

[72] Inventor **Takao Sasayama**
Hitachi, Japan
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 [73] Assignee **Hitachi, Ltd.,**
Chiyoda-ku, Tokyo-to, Japan

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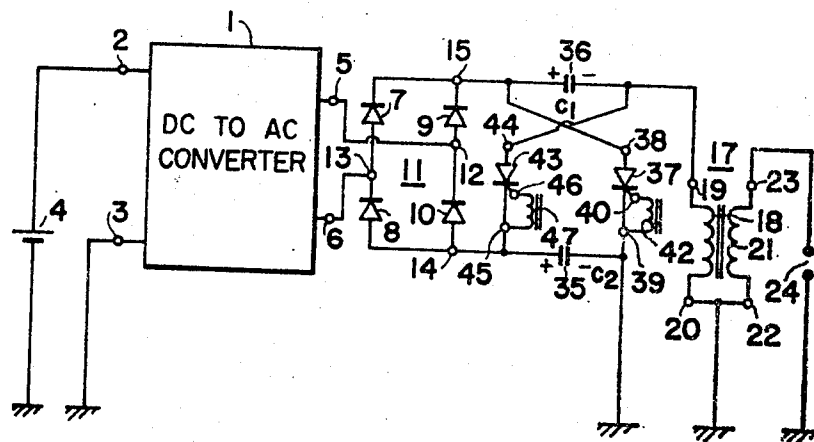
Primary Examiner—Laurence M. Goodridge
Attorney—Craig, Antonelli, Stewart and Hill

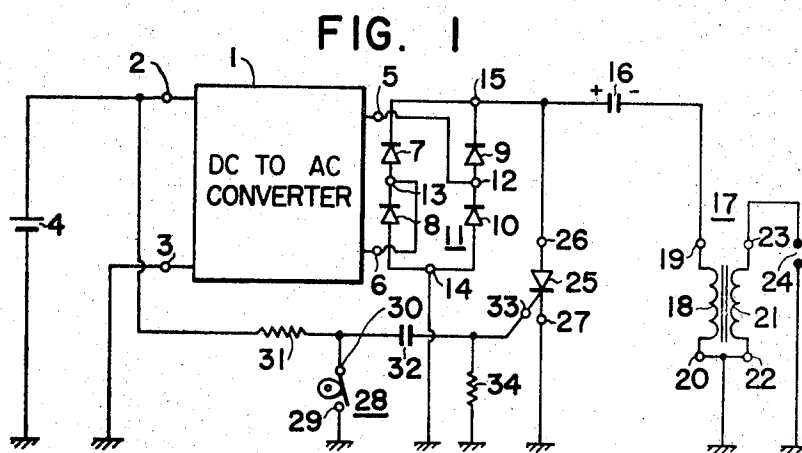
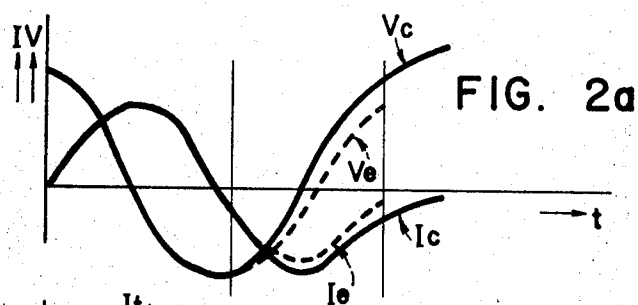
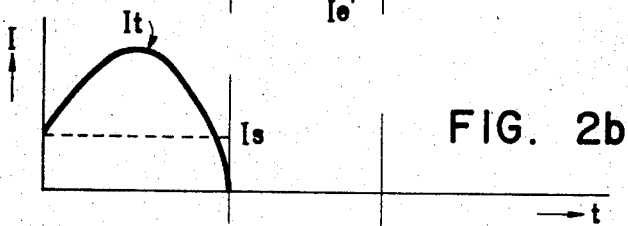
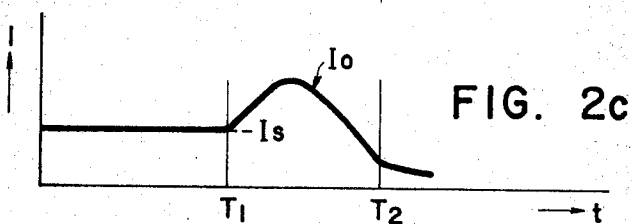
[54] **IGNITION SYSTEM FOR INTERNAL COMBUSTION ENGINE**
10 Claims, 10 Drawing Figs.

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 [51] Int. Cl..... **F02p 3/06**
 [50] Field of Search..... **123/32E-1,**
32E-2, 148E; 315/209, 209CD, 223

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ABSTRACT: An ignition system of an internal combustion engine comprises a d.c. source; an ignition coil having a primary winding; and a bridge circuit having a pair of thyristors and a pair of capacitors in its four branches and connected in such a manner that one pair of opposing branches include the respective thyristors and the other pair of opposing branches include the respective capacitors, wherein said d.c. source is operably connected between one pair of opposing connections between the branches with such polarity as to supply a current to the respective capacitor through the respective thyristor in its forward direction, the primary winding is operably connected between the other pair of opposing connections, and said pair of the thyristors are made conductive alternately by an ignition timing device so that discharge currents from the pair of discharge capacitors alternately energizes the primary winding of the ignition coil.





INVENTOR

TAKAO SASAYAMA

BY

Craig Antonelli

ATTORNEYS

FIG. 3

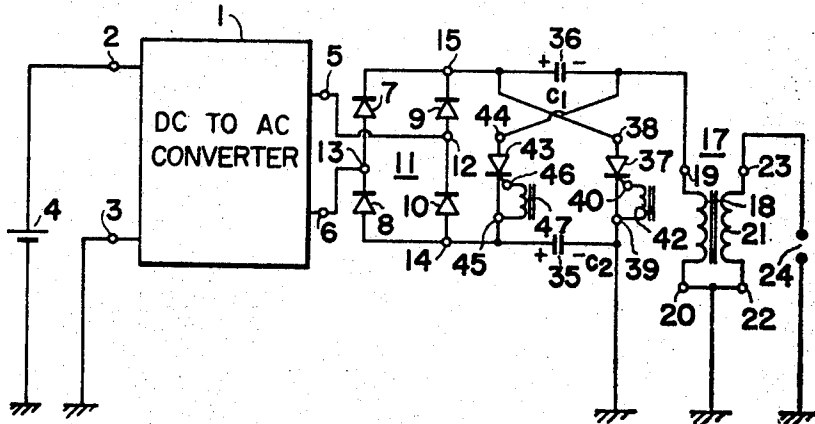
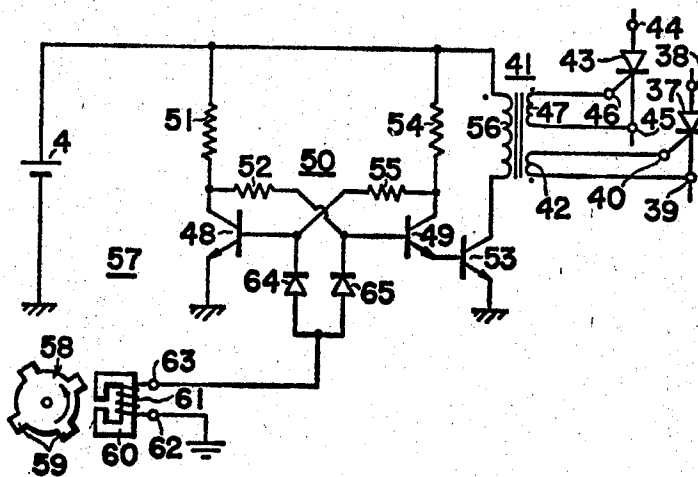


FIG. 4



INVENTOR

TAKAO SASAYAMA

BY

Craig & Antonelli

ATTORNEYS

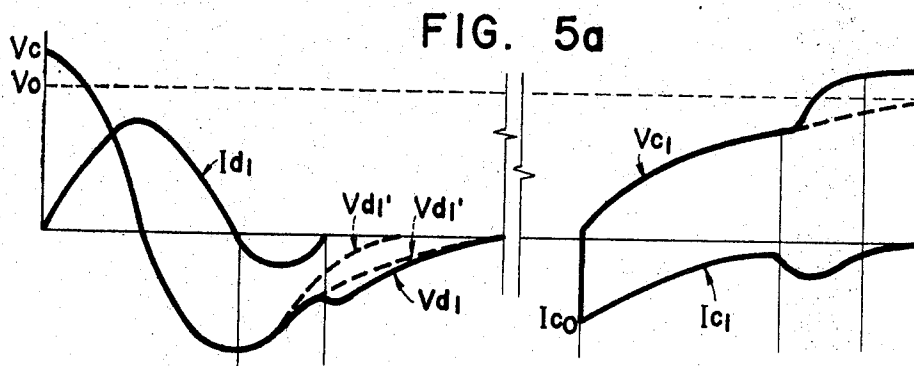
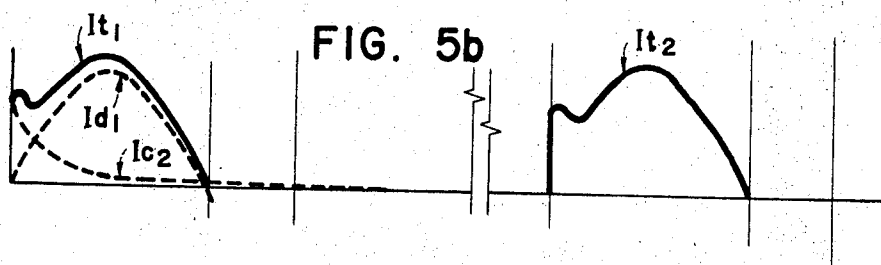
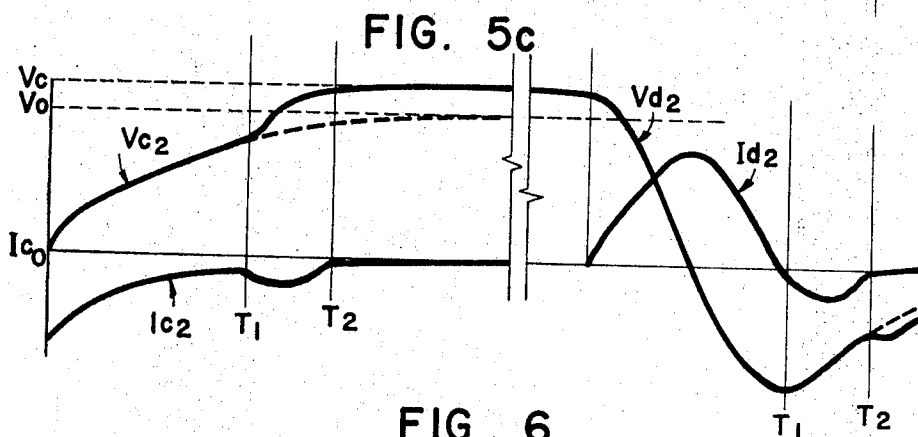
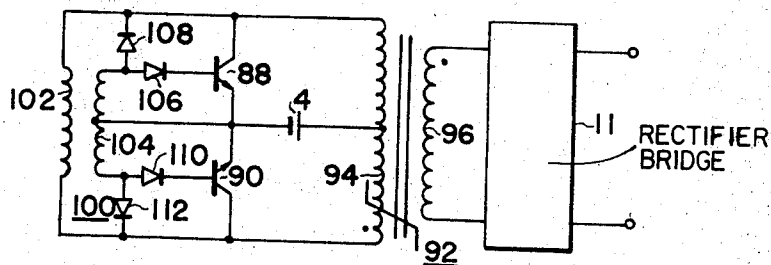


FIG. 6



INVENTOR

TAKAO SASAYAMA

BY

Craig & Antonelli

ATTORNEYS

IGNITION SYSTEM FOR INTERNAL COMBUSTION ENGINE

The present invention relates to an ignition system for an internal combustion engine and more particularly, to a semiconductor ignition system of capacitor-discharge type wherein a pair of semiconductor controlled rectifiers such as thyristors alternately control the current flow from a discharging capacitor through the primary winding of an ignition coil as well as the current flow from a d.c. source to a charging capacitor.

One of the objects of the present invention is to provide an ignition system of an internal combustion engine which is capable of high frequency ignition with sufficient accuracy.

Another object of the present invention is provision of a semiconductor ignition system for an internal combustion engine in which ignition faults are markedly reduced even at very high speed operation of the engine.

Further object of the present invention is to provide a semiconductor ignition system for an internal combustion engine in which power loss of semiconductor elements is considerably reduced as compared with conventional ignition systems and overall efficiency of the system is considerably improved.

These and other objects and advantages of the present invention will be apparent from the following description of the prior art and from the detailed description of the embodiments of the present invention, taken in conjunction with the following drawings, in which:

FIG. 1 is a circuit diagram of a conventional semiconductor ignition system of the capacitor-discharge type;

FIGS. 2a, 2b and 2c are waveform diagrams to explain the operation of the conventional system shown in the FIG. 1;

FIG. 3 is a circuit diagram of a semiconductor ignition system embodying the teaching of the present invention;

FIG. 4 is a circuit diagram of a control signal generating circuit able to be employed in the ignition system according to the present invention;

FIGS. 5a, 5b, and 5c are waveform diagrams for explanation of the operation of the ignition system of the present invention; and

FIG. 6 is a circuit diagram of a d.c.—d.c. convertor suitable for ignition systems according to the present invention. Through all of the drawings, like numerals and reference characters are employed to denote like or corresponding elements or parts.

In ignition systems of the capacitor-discharge type, electric charges stored in a capacitor are discharged suddenly through the primary winding of an ignition coil and a high voltage thereby induced across the secondary winding is supplied to a spark plug to cause a spark discharge for ignition of a combustible mixture in the cylinder of an internal combustion engine.

A conventional ignition system of this type is schematically illustrated in FIG. 1 in which 1 is a d.c.—a.c. convertor for voltage boosting, which is comprised, for example, by a conventional transistor oscillator, input terminals 2 and 3 of which are connected to a d.c. source 4, and output terminals 5 and 6 of which are connected to a.c. terminals 12 and 13 of a full wave rectifying bridge circuit 11, including diodes 7, 8, 9 and 10. Negative terminal 14 of the d.c. output of the bridge is grounded and positive terminal 15 is connected to the input terminal 19 of the primary winding 18 of an ignition coil 17 through a discharge capacitor 16. Both terminal 20 of the primary winding 18 and terminal 22 of the secondary winding 21 are commonly grounded while the output terminal 23 of the ignition coil 17 is connected to a spark plug 24. A semiconductor controlled rectifier 25 (hereafter referred to as a thyristor) has an anode terminal 26 and cathode terminal 27 which are forwardly connected with the positive output terminal 15 and ground, respectively. Distributor 28 is provided to selectively open and close in synchronization with engine rotation, the fixed contact 29 of which is grounded, the movable contact 30 of which is electrically connected with the positive terminal 2 of d.c. source 4 through a resistor 31. At the

same time, movable contact 30 is connected through a capacitor 32 to the gate terminal 33 of the thyristor 25, to which a resistor 34 is also connected.

According to this conventional ignition system, a d.c. voltage *e.g.*, 12 v., of a d.c. source 4 is converted to a d.c. voltage of a higher value *e.g.*, 500 v., by convertor 1 and rectifying bridge circuit 11. Capacitor 16 is charged by the d.c. voltage from the bridge circuit with the polarity shown through primary winding 18. When movable contact 30 of distributor 28 is in contact with fixed contact 29 and is grounded, thyristor 25 is cut-off since no gate current flows. Subsequently, when movable contact 30 is moved away from fixed contact 29 in accordance with the ignition timing of the engine, a pulse current is supplied through resistor 31 and capacitor 32 to gate electrode 33 thereby to turn on thyristor 25. Consequently, the charge on the capacitor 16 is suddenly discharged through the primary winding 18 and the thyristor 25 as a discharge current of considerable magnitude and a very high voltage *e.g.*, 10,000 v. is induced across the secondary winding which is applied across the contacts of spark plug 24 to ignite a mixture by the spark generated thereacross.

FIGS. 2a, 2b and 2c illustrate waveforms of the voltage V_c and the current I_t of capacitor 16, a waveform of the current I_t of thyristor 25, and a waveform of the output current I_o of the rectifying bridge circuit 11, respectively. When the charge on the capacitor 16 is discharged through the primary winding 18, the resultant current I_e and voltage V_e oscillate as shown in FIG. 2a because the capacitor and the primary winding form a C—L series resonant circuit. Since thyristor 25 shunts the output terminals 14 and 15 of the bridge circuit 11 when made conductive, superimposed currents of the resonant current I_e or I_c and the shunt current I_s flow through the thyristor. Since thyristor 25 is able to be conductive only in its forward direction, it turns off after the instant T_1 when the current I_t is about to change its polarity. Subsequent resonant current I_e will flow through diodes 7, 8, 9 and 10 of rectifying bridge circuit 11. The shunting of the output terminals 14 and 15 of the bridge circuit 11 ceases due to cut-off of thyristor 25 and thereafter the output of the bridge circuit again charges capacitor 16, as shown in I_o in FIG. 2c. Resonant current I_e after a cycle *i.e.* T_1 is prevented by thyristor 25 which has been cut-off and voltage of capacitor 16 is charged again to substantially the same level as the former magnitude.

By repetition of the foregoing operations, the mixture in the cylinders of the internal combustion engine is ignited intermittently. These conventional systems cannot have been utilized for engines of very high speed operation, however, due to the following disadvantages.

First, in order to secure a constant output from the ignition system even at a very high speed of operation, a convertor 1 of large capacity is required since the capacitor 16 has to be completely charged in a very short time. Increase in the capacity of the convertor 1 results in increase in shunt current I_s at the time thyristor 25 is turned on. Thus, a thyristor 25 of an increased capacity is required, resulting in increase in power loss and cost.

Second, according to these conventional systems, the ignition frequency is limited by the cut-off time of a thyristor and cannot be increased practically beyond a given limit. With this configuration of the circuit, thyristor 25 is cut-off by cancelling the shunt current I_s with the resonant current I_e and by reversely biasing the thyristor for a given time. This reverse biasing time required is called the cut-off time of a thyristor and is usually in a range from several tens of microseconds to several hundred microseconds. If it is assumed that the reverse biasing time is 100 microseconds, the frequency of the resonant current I_e should be much less than 5 kilocycles. Practically, the reverse biasing time is a time during which the resonant current I_e exceeds the shunt current I_s , and depends upon the magnitude of the shunt current I_s . For the foregoing reasons, faults in effecting cut-off of the thyristor have been frequently experienced when the ignition frequency exceeds 3 kc.

Furthermore, when the capacity of the convertor 1 is increased to shorten the charging time of the capacitor 16, the shunt current I_s will be increased. Consequently, cut-off of the thyristor 25 will become more difficult. Incidentally, increase in the shunt current I_s causes rapid increase of power loss in the rectifying bridge circuit 11 and the convertor 1 as well as in the thyristor 25 so that these semiconductor elements are apt to be damaged due to the generated heat.

The present invention provides a semiconductor ignition system in which these disadvantages of conventional systems are effectively eliminated and which is capable of very high frequency ignition without any ignition fault. According to the present invention, a four-branch bridge circuit having a pair of thyristors and a pair of capacitors is provided between a convertor and the primary winding of an ignition coil, in which one of the branches includes either one of the thyristors or one of the capacitors and the pair of the semiconductor controlled rectifiers are made conductive alternately in such a manner that one of the thyristors under conduction may pass therethrough and through the primary winding not only the charge current of one of the capacitors but also the discharge current from the other capacitor.

The present invention will be described with reference to an embodiment shown in FIG. 3 in which convertor 1 for boosting a d.c. voltage and a single phase full wave rectifying bridge 11 are of the same construction as provided in the conventional systems. In the present invention, the primary winding 18 of an ignition coil 17 is connected to the output terminals 14 and 15 of the rectifying bridge circuit through a pair of capacitors 35 and 36. A thyristor 37 is provided, the anode of which is connected to the positive terminal 15 of the rectifying bridge 11, the cathode of which is connected to ground side of the capacitor 35, and the gate electrode of which is connected to the cathode thereof through one of the secondary windings 42 of a pulse transformer 41. Another thyristor 43 is provided, the anode of which is connected with the ignition-coil-side of the capacitor 36, the cathode of which is connected with the negative terminal 14 of the rectifying bridge 11, and the gate electrode of which is connected to the cathode thereof through the other secondary winding 47 of the pulse transformer 41 (FIG. 4). As will be easily understood from the drawing, the pair of thyristors 37 and 43 and the pair of the capacitor 35 and 36 form a four branch bridge circuit in which the pair of thyristors 37 and 43 are provided in one of the opposing branches and the pair of capacitors 35 and 36 are provided in the other of the opposing branches, respectively, and the output of the rectifying bridge is applied between one pair of opposing connections between the branches and the primary winding 18 is connected between the other pair of opposing connections.

Next, a control signal generating device suitable for a semiconductor ignition system of the present invention will be explained with reference to FIG. 4, which device is comprised of a conventional bistable multivibrator 50 formed of transistors 48 and 49. A d.c. source 4 is applied in parallel across the collector to emitter circuits of transistors 48 and 49 through resistors 51 and 54, respectively, and each collector is also connected mutually to the base of the other transistor through respective coupling resistors 52 and 55. The emitter of transistor 48 is directly grounded and the emitter of transistor 49 is connected to the base of an output transistor 53 which amplifies a signal from transistor 49 and supplies an output current to the primary winding 56 of the pulse transformer 41 which is inserted in the collector path of transistor 53. An ignition or timing signal generating device 57 comprises a magnet rotor 58 having projecting portions 59 rotated in synchronization with a crank shaft of the internal combustion engine and a permanent magnet 60 positioned close to the projecting portions 59. In accordance with the ignition timing, the projecting portions 59 pulsate flux distribution in the gap of the permanent magnet 60 and thereby induce a pulse across the generating winding 61, one end 62 of which is grounded and the other end 63 is connected in parallel with

the bases of transistors 48 and 49 through diodes 64 and 65, respectively.

In operation, when an ignition time is reached by rotation of the crank shaft of the engine, a pulse voltage is generated in generating winding 61 and is supplied to the bases of transistors 48 and 49 of multivibrator circuit 50 through diodes 64 and 65. In multivibrator circuit 50, either one of transistors 48 and 49 is stably conductive and the other is kept non-conductive. Supposing that transistor 48 is on and transistor 49 is off, the multivibrator circuit changes to the other stable condition in response to a positive pulse to the bases with the result that transistor 48 is switched off and transistor 49 is switched on. Consequently, transistor 53 is made conductive and a pulse current flows through the primary winding of pulse transformer 41.

Accordingly, a pulse generated across the secondary winding 47 flows forwardly through the gate 46 to the cathode 45 and turns on thyristor 43 while a pulse across the secondary winding 42 only reversely biases the gate 40 to the cathode 39 of thyristor 37. By actuation of thyristor 43, the discharge capacitor 36 is charged by the output of rectifying bridge circuit 11 through thyristor 43. Briefly speaking, thyristor 43 is cut-off when charging current gradually decreases below its holding current with the completion of charging of capacitor 36.

When the next pulse is supplied to the multivibrator circuit 50 by ignition signal generating device 57, the circuit 50 changes again to the other stable condition and transistor 53 is turned off, thus current through the primary winding 56 of transformer 41 is eliminated. At this instant, a pulse of the opposite polarity is generated in the secondary winding 42 and causes a forward gate current to flow through the gate 40 to the cathode and to turn on thyristor 37.

Accordingly, the electric charge stored in the capacitor 36 is discharged suddenly through the primary winding 18 of ignition coil 17 and thyristor 37 as a steep rise current. A pulse having a steep wavefront is induced across the secondary winding 21 and generates a discharge spark. At the same time, since the discharge capacitor 35 is operably connected between the output terminals 14 and 15 of rectifying bridge circuit 11 through conducting thyristor 37, the capacitor 35 begins to be charged with its grounded electrode being positive.

With advance of the discharge of capacitor 36, capacitor 36 is gradually charged with reverse polarity due to the series resonance of the primary winding 18 with the capacitor 36 and current flow through the primary winding 18 gradually decreases. When this current becomes zero, the charge on the capacitor 36 stored in the reversed direction begins to discharge through the primary winding 18. This discharge current flow is opposite to the forward direction of thyristor 37 and passes through the capacitor 35 and the rectifying bridge circuit 11. Thus, the capacitor 35 is charged not only from the output of rectifying bridge circuit 11 through thyristor 37 but also by the residual charge of the capacitor 36 so that it is charged up to a higher voltage than that of rectifying bridge circuit 11. In the experiments conducted by the applicant, the resultant voltage of the capacitor 35 is about 1.3-1.7 times the output voltage of the rectifying bridge circuit. Not only is the charge on the capacitor 35 prevented from discharging by means of diodes 7, 8, 9 and 10 but also it acts to secure the cut-off of thyristor 37, serving as a reverse biasing voltage.

Subsequently, when an ignition signal pulse is again supplied to multivibrator circuit 50 by the ignition signal generating device, a gate current is provided to thyristor 43 to turn it on. Consequently, the charge on capacitor 35 is suddenly discharged through the primary winding 18 as a discharge flow having a steep wavefront and an induced high pulse voltage in the secondary winding 18 causes a spark discharge at spark plug 24. At the same time, thyristor 43 charges capacitor 36 with the output current of the rectifying bridge circuit 11. With advance of discharge of the capacitor 35, it begins to charge in the reverse direction by series resonance of the capacitor 35 and the primary winding 18 of ignition coil 17 and discharge

current through the primary winding gradually decreases. When the discharge current becomes zero, the charge on the capacitor 35 stored in the reverse polarity begins to discharge through the primary winding 18 and the other capacitor 36 and to charge the capacitor 36 up to a higher value than the output voltage of the rectifying bridge circuit. At the time, the thyristor 37 is reversely biased to a great extent by the voltage of the capacitor 36 and is completely cut-off.

Of course, induced pulses in the secondary winding 21 may be distributed to a plurality of spark plugs by means of a conventional distributor. Since an ignition system according to the present invention can provide very high frequency ignition pulses of more than 5 kc., a single system can easily ignite the mixture in a multiplicity of engine cylinders which are subjected to a high speed cycle.

Current and voltage waveforms of the thyristors and the capacitors are illustrated in FIGS. 5a, 5b, and 5c. FIG. 5a shows current and voltage waveforms of one of the capacitors in which I_{d1} and V_{d1} are current and voltage values for the discharging period and I_{c1} and V_{c1} are those values for the charging period. FIG. 5b shows current waveforms of the thyristors in which I_{T1} is current for one of the thyristors and I_{T2} is current for the other thyristor and both of them are a sum of discharge current I_{d1} and charge current I_{c2} of the capacitor. As will be clear from the drawings, the voltage V_c of the capacitor being charged is increased from the voltage V_o of the rectifying bridge circuit 11 to a voltage V_c by the discharge current I_{d1} in the reversed direction after the time T_1 when the discharge currents I_{d1} and I_{d1} change their direction and the thyristor under conduction begins to be cut-off. Similarly, the current of the capacitor being charged is a sum of charge current of the usual exponential waveform and discharge current of the other capacitor in the reverse direction. It will be easily noted that the current of the capacitor being charged corresponds to that of the output current of the rectifying bridge circuit and the maximum value of the charging current I_{c1} substantially corresponds to the shunt current I_s if the output terminal of the rectifying bridge circuit 11 were short-circuited by one of the thyristors like in the conventional systems. By the experiments, it was further confirmed that waveforms of discharging voltage V_d of the capacitor after T_1 could be easily changed to V_{d1}' by adjustment of internal impedance of the convertor 1 measured from the output terminals of the rectifying bridge circuit.

From the foregoing description, it will be appreciated that the charge voltage of the capacitor can be increased beyond the output voltage of the source, i.e., the rectifying bridge circuit and charging of one of the capacitors can be speedily effected by the source simultaneously with discharging of the other capacitor through the primary winding of the ignition coil and further that resultant voltage of one of the charged capacitors provides a sufficient reverse biasing voltage for the thyristor which is conductive to be cut-off completely. Therefore, it will be appreciated that according to the present invention, very high speed operation of the ignition system can be attained. According to an experiment where a discharge condenser of 1 μ f. and an ignition coil having a primary winding of 6 mh. are employed, an ignition spark of a frequency of 5,000 discharges per second could be obtained without any drop in strength thereof.

Moreover, since according to this configuration of the system, current flow through the thyristors does not include shunt current of the source but only effective current charging and discharging of the capacitor, power loss in the ignition system can be minimized.

FIG. 6 shows a d.c.—a.c. convertor for boosting voltage in which a pair of transistors 88 and 90 is connected in parallel with respective halves of the primary winding 94 of a transformer 92 having a saturable reactor core. Between the center of primary winding 94 and the common emitters of the transistors is connected a d.c. source 4 to be boosted. Across the primary winding 94 of transformer 92 is connected the primary winding 102 of another transformer 100, the ends of the

secondary winding 104 of which are connected through diodes 106 and 110 with the bases of transistor 88 and 90, respectively. Shunt diodes 108 and 112 are connected from bases to collectors of transistor 88 and 90, respectively.

In operation, when transistor 90 is conductive, transistor 88 is reversely biased by means of the secondary winding 104. Upon saturation of the core of transformer 92, a voltage of reverse polarity is generated across the primary winding 94 to cut-off transistor 90 and to turn on transistor 88. By repetition of the alternating turn-on and cut-off of the transistors, an a.c. output voltage of rectangular waveform is generated, the width of which is proportional to the saturation level of the core. In the device, however, a reverse current from the emitter to the collector of the transistor flows during the beginning portion of the cut-off period. This reverse current is considered to be caused due to the fact that a reverse control current flows from the base to the collector, resulting in a current flow from the emitter to collector, because of a large magnitude of reverse bias voltage from the primary winding 94. In order to prevent these reverse currents which increase heat losses in the transistor, a shunt diode and a blocking diode are provided for the base of each transistor.

From the foregoing, it will be appreciated that according to the present invention, high speed ignition performance and efficiency have been greatly improved and any fault in the cut-off of the thyristors has been completely prevented.

Although the present invention has been described with reference to certain embodiments thereof, it will now be understood that further modifications may now suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

I claim:

1. An ignition system for an internal combustion engine comprising a d.c. source; an ignition coil having a primary winding and a secondary winding; and a four-branch electrical bridge circuit having a pair of semiconductor controlled rectifiers and a pair of capacitors each included in a respective one of the four branches thereof, one pair of opposing connections of the branches being operably connected to the d.c. source and the other pair of opposing connections being connected across said primary winding; and control means for rendering the pair of the semiconductor controlled rectifiers conductive alternately, said controlled rectifiers being poled so that each semiconductor controlled rectifier when conductive passes therethrough not only the charging current of one of the capacitors but also the discharging current through the primary winding of the ignition coil from the other capacitor.

2. An ignition system of an internal combustion engine according to claim 1, in which the pair of the semiconductor controlled rectifiers and the pair of the capacitors in the four-branch electrical bridge circuit are operably connected with one pair of opposing branches including the respective semiconductor controlled rectifiers and the other pair of opposing branches including the respective capacitors so as to supply charging current to the one of the capacitors and discharge current from the other capacitor to the primary winding through the one of the semiconductor controlled rectifiers which is capable of conduction.

3. An ignition system of an internal combustion engine according to claim 2, in which the secondary winding of the ignition coil are operably connected to a plurality of ignition devices through distributing means.

4. An ignition system of an internal combustion engine according to claim 1, in which one of the capacitors is connected between one end of the primary winding and the positive terminal of the d.c. source, the other capacitor is connected between the other end of the primary winding and the negative terminal of the d.c. source, one of the semiconductor controlled rectifiers is connected between the one end of the primary winding and the negative terminal of the d.c. source in the forward direction, and the other semiconductor controlled rectifiers is connected between the positive terminal of the d.c. source and the other end of the primary winding in the forward direction.

5. An ignition system according to claim 2, in which the d.c. source comprises a low voltage d.c. source, a d.c.—a.c. converter for changing the low voltage d.c. to high voltage a.c., and a full wave rectifying means for rectifying the high voltage a.c. to high voltage d.c.

6. An ignition system according to claim 4, in which the secondary winding of the ignition coil is operably connected to a plurality of ignition devices through distributing means.

7. An ignition system according to claim 1, in which said control means comprises ignition signal generating means for providing alternately a gate signal to one of the semiconductor controlled rectifiers in response to rotation of the engine.

8. An ignition system according to claim 2, in which said

control means comprises ignition signal generating means for providing alternately a gate signal to one of the semiconductor controlled rectifiers in response to rotation of the engine.

9. An ignition system according to claim 2, in which the secondary winding of the ignition coil is operably connected to a plurality of ignition coils through distributing means.

10. An ignition system according to claim 6, in which the d.c. source comprises a low voltage d.c. source, a d.c.—a.c. converter for changing the low voltage d.c. to high voltage a.c., and a full wave rectifying means for rectifying the high voltage a.c. to high voltage d.c.

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