywheel action takes place causing the current to reverse when the capacitor **216** reaches a state of zero charge. Since it is an inherent characteristic of a silicon-controlled rectifier to turn off and become nonconductive when the current becomes zero or is reversed, SCR **278** now turns off and capacitor **216** is recharged by the power supple.

At high engine r.p.m.'s the spark pulse rate approaches 600 cycles per second, and the power supply requires at least one-half cycle to recharge capacitor **216**. It is therefore essential that the converter frequency follow the engine speed. For example, it would be impossible to develop the required amount of energy if the converter were to continue to operate 50 cycles when the spark pulse rate might be 300 or 400 cycles per second. This circuit is unique in that it is so designed that the converter does follow the pulse or spark repetition rate. This is accomplished as follows: During the time that the silicon-controlled rectifier SCR **278** is turned on and discharging capacitor **216**, it also places an effective short circuit across the output of the power supply. This absorbs the energy which might be stored in the transformer core and effectively cause the converter to restart, regardless of the state that it may be in during a cycle. It also might be interpreted that this short circuit reduces the transformer inductance thus allowing it to operate at a much higher frequency. Since the point of interruption, during the oscillator converter cycle, is random, the load tends to divide on alternate half cycles, thus equalizing the energy supplied by transistors **236** and **238**. It is also essential that the transformer core be reset on alternate cycles in order to develop sufficient energy. This method of operation insures core resetting.

Thunderbolt is unique in its circuitry since it is the first unit of its type to use a silicon-controlled rectifier in an energy storage system. The variable frequency operation of the oscillator is unique, as is the transistor switching of the silicon-controlled rectifier. These circuits are the basic heart of the circuits operation, and account for its extreme efficiency and reliability. This method of operation also accounts for the extreme ease of installation, since the efficiencies are many times higher than any ignition system to date. This high efficiency allows the circuit to operate over extremes of input resistance, and voltages not acceptable by any other ignition system. The circuit of this invention can serve as the primary building block for complete ignition control systems including electrical spark advance and retard.

While there have been described what at present are considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention. It is aimed therefore in the appended claims to cover all such changes and modifications which fall within the true spirit and scope of the invention.

What is claimed is:

1. An ignition circuit for internal combustion engines and rotating turbine engines having a spark plug in each combustion chamber comprising a source of direct current, a charging circuit including converter means having an input connected to said current source and an output adapted to develop a relatively high DC potential, said converter being substantially devoid of parasitic oscillation on being short circuited, a storage capacitor connected to the converter output to be charged thereby, a discharge circuit including the capacitor, a switching means, and an input winding of an output transformer, said transformer having a winding connected to said spark plugs, sensing means adapted to develop signals in response to the predetermined positioning of an engine part representative of the occurrence of a preselected portion of the engine cycle and control means adapted to actuate said switching means in response to a signal developed by said sensing means and discharge said discharge capacitor through said switching means and said output transformer winding to fire said spark plugs, wherein said control means includes electrical storage means adapted to transfer electrical energy

to said switching means to actuate same in response to a signal from said sensing means and a feedback means connected between said output transformer and said electrical storage means adapted to feed a small portion of the electrical energy developed in said output transformer to said electrical storage means to substantially completely reverse charge same on discharge of the discharge capacitor thereby to prevent more than a single effective discharge in the discharge circuit during a single discharge cycle.

2. The circuit of claim 1 including delay means with unidirectional current means adapted to introduce a predetermined time delay before the electrical storage means of the control means can be recharged after a signal from the sensing means has been received and the electrical energy has been transferred.

3. An ignition circuit according to claim 1 wherein the charging circuit includes a converter having a variable repetition rate and being responsive to the application of a low impedance load thereto to interrupt operation and responsive upon removal of such load to resume operation.

4. The circuit of claim 1 wherein said switching means includes rectifier means having a cathode and a switching electrode forming triggers of opposite polarity, signal path means connecting both said cathode and said switching electrode to potentials of opposite polarity to apply a reverse gate voltage thereto in the absence of a developed signal from the sense means.

5. The circuit of claim 4 wherein the signal path means connected to said cathode further includes a unidirectional current means and a charge storage means, which storage means serves to reverse bias the rectifier means whenever the DC potential of the charging circuit falls below the potential of the charge storage means.

6. An ignition circuit for internal combustion engines and rotating turbine engines having a spark plug in each combustion chamber comprising: a source of direct current; a DC to DC converter connected thereto including a pair of transistors, transformer means coupling said transistors through the primary winding thereof to provide a variable frequency oscillator circuit including a portion of the transformer primary winding in the feedback circuit thereof, and rectifier means connected across the secondary winding of said transformer to rectify the output signals developed in the secondary winding of the converter transformer; an output transformer having a primary winding and an output winding; a storage capacitor serially connected across the output of said converter; switching means also connected across the output of the converter in parallel with said output transformer and said capacitor; control means adapted to actuate said switch means to provide a short circuit low impedance electrical path therethrough for the discharge of an electrical charge stored in the storage capacitor through the output transformer and at the same time by means of a reflected load from the secondary winding of the converter transformer to the primary winding thereof to effectively remove the drive to the transistor oscillators and momentarily interrupt the operation of the converter, which operation will resume upon the opening of said switching means; and, sensing means responsive to the movement of component parts of an engine to develop signals as a function of time representative of the proper timing to be applied to said control means to actuate said switch means and apply firing potential to the spark plugs from said output winding in timed relation to the movement of the engine, wherein said control means includes electrical storage means adapted to transfer electrical energy to said switching means to actuate same in response to a signal from said sensing means and a feedback means connected between said output transformer and said electrical storage means adapted to feed a small portion of the electrical energy developed in said output transformer to said electrical storage means to substantially completely reverse charge same on discharge of the discharge capacitor thereby to prevent more than a single effective discharge in the discharge circuit during a single discharge cycle.

7. The circuit of claim 6 including delay means adapted to introduce a predetermined time delay before the electrical storage means of the control means can be recharged after a signal from the sensing means has been received and the electrical energy has been transferred.

8. The circuit of claim 6 wherein said switching means includes rectifier means having a cathode and a switching electrode forming triggers of opposite polarity, signal path means connecting both said cathode and said switching electrode to potentials of opposite polarity to apply a reverse gate voltage thereto in the absence of a developed signal from the sensing means.

9. The circuit of claim 8 wherein the signal path means connected to said cathode further includes a unidirectional current means and a charge storage means, which storage means serves to reverse bias the rectifier means wherever the DC potential of the charging circuit falls below the potential of the charge storage means.