ABSTRACT

An ignition system providing a continuous source of spark ignition pulses for igniting a fuel-air mixture. The ignition system includes solid state circuit means for providing a substantially constant spark repetition rate and constant spark energy over a wide range of input voltages.

8 Claims, 6 Drawing Figures
IGNITION SYSTEM SUPPLYING CONTINUOUS SOURCE OF SPARKS

BACKGROUND OF THE INVENTION

This invention relates to an ignition system that provides a continuous source of sparks for igniting a fuel-air mixture, and more particularly, to such a system that provides a constant spark repetition rate and constant energy pulses over a wide range of input voltages. This system may be employed to ignite the fuel-air mixture in a burner, for example, a burner in a gas turbine engine. There are many prior art ignition systems of the continuous spark type in which a train of ignition pulses is applied to a spark plug to ignite a fuel-air mixture. Such ignition systems may be employed to ignite the fuel-air mixture in the burner of the gas turbine engine. The present invention provides an improvement over the prior art devices in that circuit means of the solid state type are connected to a source of electrical energy and this circuit means applies a continuous train of substantially rectangular pulses to an energy storage device, for example, the primary winding of an ignition coil. A spark igniter, or spark plug, is connected to the secondary winding of the ignition coil and will have high voltages produced across it when the current through the primary winding is periodically interrupted. The solid state circuit means includes means for generating substantially rectangular pulses that have substantially constant electrical energy in each pulse and that have a substantially constant repetition rate over wide ranges of the terminal voltage of the source of electrical energy to which the circuit means is coupled. As a result, an ignition system is provided that has low power consumption, reliable operation over wide ranges of input voltages and regulated energy of the spark discharges which are relatively unaffected by a continuous flame, i.e. ionization of plasma in the spark gap. The ignition system of the present invention overcomes the disadvantage or shortcoming of prior art systems, i.e., poor low input voltage performance, by providing automatic and continuous compensation of the spark energy in direct response to input voltage fluctuations. As mentioned above, this spark energy is maintained substantially constant over wide variations in the input voltage. Moreover, the solid state components of the ignition system are protected against excessive current surges that might occur at high input voltages or when a flame in the spark gap causes a high load component of current to be drawn through the ignition coil by transformer action.

SUMMARY OF THE INVENTION

The ignition system of the present invention includes an electrical storage device, preferably in the form of an inductor which may by the primary winding of an ignition coil. The secondary winding of the ignition coil is connected to a spark gap in the form of a spark plug. A solid state switching device, preferably in the form of a transistor, is connected in series with a source of direct current electrical energy and the electrical storage device. Circuit means are connected to the source of electrical energy and the input circuit of the solid state switching device for switching it between conductive and nonconductive states. This means includes means for maintaining the energy in the output pulses from the solid state switching device substantially constant for wide variations in the terminal voltage of the source of electrical energy. Moreover, means are provided in the circuit means for maintaining the repetition rate, i.e., the time interval between successive switchings of the solid state switching device to its conductive state, substantially constant over wide variations in the input voltage, i.e. the terminal voltage of the source of electrical energy. This circuit means may take the form of an oscillator that produces substantially rectangular voltage pulses, with the energy in the pulses being substantially constant and with the repetition rate of the pulses being substantially constant despite wide variations in the input voltage, i.e. the terminal voltage of the source of electrical energy.

The above purposes are accomplished by a first RC circuit connected to the input of the solid state switching device through a transistorized switching network. This transistorized switching network will maintain the solid state switching device in the conducting state until a predetermined charge or voltage appears across the capacitor. The solid state switching device will be switched to its nonconducting state, thereby interrupting current through the primary winding of the ignition coil, when the voltage on the capacitor reaches this predetermined level. The desired output energy level determines the choice of this predetermined voltage level. Additionally, a second RC circuit means is provided that charges through the base of a transistor. The capacitor of this second RC circuit is connected across the solid state switching device and therefore is prevented from charging when the solid state switching device is in the conducting state. When the solid state switching device switches to the nonconducting state, however, this capacitor charges through the transistor thereby switching it to a conducting state. Circuit means are connected to the transistor for discharging the first capacitor when the transistor is in the conducting state and circuit means are also connected to the transistorized switching network and this transistor for maintaining the solid state switching device in the nonconducting state until such time as the second capacitor charges to a level where the current through the base of the transistor is no longer sufficient to maintain it in a conducting state. At this time the transistor switches to a nonconducting state, the first capacitor again commences to charge, the solid state switching device is switched to a conducting state and the second capacitor discharges through the solid state switching device.

The time constants of the first and the second RC circuits are selected so that the repetition rate of the rectangular pulses appearing at the output of solid state switching device and applied to the primary winding of the ignition coil is substantially constant. Moreover, the first RC circuit insures that the energy in each voltage pulse, which is proportional to the voltage-second product squared, is substantially constant irrespective of the terminal voltage of the source of electrical energy. When the terminal voltage of the source is high, the pulses will have a large magnitude but a relatively short time duration and the time that the transistor is maintained in a conductive state will be large. On the other hand, when the terminal voltage of the source of electrical energy is at a lower level, the magnitude of the pulse will be lower, but its width in terms of time will be larger and the length of time that the transistor is in a conducting state will be reduced. Consequently, the time interval between the leading edges of successive rectangular pulses will be substantially constant irrespective of the terminal voltage of the source of electrical energy.

An object of the present invention is the provision of a continuous spark ignition system that is reliable, that operates over a wide range of input voltages and that has low power consumption.

A further object of the invention is the provision of a continuous spark ignition system in which the repetition rate of the pulses of electrical energy applied to a spark plug and the electrical energy in each pulse are substantially constant over wide variations of the terminal voltage of the source of electrical energy employed in the ignition system.

Other objects and attendant advantages of the present invention will become more readily apparent as the specification is considered in connection with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of the ignition system of the present invention.

FIG. 2 is a plot of the time that electrical energy is applied to the primary winding of the ignition coil of the present invention when different terminal voltages are available from a source of electrical energy.
FIG. 3 is a plot showing the time that electrical energy is not applied to the primary winding of the ignition coil when different terminal voltages are available from a source of electrical energy.

FIG. 4 shows a rectangular voltage pulse train applied to the primary winding of the ignition coil when the terminal voltage of the source of electrical energy is at a given magnitude.

FIG. 5 is a plot similar to FIG. 4, but showing pulses applied to the primary winding of the ignition coil when the magnitude of the terminal voltage of the source of electrical energy is somewhat lower and hence begins to drop.

FIG. 6 is a plot similar to FIGS. 4 and 5, but showing pulses applied to the primary winding of the ignition coil when the magnitude of the terminal voltage of the source of electrical energy is still a lower level.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a source of direct current electrical energy 10 which may be in the form of an electrical storage battery having a negative terminal 12 connected to ground and a positive terminal 14 connected to a movable blade 16 of an ignition switch 18. A stationary contact 20 of the ignition switch 18 is connected to a line 22 via junction 24.

The ignition system of the present invention includes an energy storage device in the form of an ignition coil 26 having an energy storage inductor or primary winding 28 and a secondary winding 30 connected to a spark discharge device or spark plug 32.

The primary winding 28 of the ignition coil 26 is connected to the positive terminal 14 of the source of electrical energy 10, when ignition switch 18 is closed, through the solid state switching device 34 which may comprise a transistor 36 and a second transistor 38. One output electrode, emitter 40, of the first transistor 36 is connected to the junction 24, while the other output electrode, collector 42, is connected to the primary winding 28 of the ignition coil 26 through leads 44 and 46. The control electrode, base 48, of first transistor 36 is connected to an output electrode, emitter 50, of second transistor 38, and the emitter 50, together with the control electrode, base 48, of second transistor 36 are connected to a resistor 52 to line 22. The other output electrode, collector 54, of second transistor 38 is connected to a lead 56 having one end connected to ground through a resistor 58. The control electrode, base 60, of second transistor 38 is connected to a junction 62 between a resistor 64 and a resistor 66 that are connected in series with the output electrodes, i.e., collector 68 and emitter 70 of a transistor 72. The emitter 70 is in turn connected to a junction 74 that is connected to one terminal of a resistor 76. The other terminal of the resistor 76 is connected to ground as shown in the drawing. The series circuit comprising resistor 64, resistor 66, the collector 68-emitter 70 circuit of transistor 72 and resistor 76 is connected across the source of electrical energy 10, when ignition switch 18 is closed, by having the terminal of resistor 64 opposite junction 62 connected to line 22 and by having the terminal of resistor 76 opposite junction 74 connected to ground.

The base 78 of transistor 72 is connected through resistor 80 to line 22 and is also connected to a collector 82 of transistor 84. The emitter 86 of transistor 84 is connected to lead 88 through lead 90, and the lead 88 is in turn connected to junction 74 and hence to ground through resistor 76. The base 92 of transistor 84 is connected through lead 94 to a junction 96. This junction 96 is in turn connected to grounded line 98 through a resistor 100 and to collector 102 of transistor 104 through a series connected resistor 106 and diode 108.

The emitter 110 of transistor 104 is connected to the line 22, while the base 112 is connected through resistor 114 to a junction 116. The junction 116 is connected to one terminal 118 of a capacitor 120, while the other terminal 122 of capacitor 120 is connected to line 56. A diode 124 is connected between line 116 and line 22, and hence across the base 112-emitter 110 circuit of transistor 104.

A resistor 126 has one terminal connected to line 22 via lead 128 and the other terminal connected to a junction 130 via lead 132. The junction 130 is in turn connected to one terminal 134 of a capacitor 136, and the other terminal 138 of capacitor 136 is connected to line 88 and hence to ground through resistor 76. A zener diode 140 has its cathode 142 connected to junction 130 and its anode 144 connected to the anode 146 of diode 148. The cathode 150 of diode 148 is in turn connected to junction 96.

Another transistor 156 has its emitter 158 connected to the line 98 and hence to ground, its collector 160 connected to junction 130 and its base 162 connected to collector 102 of transistor 104 via lead 164, resistor 166 and lead 168. Thus, the output circuit of transistor 156 is connected to the series circuit comprised of capacitor 138 and resistor 76.

In addition, the ignition system of the present invention includes a transient suppression capacitor 170 connected across lines 22 and 98, and a zener diode 172 connected across the emitter 40 and collector 42 of transistor 36. This zener diode serves to protect the transistor against high reverse voltages that occur when current through primary winding 28 of ignition coil 26 is interrupted.

OPERATION

It is considered best for the purposes of understanding the operation of the present invention to assume that the circuit is initially de-energized so that both capacitors 120 and 136 are discharged. When ignition switch 18 is closed, the terminal voltage of the source of electrical energy 10 will be applied to line 22. Current will flow from this line through resistor 80 through base 78 and emitter 70 of transistor 72 and then to ground through resistor 76, thereby switching transistor 72 to a fully conducting state. This will permit current flow out of base 60 of transistor 38 through resistor 66 and the collector 68-emitter 70 circuit of transistor 72 to ground through resistor 76 thereby switching transistor 38 to its fully conducting state. This permits current flow out of base 48 of transistor 36 thereby switching it to its fully conducting state. The switching of transistor 36 to its fully conducting state immediately applies the terminal voltage of the source of electrical energy 10 to the primary winding 28 of ignition coil 26 and current begins to flow and build up in primary winding 28.

When the solid state switching device 34 comprised of transistors 36 and 38 is in its conducting state as described above, the two terminals 118 and 122 of capacitor 120 are essentially short-circuited through the solid state switching device thereby preventing the charging of capacitor 120, and preventing current flow into the base 112 of transistor 104. Transistor 104 is thereby held in a nonconducting state. Simultaneous with the flow of current through resistor 80 to switch transistor 72 and hence transistors 38 and 36 of solid state switching device 34 to their conducting states, current will flow through lead 128 and resistor 126 into capacitor 136, thereby charging this capacitor. During the initial stages of the charging of capacitor 136, the zener diode 140 prevents current flow from junction 130 toward junction 96 and thereby preventing current flow into base 92 of transistor 84. As a result, transistor 84 is held in a nonconducting state. Since transistor 104 is also in a nonconducting state at this time, transistor 156 is held in a nonconducting state since no current can flow into its base 162 from collector 102 of transistor 104.

The values of resistor 126 and capacitor 138 are chosen so that capacitor 138 charges to a threshold voltage equal to the zener breakdown voltage of zener diode 140 plus the forward voltage drop across diode 148 and the forward voltage drop across the base 92-emitter 86 circuit of transistor 84 in a time period which is a function of the terminal voltage at source 10. When this voltage is reached, the zener diode 140 breaks down and current flows through zener diode 140 from junction 130 through diode 148 and through the base 92-emitter 86 circuit of transistor 84 to ground. This prevents further build-up of voltage on capacitor 136 and switches transistor
In the transmission system according to the invention the transmission of the address signal takes place in this manner without frequency separation and without time separation within the speech band, while nevertheless the speech quality is substantially not influenced by the address signal.

FIG. 3 shows a variation of the transmission system according to the invention in which elements corresponding to FIG. 1 are denoted by the same reference numerals.

The difference of this transmission system with respect to that shown in FIG. 1 lies in the construction of the modulation device 19 which in this system consists of a modulo-2-adder 25 preceded by a limiter 26 so that the received information signals are converted into a binary signal.

The operation of the receiver corresponds essentially to that of the receiver shown in FIG. 1: in particular, the integration voltage occurring at the output of the integrating network 20 also shows the variation as shown in FIG. 2c.

However, the construction of the receiver shown in FIG. 3 is to be preferred since the modulo-2-adder 25 preceded by a limiter 26 constitutes a simpler and more reliable modulation device than the product modulator used in FIG. 1.

FIG. 4 shows a preferred embodiment of the transmission system according to the invention in which elements corresponding to FIGS. 1 and 3 are again denoted by the same reference numerals. Instead of a single modulation device as in FIGS. 1 and 3, a double modulation device is used.

In the embodiment shown the modulation device 19 comprises two modulo-2-adders 27, 28 which are connected with their first inputs in parallel arrangement to the limiter 26 and the output terminals of which are connected to a linear difference producer 29 the output voltage of which is applied to the integrating network 20. The local pulse pattern \( a(t \rightarrow D) \) advanced over one shift period \( D \) is applied to the second input of the modulo-2-adder 27, while the second input of the modulo-2-adder 28 is applied the local pulse pattern \( a(t \rightarrow \tau) \) which are already small in the case of phase stabilization can now be reduced to substantially zero.

The above described transmission systems according to the invention are always constructed for the transmission of one speech signal as a main information signal, while an address signal is always used as an auxiliary information signal.

In the embodiments shown in FIGS. 5 and 6 and on the contrary a large number of main information signals are transmitted through a common transmission path successively in time multiplex, the auxiliary information signal being used as a synchronization signal in restoring the individual main information signals at the receiver end.

The transmission system according to the invention shown in FIG. 5 is constructed for the transmission of a number of speech signals, each originating from an individual signal source 31, 32 . . . 33 and each having a bandwidth of, for example, 0–4 KHz. At the transmitter end in this transmission system each source 31, 32 . . . 33 is connected, through an individual line including analog-to-digital converters 34, 35 . . . 36, for example, in the form of a deltamodulator, to one of the inputs 37, 38 . . . 39 of commutator 40 by means of which the speech signals in a digital form are transmitted successively in time multiplex through a transmission path 41. At the receiver end each of the speech signals is restored in a digital form from the transmitted time multiplexing signal by means of a corresponding commutator 42 and applied to one of the commutator outputs 43, 44 . . . 45 which are each connected, through individual lines in which digital-to-analog converters 46, 47 . . . 48 corresponding to the analog-to-digital converter are incorporated, for example, in the form of an integrating network associated with the delta-modulator, to a separate load 49, 50 . . . 51.

For controlling the commutator 40 at the transmitter end the clock pulse generator 16 in the pulse pattern generator 8 which is constructed in the same manner as in the preceding transmission systems, is also connected to a control circuit 52 of the commutator 40, the control circuit 52 determining which commutator input 37, 38 . . . 39 is connected to the transmission path 41 at a given instant. The initial position of the commutator 40 in which, for example, the first commutator input 37 is connected to the transmission path 41, is coupled with a given condition of the shift register 10 in the pulse pattern generator 8, which condition, as is known, occurs only once per period \( T \) of the generated periodic pulse pattern. For that purpose, in the embodiment shown, the output of each shift register element 11, 12, 13, 14, 15 is connected to an individual input of an AND-gate 53 which supplies an output pulse only when simultaneously a pulse appears at the output of all the shift register elements 11, 12, 13, 14, 15 which output pulse each time resets the commutator 40 to its initial position through the control circuit 52.

At the receiver end the control of the commutator 42 is effected in quite the same manner as at the transmitter end, corresponding elements in FIG. 5 for the devices being denoted by the same reference numerals but being provided with an index.

For the mutual synchronization of the commutators 40, 42 at the transmitter and receiver ends a synchronization signal is also transmitted in this transmission system together with the speech signals for which, as already described above, no additional frequency and time space is necessary.

For that purpose, at the transmitter end the pulse pattern occurring at the output of the pulse pattern generator 8 is added as a synchronization signal by means of linear combination devices 54, 55 . . . 56 without frequency separation and without time separation to each speech signal within the speech band of 0–4 KHz. At the output of these linear combination devices 54, 55 . . . 56, the restored information signals, consisting of the speech signals and the synchronization signals added to each of them, are combined in a linear combination device 57 and, like the locally generated pulse pattern, applied to the modulation device 19 which is constructed in the manner already described with reference to FIG. 3 and the output voltage of which controls the frequency corrector 21 connected to the local clock pulse generator 16 through the integrating network 20.

In the manner already described above in detail a phase stabilization on the local clock pulse generator 16 at the phase of the pulse pattern produced at the transmitter end is obtained, said pulse pattern and the local pulse pattern coinciding and consequently also the conditions of the shift register 10, 10' at the transmitter and receiver ends being the same at any moment so that an accurate synchronization of the commutators 40, 42 at the transmitter and receiver ends is obtained.

Influencing of the speech quality by the synchronization signal can be reduced particularly efficiently in this case by using the measures already described above and not shown in the FIG. 5, for example, by subtracting the local pulse pattern from the restored information signals and including de-emphasis networks, while in the transmission system shown in FIG. 5 a further reduction is possible since in the combination of the restored information signals at the receiver end the
Capacitor 170-40 Mfd., 50 volts
Capacitor 136-0.22 Mfd. x 10% -35 volts-tantalum
Capacitor 120-0.02 Mfd.-200 volt-disc

All Resistors ¥½ watt unless otherwise specified.

Thus, the present invention provides a reliable ignition system that produces a continuous series of spark ignition pulses having a substantially constant repetition rate and having substantially constant energy over wide ranges in the terminal voltage of the source of electrical energy employed to energize the ignition system.

The invention disclosed will have many modifications which will be apparent to those skilled in the art in view of the teachings of this specification. It is intended that all modifications which fall within the true spirit and scope of this invention be included with the scope of the appended claims.

1. In an ignition system for supplying a continuous source of spark ignition pulses having substantially constant energy and a substantially constant repetition rate comprising an ignition coil having a primary winding and a secondary winding, a spark plug connected to said secondary winding, a source of direct current electrical energy, a solid state switching device having an output circuit and an input circuit, said output circuit connected in series with said primary winding of said ignition coil, means coupled to said source of electrical energy and to the input circuit of said solid state switching device for periodically switching said solid state switching device between its conducting and nonconducting states, said means including a first RC circuit comprising a series connected resistor and capacitor connected across said source of electrical energy and a second RC network comprising a series connected resistor and capacitor connected across said source of electrical energy, means coupling said first RC circuit and said input circuit of said solid state switching device for switching said solid state switching device to a nonconducting state when current through the primary winding and the voltage on the capacitor of said first RC circuit reaches a predetermined value, and means coupled to said second RC circuit, said input circuit of said solid state switching device and said first RC circuit for permitting current flow into said second RC circuit when said solid state switching device is switched to its nonconducting state, and means coupled to said second RC circuit and the input circuit of said solid state switching device for switching said solid state switching device to a conducting state when the voltage across the capacitor of said second RC circuit reaches a predetermined fraction of the terminal voltage of said source of electrical energy.

2. An ignition system comprising a spark plug, an ignition coil having a primary and a secondary winding, a source of electrical energy, the terminal voltage of which may vary over wide limits, an electronic circuit means coupled to said source of electrical energy and said primary winding, said electronic circuit means including a solid state switching device having an output circuit and an input circuit, said output circuit of said solid state switching device connected in series with said source of electrical energy and said primary winding, a capacitive means, means coupled to said source of electrical energy and said capacitive means for charging said capacitive means at a predetermined time rate, and means coupled to said capacitive means and said input circuit of said solid state switching device for switching said solid state switching device to a nonconducting state thereby interrupting current flow in primary winding when said capacitive means is charged to a predetermined voltage level corresponding to a predetermined current level in said primary winding, said predetermined voltage level being lower than the lowest terminal voltage of said source of electrical energy whereby the voltage delivered to said spark plug is substantially constant irrespective of wide variations of the terminal voltage of said source of electrical energy, and a second capacitive means, a transistor having a base, an emitter electrode and a collector electrode, said electrodes being coupled to said source of electrical energy, means connecting said second capacitive means to the base of said transistor, and across the output circuit of said solid state switching means whereby said second capacitive means is prevented from being charged when said solid state switching device is in a conducting state and said transistor is maintained in a nonconducting state, said transistor being switched to a conducting state by current flow through said base and into said second capacitive means when said solid state switching means is switched to a nonconductive state, first circuit means coupled to one of said electrodes of said transistor and said first capacitive means for discharging said first capacitive means when said transistor is in a conducting state, second circuit means coupled to one of said electrodes of said transistor and said first capacitive means and means for restoring current through said inductor at a time interval after the current through said inductor has been interrupted,
said last mentioned means including means for causing said time interval to vary as a function of the terminal voltage of said source of electrical energy.

7. In an ignition system, a spark plug, an ignition coil having a primary and a secondary winding, a source of direct current electrical energy, means coupling said secondary winding of said ignition coil to said spark plug, and circuit means coupled to said source of direct current electrical energy and to said primary winding of said ignition coil for applying a series of voltage pulses having a substantially constant repetition rate and substantially constant electrical energy to said primary winding over wide ranges of the terminal voltage of said source of electrical energy, said circuit means including a solid state switching device having an output circuit and an input circuit, said output circuit connected in series with said source of electrical energy and said primary winding of said ignition coil, a voltage responsive means coupled to the input circuit of said solid state switching device for switching said solid state switching device to a nonconducting state when the voltage on said voltage responsive means is at a predetermined value, and current responsive means coupled to the input circuit of said solid state switching device for switching said solid state switching device to a conducting state when the current through said current responsive device is at a predetermined magnitude.

8. In an ignition system, a spark plug, an ignition coil having a primary and a secondary winding, a source of direct current electrical energy, means coupling said secondary winding of said ignition coil to said spark plug, and an oscillator coupled to said source of direct current electrical energy and to said primary winding of said ignition coil for applying a series of substantially rectangular voltage pulses having a substantially constant repetition rate and substantially constant electrical energy to said primary winding over wide ranges of the terminal voltage of said source of electrical energy, said oscillator comprising a solid state switching device having first and second output electrodes and a control electrode, said first and second output electrodes being connected in series with said source of electrical energy and said primary winding of said ignition coil, a first capacitor, means coupling said source of electrical energy and said first capacitor for charging said first capacitor from said source of electrical energy, circuit means coupled to said source of electrical energy, to one terminal of said first capacitor and to said control electrode of said solid state switching device for maintaining said solid state switching device in a conducting state as said first capacitor charges to a predetermined voltage level and for switching said solid state switching device to a nonconducting state when said first capacitor charges to said predetermined voltage level, a second capacitor having a first terminal and a second terminal connected across said first and second output electrodes of said solid state switching device, and current responsive means coupled to said source of electrical energy and said second capacitor for charging said second capacitor therethrough, said current responsive means switching said solid state switching device to a conducting state when current therethrough declines to a predetermined level as said second capacitor charges to a predetermined voltage level.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION


Inventor(s) Wesley D. Boyer

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Cancel columns 5 and 6 and insert the following pages:

84 to its conducting state. Switching of transistor 84 to its conducting state diverts current from base 78 of transistor 72 and switches it to a nonconducting state. This blocks current flow out of the base 60 of transistor 38, switching it to its nonconducting state, thereby blocking current flow out of base 48 of transistor 36 and switching it to its nonconducting state. Switching of transistor 36 to a nonconducting state abruptly interrupts current through primary winding 28 of ignition coil 26 and causes a high voltage to be generated in secondary winding 30 and applied to spark discharge device or plug 32.

When the solid state switching device, comprised of transistors 38 and 36, is switched to its nonconducting
state, the capacitor 120 is no longer shortcircuited. Since terminal 122 of capacitor 120 is connected to ground via lead 56 and resistor 58, current flows from line 22 through the emitter 110 - base 112 circuit of transistor 104 and resistor 114 to terminal 118 of capacitor 120, thereby initiating charging of capacitor 120. Current flow through the emitter 110 - base 112 circuit of transistor 104, switches it to its conducting state. Current will therefore flow out of collector 102 and into the base 92 of transistor 84 via resistor 106, diode 108, junction 96 and lead 94, thereby latching transistor 84 in its conducting state and latching transistors 72, 38 and 36 in their nonconducting states.

When transistor 104 is in a conducting state, current will flow from collector 102 of transistor 104 into base 162 of transistor 156 via lead 168, resistor 166 and lead 164 thereby switching transistor 156 to its conducting state. This provides a discharge path for capacitor 136, and it will discharge through junction 130, collector 160 and emitter 158 of transistor 156, line 98, resistor 76 and lead 88. Resistor 76 has a very small value, for example, 10 ohms, so that capacitor 120 may be discharged in a very short time period.

The resistor 114 and capacitor 120 serve as a differentiating network for the voltage applied to line 22, i.e., the terminal voltage of the source of electrical energy 10, and the current through the emitter 110 - base 112 circuit of transistor 104 will decay exponentially as the voltage on capacitor 120 builds up. When this current drops to a given threshold current, below the base current,
I_b, necessary to sustain conduction of transistor 104, transistor 104 will switch to its nonconducting state. It can be appreciated that when transistor 104 switches to its nonconducting state, transistor 156 is switched to its nonconducting state, as well as transistor 84. Switching of transistor 156 to a nonconducting state permits voltage to build up again across capacitor 136, while switching of transistor 84 to its nonconducting state switches transistor 72 to its conducting state. As explained previously, when transistor 72 switches to its conducting state, the solid state switching device 34 comprised of transistors 38 and 36 also switches to its conducting state and the full terminal voltage of the source of electrical energy 10 is again applied to the primary winding 28 of the ignition coil 26. The cycle described above then repeats continuously.

It can be readily appreciated from the above description that a substantially rectangular train of voltage pulses is applied to the primary winding 28 of the ignition coil 26. This train of voltage pulses, that appear on lines 44 and 46, is shown in Figure 4 for a terminal voltage of the source of electrical energy 10 equal to some arbitrary constant value, \( V_3 \). Referring now to Figure 2, there is shown the voltage that would appear across capacitor 136 as a function of time for three different values, \( V_3' \), \( V_2 \), and \( V_1 \), of the terminal voltage of the source of electrical energy 10. The voltage \( V_1 \) is equal to the zener breakdown voltage of zener diode 140 plus the forward voltage drop of diode 148 plus the forward drop through the base 92 - emitter 86 circuit of
transistor 84. This voltage value is shown in the dotted line and is substantially below the terminal voltages, \( V_3 \), \( V_2 \), or \( V_1 \), of the source of electrical energy 10. It is preferred that the value of this voltage, \( V_f \), shown at the dotted line be such that the voltage build-up across capacitor 136 prior to reaching this threshold voltage be linear as shown for the values of terminal voltage \( V_3 \), \( V_2 \) and \( V_1 \). It will be seen that this voltage is reached in time \( T_3 \) for terminal voltage \( V_3 \), \( T_2 \) for terminal voltage \( V_2 \) and \( T_1 \) for terminal voltage \( V_1 \).

Referring now to Figure 3, there is shown a plot of currents through the emitter 110 - base 112 circuit of transistor 104 for the different values, \( V_3 \), \( V_2 \) and \( V_1 \), of the terminal voltage of source 10. The dotted line shows the current \( I_b \) at which the transistor 104 will switch into its nonconducting state. This current is reached in time \( T_6 \) for a terminal voltage equal to \( V_3 \). Hence, the pulse appearing at the output of the solid state switching device 34 and that is applied to the primary winding 28 will have a width equal to time \( T_3 \), with a time spacing between the trailing edge of the pulse and the leading edge of the next pulse equal to \( T_6 \). With respect to the current shown in Figure 3, it can be appreciated that it is a decaying exponential brought about by the charging of capacitor 120 and has an initial value equal to the terminal voltage of the source of electrical energy 10 divided by the value of resistor 114.

If the terminal voltage of the source 10 is at a lower value, i.e., \( V_2 \), the magnitude of the pulse appearing at the output of the solid state switching device 34
will be reduced to the value of $V_2$ as shown in Figure 5. Its time width, however, will be equal to $T_2$ as shown in Figure 2 and the time between the trailing edge of the pulse and the leading edge of the next pulse will be equal to $T_5$ so that the pulse train will have a configuration as shown in Figure 5. On the other hand, if the terminal voltage of source 10 is at still a lesser value, $V_1$, the magnitude of the pulse will be that shown in Figure 6 and is equal to $V_1$. Its width in terms of time is equal to $T_1$, as shown in Figure 2, while the time between the trailing edge of the pulse and the leading edge of the next successive pulse is equal to $T_4$ as shown in Figure 3. The time width, $T_3$, $T_2$ and $T_1$, of the pulses shown in Figures 4, 5 and 6, respectively, is a function of the time constant of the RC network comprised of resistor 126 and capacitor 136 and the terminal voltage of source 10. Similarly, the times $T_4$, $T_3$ and $T_6$, the time that the solid state switching device 34 is in the nonconducting state, for a different value of the terminal voltage of source 10 is a function of the time constant of the RC circuit comprised of resistor 114 and capacitor 120 and the terminal voltage of the source 10. By proper selection of the time constants of the RC network comprised of resistor 126 and capacitor 136 and of the RC network comprised of resistor 114 and capacitor 120, the pulse repetition rate will be substantially constant over a wide range of terminal voltages of the source of electrical energy 10 as illustrated in the Figures 4, 5 and 6. The pulse repetition rate is equal to $T_3$ plus $T_6$, $T_2$ plus $T_5$, and $T_1$ plus $T_4$ as shown in Figures 2 and 3 for the different values of terminal
voltage $V_3$, $V_2$ and $V_1$. Similarly, it can be appreciated that the volt seconds applied by each of the pulses shown in the Figures 4, 5 and 6 is substantially constant, since the time width increases proportionally to the decrease in the magnitude of the terminal voltage of the source 10. This is brought about because of the operation of the capacitor 136 in the switching of the solid state switching device 34 and the linear range of its charging curve shown at Figure 2.

A typical parts list for a pulse repetition rate of 100 pulses per second and a nominally ten ampere peak primary current in primary winding 28 is given below. It is readily apparent, of course, that for different peak primary currents and different pulse repetition rates, the values of the resistors 126 and 114 and the values of capacitors 136 and 120 may be changed or suitably adjusted.

**Typical Parts List**

- Transistor 156 - MPS - 6531
- Transistor 104 - MPS - 6534
- Transistor 84 - MPS - 6531
- Transistor 72 - MPS - 6531
- Transistor 38 - MJE - 371
- Transistor 36 - C5TF - 12A027-A
- Diode 140 - MZ - 500 - 3
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION


Inventor(s) Wesley D. Boyer

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Signed and sealed this 26th day of December 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents