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Preiser et al.

[11] **3,892,219**

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[54] **INTERNAL COMBUSTION ENGINE IGNITION SYSTEM**

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[73] Assignee: **General Motors Corporation**, Detroit, Mich.

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[52] **U.S. Cl.** ..... **123/148 E**; 315/209

[51] **Int. Cl.** **F02p 1/00**

[58] **Field of Search** ..... 123/148 E; 315/209

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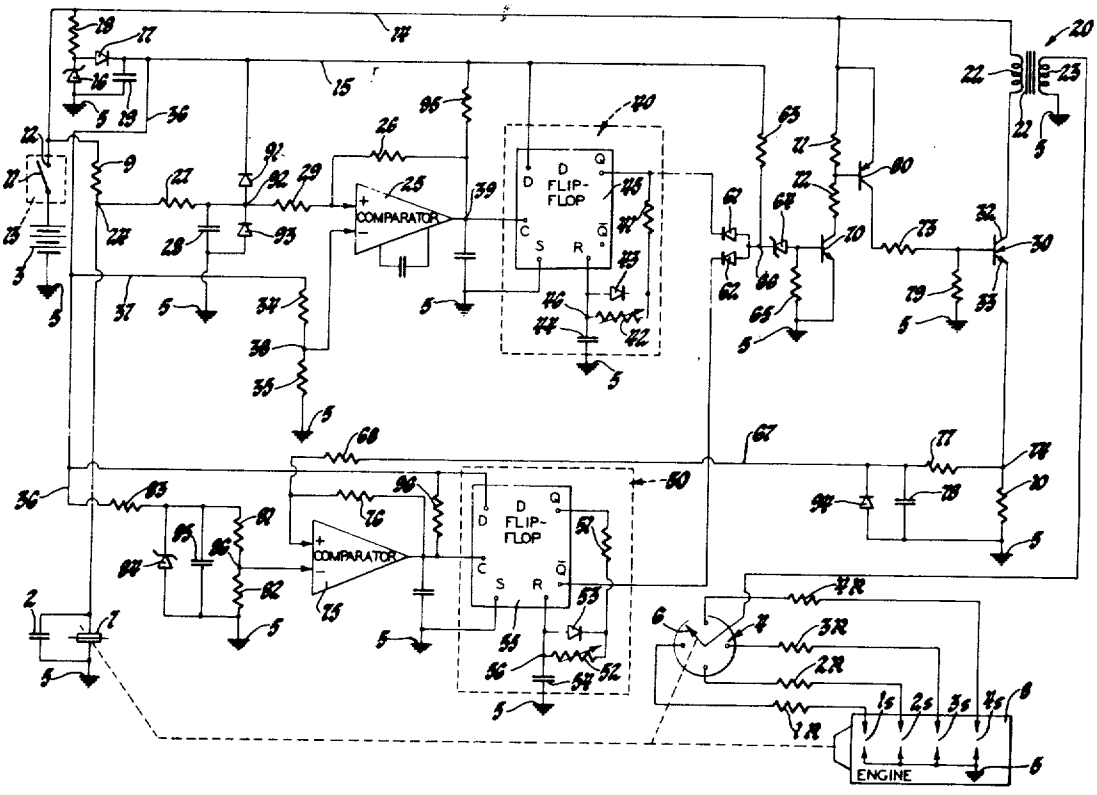
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[57] **ABSTRACT**

An internal combustion engine ignition system which produces an ignition spark of a preselected duration for each cylinder of the engine. An arc-duration monostable multivibrator circuit produces an output timing signal of the preselected duration which operates a switching transistor conductive to complete the ignition coil primary winding energizing circuit. Each time the ignition coil primary winding energizing current reaches a predetermined magnitude, a control monostable multivibrator circuit produces a control signal which operates the switching transistor not conductive to interrupt the ignition coil primary winding energizing circuit. The ignition coil has a primary to secondary windings turns ratio such that, during the buildup of energizing current through the primary winding, a potential of sufficient magnitude to maintain the arc initiated across each spark plug gap is induced in the secondary winding and the primary winding is designed to have an inductance value which, with a predetermined magnitude of energizing current, will provide sufficient stored energy to maintain the arc initiated across each spark plug gap for a duration of time at least as long as the period between successive energizations thereof.

2 Claims, 5 Drawing Figures



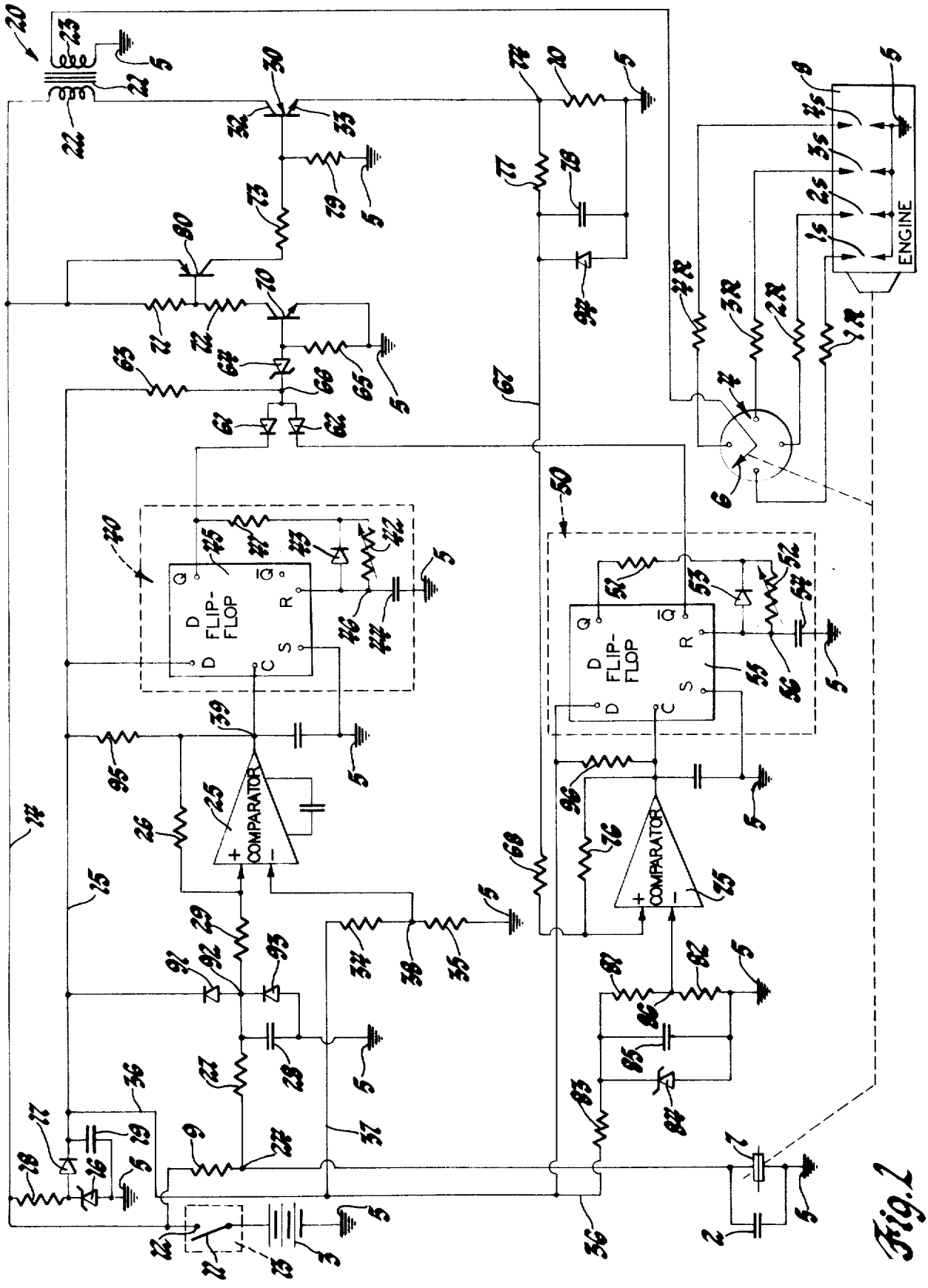


Fig. 1

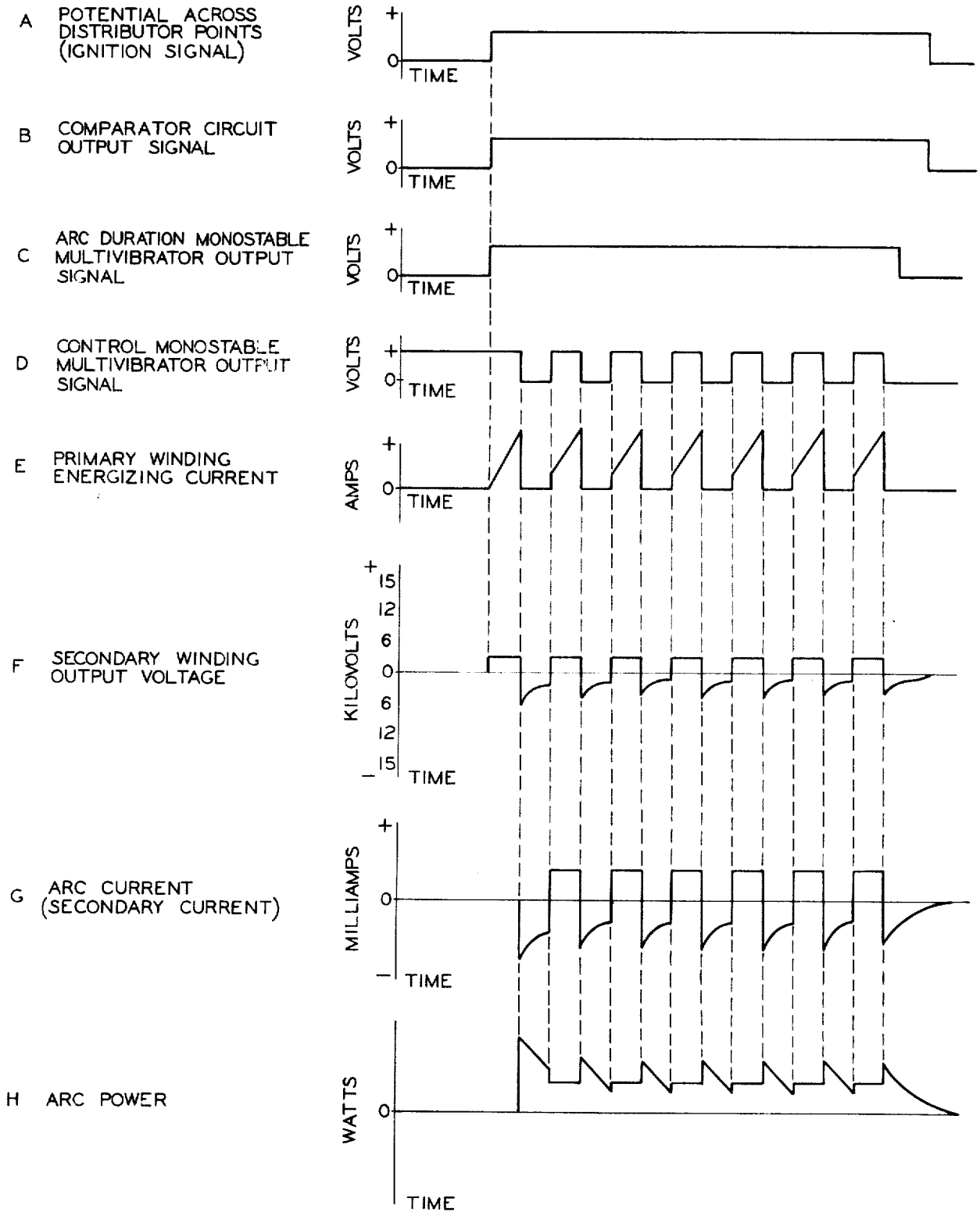

A POTENTIAL ACROSS DISTRIBUTOR POINTS (IGNITION SIGNAL)
VOLTS
+
0
TIME
B COMPARATOR CIRCUIT OUTPUT SIGNAL
VOLTS
+
0
TIME
C ARC DURATION MONOSTABLE MULTIVIBRATOR OUTPUT SIGNAL
VOLTS
+
0
TIME
D CONTROL MONOSTABLE MULTIVIBRATOR OUTPUT SIGNAL
VOLTS
+
0
TIME
E PRIMARY WINDING ENERGIZING CURRENT
AMPS
+
0
TIME
F SECONDARY WINDING OUTPUT VOLTAGE
KILOVOLTS
+
15
12
6
0
6
12
15
TIME
G ARC CURRENT (SECONDARY CURRENT)
MILLIAMPS
+
0
TIME
H ARC POWER
WATTS
0
TIME

Fig. 2

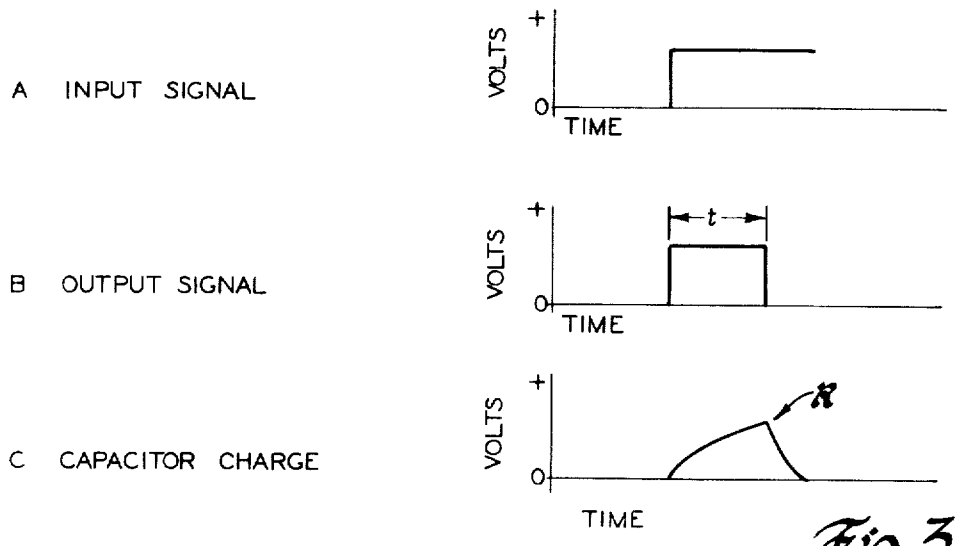


Fig. 3

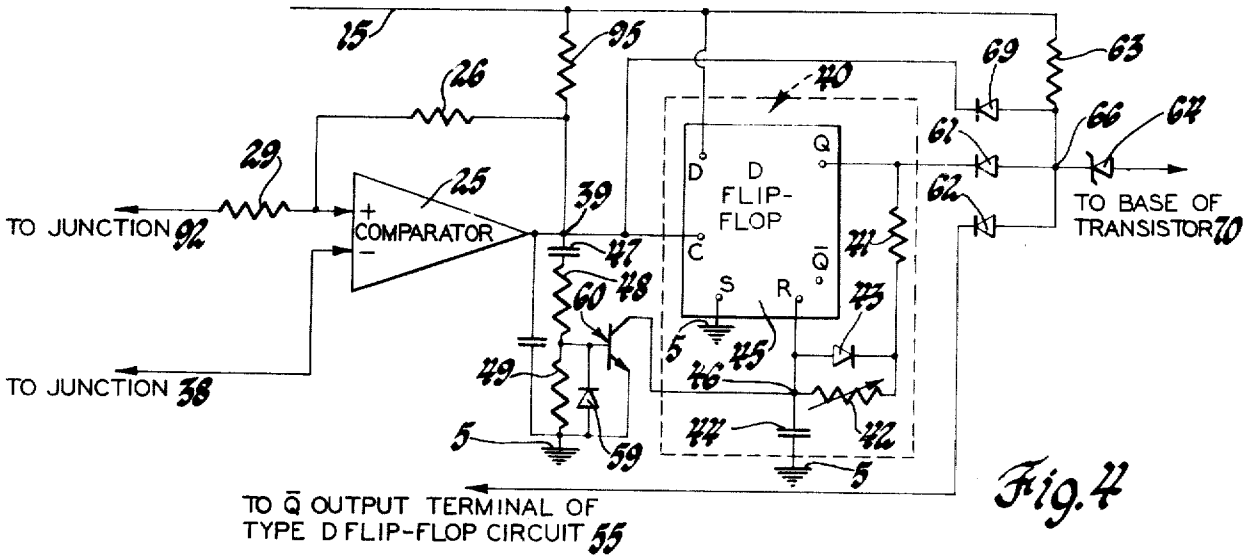


Fig. 4

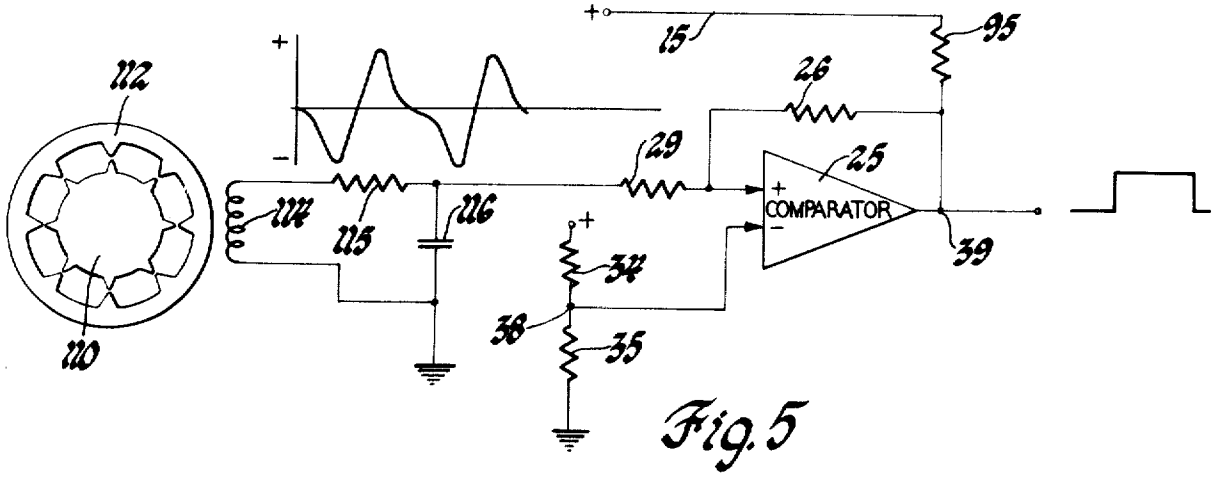


Fig. 5

INTERNAL COMBUSTION ENGINE IGNITION SYSTEM

This invention relates to an internal combustion engine ignition system and, more specifically, to an internal combustion engine ignition system which produces an ignition spark of a predetermined duration for each engine cylinder.

As is well known in the automotive art, the combustible fuel-air mixture in each of the cylinders of the engine during each compression stroke is ignited by an electrical spark produced by the associated ingition system. The ignition spark, therefore, must be of sufficient intensity to initiate combustion and should have sufficient power to maintain combustion during the power stroke. Therefore, an ignition system for internal combustion engines which provides an ignition spark of a sufficient magnitude to initiate combustion and of a duration long enough to maintain combustion during the power stroke, is desirable.

It is therefore, an object of this invention to provide an improved internal combustion engine ignition system.

It is an additional object of this invention to provide an improved internal combustion engine ignition system which produces an ignition spark and maintains the spark for a predetermined period of time.

In accordance with this invention, an internal combustion engine ignition system is provided wherein an "arc-duration" monostable multivibrator circuit produces a timing signal of a predetermined duration which operates an electrical switching device to the electrical circuit closed condition to establish the ignition coil primary winding energizing circuit and another control monostable multivibrator circuit produces a control signal each time the ignition coil energizing current reaches a predetermined maximum to operate the electrical switching device to the electrical circuit open condition.

For a better understanding of the present invention, together with additional objects, advantages, and features thereof, reference is made to the following description and accompanying drawing in which:

FIG. 1 sets forth the internal combustion engine ignition system of this invention is schematic form;

FIG. 2 is a set of curves useful in understanding the operation of the circuitry of FIG. 1;

FIG. 3 is a set of curves useful in understanding a portion of the circuit of FIG. 1;

FIG. 4 sets forth an alternate embodiment of a portion of the ignition system of FIG. 1 in schematic form; and

FIG. 5 is an alternate embodiment of a portion of the circuit of this invention in schematic form.

As a point of reference or ground potential is the same point electrically throughout the system it has been represented in FIG. 1 by the accepted schematic symbol and referenced by the numeral **5.**

In FIG. 1 of the drawing, the internal combustion engine ignition system of this invention is set forth in schematic form in combination with a source of direct current potential, which may be a conventional storage battery **3**, and an ignition distributor **4** having a movable electrical contact **6**, rotated in timed relationship with an associated engine, through which ignition spark potential is applied to the spark plugs of the engine individually, in a manner well known in the automotive art.

The internal combustion engine with which the ignition system of this invention may be used is set forth in block form, is referenced by the numeral **8** and is illustrated as having four spark plugs **1S**, **2S**, **3S**, and **4S**, each having an arc gap, as is well known in the automotive art. It is to be specifically understood, however, that the ignition system of this invention may be used with internal combustion engines having more or less cylinders or also with rotary type engines.

Mounted within ignition distributor **4** is a pair of ignition distributor breaker contacts **7** which are operated to the electrical circuit open and closed conditions in timed relationship with engine **8** in a manner well known in the automotive art. A resistor **9** is connected in series with battery **3** and the ignition distributor breaker contacts **7** to provide a load for battery **3** when the breaker contacts **7** are closed. Capacitor **2** is the ignition capacitor connected across the breaker contacts **7.**

To supply operating potential to the system, movable contact **11** of an electrical switch **13** may be closed to stationary contact **12** to supply battery potential across lead **14** and point of reference or ground potential **5.** Movable contact **11** and stationary contact **12** may be a pair of normally open ignition contacts included in a conventional automotive ignition switch of the type well known in the automotive art. For purposes of this specification, it will be assumed that movable contact **11** is closed to stationary contact **12.**

To supply a substantially constant direct current potential free of ripples and noise across lead **15** and point of reference or ground potential **5,** battery potential may be regulated to a selected maximum value by Zener diode **16,** which clips off positive polarity spikes greater than fifteen volts. Any negative polarity spikes are clipped by resistor **18** and Zener diode **16.** Diode **17** prevents filter capacitor **19** from discharging through the battery with any momentary drop of battery potential.

The ignition coil **20** has a magnetic core **21,** a primary windng **22** which, during the buildup of the flow of an energizing current therethrough, produces a magnetic flux in core **21** and a secondary winding **23,** connected to the movable electrical contact **6** of ignition distributor **4.** With none of the engine spark plugs fired, an ignition spark potential of sufficient magnitude to initiate an arc across the arc gap of each of the spark plugs **1S, 2S, 3S** and **4S** is induced by induction coil action in secondary winding **23** upon the interruption of the flow of energizing current through primary winding **22,** in a manner well known in the automotive art. Primary winding **22** is designed to have an inductance value which, with a predetermined magnitude of energizing current, will provide sufficient stored energy to charge the total output capacitance to the desired peak output potential and to maintain the arc initiated across each spark plug arc gap for a duration of time at least as long as the period between successive energizations thereof in a manner to be explained later in this specification. Ignition coil **20** is additionally designed to have a primary to secondary windings turns ratio such that, during the buildup of energizing current through primary winding **22,** a potential of sufficient magnitude to maintain the arc initiated across each spark plug arc gap is induced by transformer action in secondary winding **23.** If desirable, ignition coil **20** may have an open magnetic core. That is, magnetic core **21** may

have an air gap of the order of 0.015 inch, as is well known in the automotive art.

An electrical switching device having current carrying members and being of the type which may be operated to the electrical circuit open and closed conditions in response to electrical signals is provided for establishing a circuit for the flow of energizing current from the source of direct current potential, battery **3**, through the primary winding **22** of ignition coil **20**. This switching device may be a type NPN transistor **30**, however, any other electrical switching device having similar electrical characteristics may be substituted therefor without departing form the spirit of the invention. The ignition coil primary winding **22** and the current carrying members of the electrical switching device, collector electrode **32** and emitter electrode **33** of switching transistor **30**, are connected in series across the source of direct current potential through a circuit which may be traced from the positive polarity terminal of battery **3**, through switch **13**, lead **14**, primary winding **22**, the collectoremitter electrodes of switching transistor **30**, control impedance element **10**, and point of reference or ground potential **5** to the negative polarity terminal of battery **3**. This circuit is the ignition coil primary winding energizing circiut through which energizing current flows from the source of direct current potential through the ignition coil primary winding. Control impedance element **10** is illustrated in the drawing as a resistor. It is to be specifically understood, however, that any other suitable electrical impedance element which will provide a potential drop thereacross with current flow therethrough may be substituted therefor without departing from the spirit of the invention.

While engine **8** is in the running mode, the ignition distributor breaker contacts **7** are operated to the electrical circuit open and closed conditions in timed relationship with the engine in a manner well known in the automotive art. While ignition distributor breaker contacts **7** are operated to the electrical circuit open condition, a potential ignition signal appears across junction **24** and point of reference or ground potential **5** of a positive polarity upon junction **24** with respect to point of reference or ground potential **5**, curve A of FIG. **2**, and while ignition distributor breaker contacts **7** are operated to the electrical circuit closed condition, junction **24** is at substantially ground potential. The ignition signal appearing upon junction **24** may be filtered by the resistor **27** and capacitor **28** filter circuit combination and is applied through input resistor **29** to the positive polarity input terminal of a comparator circuit **25**. The comparator circuit is a commercially available logic circuit element well known in the art having a positive polarity input terminal and a negative polarity input terminal. Without intention or inference of a limitation thereto, in a practical application of the ignition system of this invention, a type MC-3302P comparator circuit marketed by Motorola, Inc. was employed. Comparator circuit **25** produces a substantially ground output signal when an input signal applied to the positive polarity input terminal thereof is of a magnitude less positive than a signal applied to the negative polarity input terminal and an output signal of a positive polarity with respect to point of reference or ground potential **5** when an input signal applied to the positive polarity input terminal is of a magnitude more positive than a signal applied to the negative polarity input terminal. To provide the comparison signal applied to the negative polarity input terminal of comparator circuit **25**, resistors **34** and **35** are connected across the regulated and filtered supply potential appearing across lead **15** and point of reference or ground potential **5** through leads **36** and **37**. Resistors **34** and **35** are so porportioned that the potential upon junction **38**, to which the negative polarity input terminal of comparator circuit **25** is connected, is of a magnitude less than the potential across junction **24** and point of reference or ground potential **5** while the ignition distributor breaker contacts **7** are operated to the electrical circuit open condition. Consequently, while ignition distributor breaker contacts **7** are operated to the electrical circuit closed condition, comparator circuit **25** produces a substantially ground output signal and while ignition distributor breaker contacts **7** are operated to the electrical circuit open condition, comparator circuit **25** produces an output signal of a positive polarity with respect to point of reference or ground potential **5**. Feedback resistor **26** serves to produce a sharp switching action, consequently, the output signal of comparator circuit **25** is of a square waveform pulse having substantially vertical leading and trailing edges corresponding to the time that ignition distributor breaker contracts **7** are operated to the electrical circuit open and closed conditions, respectively, curve B of FIG. **2**. Comparator circuit **25**, therefore, operates as a signal shaper circuit which shapes the potential signal appearing across junction **24** and point of reference or ground potential **5** while the ignition distirbutor breaker contacts **7** are operated to the electrical circuit open condition to a substantially square waveform signal upon output terminal **39** thereof of a positive polarity upon output terminal **39** with respect to point of reference or ground potential **5** and of a duration of time equal to the time the ignition distributor breaker contacts **7** are open.

Breifly, over the duration of each timing signal produced by arc-duration monostable multivibrator circuit **40**, curve C of FIG. **2**, ignition coil primary winding switching transistor **30** is operated conductive through the collector-emitter electrodes thereof to complete an energizing circuit for primary winding **22** between each output control signal produced by a control monostable multivibrator circuit **50**, curve D of FIG. **2**, and is operated not conductive through the collector-emitter electrodes in response to each output control signal produced by control monostable multivibrator circuit **50**, curve D of FIG. **2**, when the energizing current through ignition coil primary winding **22** has reached a predetermined magnitude, in a manner to be later explained.

As is well known in the art, the monostable multivibrator circuit normally operates in a stable state and may be switched to an alternate state by an electrical signal, in which it remains for a period of time as determined by an internal R-C timing network. After timing out, the device spontaneously returns to the stable state. The arc-duration monostable multivibrator circut **40** and the control monostable multivibrator circuit **50** each includes a type D flip-flop circuit, referenced by the numerals **45** and **55**, respectively. The type D flip-flop circiut is a commercially available logic circuit element well known in the art which in the "Set" condition produces a logic 1 signal upon the Q output terminal and a logic 0 signal upon the $\bar{Q}$ output terminal in

the "Reset" condition produces a logic 0 signal upon the Q output terminal and a logic 1 signal upon the $\overline{Q}$ output terminal and transfers the logic signal present upon the D input terminal to the Q output terminal upon the application of a logic 1 signal to the C clock input terminal. A type D flip-flop circuit suitable for use with this application is marketed by RCA under the designation "Type CD4013". For purposes of this specification, a logic 1 signal is a potential signal of a positive polarity, a logic 0 signal is of ground potential and, when monostable multivibrator circuits **40** and **50** are operating in the stable state, respective type D flip-flop circuits **45** and **55** are in the "Reset" condition with a logic 0 signal upon the Q output terminal and a logic 1 signal upon the $\overline{Q}$ output terminal. As the output signal of the arc-duration monostable multivibrator circuit **40** appears upon the Q output terminal of type D flip-flop circuit **45** and the output signal of the control monostable multivibrator circuit **50** appears upon the $\overline{Q}$ output terminal of type D flip-flop circuit **55**, when in the stable state, the output signal of arc-duration multivibrator circuit **40** is a logic 0 and the output signal of control monostable multivibrator circuit **50** is a logic 1 and, when in the alternate state, the output signal of arc-duration monostable multivibrator circuit **40** is a logic 1 and the output signal of control monostable multivibrator circuit **50** is a logic 0 .

As the D input terminal of both type D flip-flop circuits **45** and **55** is connected to the regulated and filtered potential appearing across lead **15** and point of reference or ground potential **5**, a logic 1 signal is maintained upon these D input terminals. Consequently, the application of a logic 1 clock signal to the C clock input terminal of each will transfer the logic 1 signal present upon the D input terminal to the Q output terminal to place the flip-flop in the "Set" condition and, consequently, the corresponding monostable multivibrator circuit in the alternate state.

Upon the initial operation of ignition distributor breaker contacts **7** to the electrical circuit open condition, the potential signal appearing across junction **24** and point of reference or ground potential **5** is filtered by the resistor **27** and capacitor **28** filter circuit combination, shaped to a substantially square waveform signal by comparator circuit **25** and applied as a logic 1 clock input signal, curve A of FIG. **3**, to the C clock input terminal of type D flip-flop circuit **45** of arc-duration monostable multivibrator circuit **40**. Upon the rise of this signal, the logic 1 signal present upon the D input terminal is transferred to the Q output terminal, curve B of FIG. **3**, to place type D flip-flop circuit **45** in the "Set" condition and, consequently, arc duration monostable multivibrator circuit **40** in the alternate state with a logic 1 signal upon the output terminal. This logic 1 output signal charges capacitor **44** through resistor **41** and resistor **42**. Resistor **42** is illustrated as a variable resistor but may be a fixed resistor if desired. As capacitor **44** charges, the potential upon junction **46** to which the R reset input terminal of type D flip-flop circuit **45** is connected, increases in a positive direction, curve C of FIG. **3**, until it reaches a value of sufficient magnitude, point R of FIG. **3**, to reset type D flip-flop circuit **45** which places arc-duration monostable multivibrator circuit **40** in the stable state with a logic 0 signal present upon the output terminal. At this time, capacitor **44** discharges, curve C of FIG. **3**, through diode **43**, resistor **41** and the output transistor for the Q output terminal of type D flip-flop circuit **45** to point of reference or ground potential **5**. From this description, it is apparent that arc-duration monostable multivibrator circuit **40** is triggered to the alternate state with the rise of the output signal of comparator circuit **25**, remains in the alternate state for a period of time, period "*t* " of curve B of FIG. **3**, as determined by the R-C time constant of the charging circuit of capacitor **44** and spontaneously returns to the stable state when capacitor **44** has become charged to a value of sufficient magnitude to reset type D flip-flop circuit **45**. The logic 1 output signal of arc-duration monostable multivibrator circuit **40** is the timing signal, curve C of FIG. **2**, during which an arc is to be maintained across each of the spark plugs of the engine. The duration of the timing signal produced by arc-duration monostable multivibrator circuit **40** is determined by the ohmic value of series resistors **41** and **42**, consequently, the duration may be selectively varied by varying the ohmic value of variable resistor **42**. If resistor **42** is a fixed resistor, the ohmic value of resistors **41** and **42** may be proportioned to provide a timing signal of a predetermined duration. Diode **43** provides a low impedance path in shunt with variable resistor **42** to permit capacitor **44** to discharge in a length of time shorter than it took to charge. As arc-duration monostable multivibrator circuit **40** produces a logic 1 output signal each time ignition distributor breaker contacts **7** are operated to the electrical circuit open condition, this device produces a timing signal corresponding to each spark plug of the engine in timed relationship with and during each revolution of the crankshaft of the engine and of a duration corresponding to the period of time ignition spark energy is to be applied to the spark plug to which it corresponds.

The logic 1 timing signal is applied to the cathode electrode of diode 61, consequently, this device is reverse biased thereby and the logic 1 signal produced by control monostable multivibrator circuit **50**, operating in the stable state, is applied to the cathode electrode of diode **62** to reverse bias this device. With diodes **61** and **62** reverse biased, the filtered and regulated potential appearing across lead **15** and point of reference or ground potential **5** is applied across the series combination of resistor **63**, Zener diode **64** and resistor **65**. Zener diode is selected to have an inverse breakdown potential less than the potential present upon junction **66** with both diodes **61** and **62** reverse biased, consequently, Zener diode **63** breaks down and conducts in a reverse direction to complete a circuit through which base-emitter drive current is supplied to type NPN transistor **70** which may be traced from the positive polarity terminal of battery **3**, through switch **13**, resistor **18**, diode **17**, lead **15**, resistor **63**, Zener diode **64**, the base-emitter electrodes of transistor **70** and point of reference or ground potential **5** to the negative polarity terminal of battery **3**. This base drive current produces collector-emitter conduction through transistor **70** through a circuit which may be traced from the positive polarity terminal of battery **3**, through switch **13**, lead **14**, series resistors **71** and **72**, the collector-emitter electrodes of transistor **70** and point of reference or ground potential **5** to the negative polarity terminal of battery **3**. While transistor **70** is conducting through the collector-emitter electrodes, a circuit is established thereby through which emitter-base drive current is supplied to type PNP transistor **80** which may be traced

from the positive polarity terminal of battery **3**, through switch **13**, lead **14**, the emitter-base electrodes of transistor **80**, resistor **72**, the collector-emitter electrodes of transistor **70** and point of reference or ground potential **5** to the negative polarity terminal of battery **3**. This emitter-base current flow through transistor **80** produces emitter-collector current flow therethrough which establishes a circuit through which base drive current is supplied to type NPN switching transistor **30** which may be traced from the positive polarity terminal of battery **3**, through switch **13**, lead **14**, through the emitter-collector electrodes of transistor **80**, resistor **73**, the base-emitter electrodes of switching transistor **30**, impedance element **10** and point of reference or ground potential **5** to the negative polarity terminal of battery **3**. This base-emitter drive current through switching transistor **30** produces collector-emitter conduction therethrough to complete the ignition coil primary winding energizing circuit, previously described, for the flow of ignition coil primary winding energizing current from the source of direct current potential, battery **3**, through primary winding **22**, the collector-emitter electrodes of switching transistor **30** and impedance element **10**, curve E of FIG. **2**. The flow of ignition coil primary winding energizing current through impedance element **10** produces a potential drop thereacross which is of a positive polarity upon junction **74** with respect to point of reference or ground potential **5**. Impedance element **10**, therefore, is responsive to the flow of energizing current through the ignition coil primary winding energizing current for producing an electrical potential signal of a magnitude proportional to the magnitude of the flow of this energizing current. This electrical potential signal may be filtered by the resistor **77** and capacitor **78** filter circuit combination and applied to the positive polarity input terminal of comparator circuit **75** through lead **67** and current limiting resistor **68**. Comparator circuit **75** may be the same as comparator circuit **25** previously described. To provide the comparison signal applied to the negative polarity input terminal of comparator circuit **75** with which the control potential signal produced across impedance element **10** may be compared, resistors **81** and **82** are connected across the regulated and filtered supply potential appearing across lead **15** and point of reference or ground potential **5** through lead **36**. This potential is regulated to a desired constant magnitude by Zener diode **84** and may be filtered by the resistor **83** and capacitor **85** filter circuit combination. Resistors **81** and **82** are so proportioned that the potential upon junction **86**, to which the negative polarity input terminal of comparator circuit **75** is connected, is of a magnitude substantially equal to the magnitude of the control potential produced across control impedance element **10** when the ignition coil primary windng energizing current is of the predetermined magnitude. Consequently, when the electrical potential produced across control impedance element **10** is equal to the comparison potential signal appearing across junction **86** and point of reference or ground potential **5**, comparator circuit **75** produces a logic 1 output signal having a substantially vertical leading edge, as feedback resistor **76** produces a rapid switching action, which is applied to the C clock input terminal of type D flip-flop circuit **55** of control monostable multivibrator circuit **50**. Upon the rise of this logic 1 signal, the logic 1 signal present upon the D input terminal is transferred to the Q output terminal to place type D flip-flop circuit **55** in the "Set" condition and, consequently, control monostable multivibrator circuit **50** in the alternate state with a logic 0 control signal upon the output terminal, Control monostable multivibrator circuit **50**, therefore, is responsive to the electrical potential signal of a predetermined magnitude, produced by impedance element **10**, for producing an output logic 0 control signal when the ignition coil primary winding energizing current has reached a predetermined magnitude. The logic 0 control signal upon the output terminal of control monostable multivibrator circuit **50**, curve D of FIG. **2**, places a forward anode-cathode bias upon diode **62**, consequently, the potential upon junction **66** reduces to a value below the inverse breakdown potential of Zener diode **64**. As Zener diode **64** no longer conducts in a reverse direction at this time, the circuit through which base-emitter drive current is supplied to transistor **70** is interrupted, consequently, this device extinguishes. When transistor **70** extinguishes, the circuit through which emitter-base current is supplied to transistor **80** is interrupted thereby, consequently, transistor **80** also extinguishes. When transistor **80** extinguishes, the circuit through which base-emitter drive current is supplied to switching transistor **30** is interrupted thereby, consequently, switching transistor **30** extinguishes to interrupt the ignition coil primary winding energizing circuit. Resistor **79** speeds up the cut-off or turn-off time of switching transistor **30**. The resulting collapsing magnetic field induces, by induction coil action, a potential of a negative polarity in secondary winding **23** of ignition coil **20**, curve F of FIG. **2**. As secondary winding **23** is open-circuited at this time, the potential induced therein increases rapidly, curve F of FIG. **2**, to a magnitude, for example 15 kilovolts, at which an arc is initiated across the arc gap of the one of the engine spark plugs to which this potential is directed through distributor **4**. Upon the initiation of the arc across the arc gap of one of the engine spark plugs, the potential in secondary winding **23** falls rapidly to a magnitude, for example 3 kilovolts, which is sufficient to maintain the arc current, curve G of FIG. **2**, which is of a maximum magnitude at the instant of spark initiation. While control monostable multivibrator circuit **50** is in the alternate state, the logic 1 signal upon the Q output terminal of type D flip-flop circuit **55** charges capacitor **54** through resistor **51** and resistor **52**. Resistor **52** is illustrated as a variable resistor but may be a fixed resistor if desired. As capacitor **54** charges, the potential upon junction **56**, to which the R reset input terminal of type D flip-flop circuit **55** is connected, increases in a positive direction until it reaches a value of sufficient magnitude to reset type D flip-flop circuit **55** which places control monostable multivibrator circuit **50** in the stable with a logic 1 signal present upon the output terminal. At this time, capacitor **54** discharges through diode **53**, resistor **51** and the output transistor for the Q output terminal of type D flip-flop circuit **50** to point of reference or ground potential **5**. From this description, it is apparent that control monostable multivibrator circuit **50** is triggered to the alternate state when the ignition coil primary winding energizing current has reached the predetermined maximum in response to the electrical potential signal of a predetermined magnitude, remains in the alternate state for a period of time as determined by the R-C time constant of the charging circuit of capacitor **54** and spontane-

ously returns to the stable state when capacitor **54** has become charged to a value of sufficient magnitude to reset type D flip-flop circuit **55**. when monostable multivibrator **50** has spontaneously returned to the stable state, the logic 1 output signal thereof again reverse biases diode **62**. As timing signal produced by arc-duration monostable multivibrator circuit **40** is still present to maintain a reverse bias upon diode **61**, switching transitor **30** is again rendered conductive through the collector-emitter electrodes to complete the ignition coil primary winding energizing circuit in a manner previously described. The resulting flow of energizing current through ignition coil primary winding curve **22**, curve E of FIG. **2**, is initially of a magnitude determined by the arc current through the fired spark plug and increases in magnitude to the predetermined maximum to induce a potential, by transformer action, in secondary winding **23** of a sufficient magnitude to maintain the arc across the fired plug, curve F of FIG. **2**. When the ignition coil primary winding energizing curent has again reached the predetermined maximum, the control monostable multivibrator circuit **50** is again triggered to the alternate state, in a manner previously explained, to place a forward anode-cathode bias upon diode **62**, a condition which results in the interruption of the ignition coil primary winding energizing circuit in a manner previously explained. The resulting collapsing magnetic field induces a potential, by induction coil action, in secondary winding **23** which is limited to approximately 3 kilovolts, the magnitude required to maintain the arc of the fired plug, curve F of FIG. **2**. From this description, it is apparent that, during each timing signal period, curve C of FIG. **2**, switching transistor **30** is conductive through the collector-emitter electrodes thereof between each logic 0 output signal of control monostable multivibrator circuit **50**, curve D of FIG. **2**, to complete the ignition coil primary winding energizing circuit through which energizing current flows through primary winding **22**, curve E of FIG. **2**, and is not conductive through the collector-emitter electrodes thereof during each output signal of control monostable multivibrator circuit **50** to interrupt the ignition coil primary winding energizing circuit. Upon each completion of the energizing circuit for ignition coil primary winding **22**, the resulting expanding magnetic field produced by the flow of energizing current through primary winding **22** induces, by transformer action, a potential in secondary winding **23**, curve F of FIG. **2**, of a magnitude sufficient to maintain the arc across any fired plug and upon the interruption of the energizing circuit for ignition coil primary winding **22**, the resulting collapsing magnetic field induces, by induction coil action, a potential in ignition coil secondary winding **23** of a magnitude sufficient to initiate a spark across the arc gap of any plug or, in the event a plug has already been fired, of a sufficient magnitude to maintain the arc thereacross, as is shown by curve G of FIG. **2**. Should the arc extinguish at any time during any of the timing signals, therefore, upon the next interruption of the flow of energizing current through ignition coil primary winding **22**, the potential induced in secondary winding **23** by induction coil action increases rapidly to a magnitude at which the spark is again initiated across the arc gap of the plug to which the energy is directed through ignition distributor **4**. It may be noted that the reversal of polarity of the potential induced in secondary winding **23** during transformer action and induction coil action does not extinguish the arc across any plug as this reversal of polarity occurs in a length of time less than that required for the arc gap to deionize. From this description, it is apparent that switching transistor **30** is responsive to each of the timing signals for establishing and to each of the control signals for interrupting the ignition coil primary winding energizing circuit.

During the transformer action period, the potential induced in secondary winding **23** may be of a magnitude of 3 kilovolts while the potential across the arc may be only 1 kilovolt. Consequently, 2 kilovolts must be dropped across the remainder of the circuit. To drop these 2 kilovolts, a resistor is connected in series with each of the engine spark plugs and is selected to have an ohmic value which will limit the arc current to a desired value, for example 50 milliamperes These resistors are referenced in the drawing by numerals **1R**, **2R**, **3R** and **4R**, respectively.

In a practical application of the internal combustion engine ignition system of this invention, an ignition coil having a turns ratio of 250 to 1 with a primary voltage of 12 volts was employed to produce an output voltage of 3000 volts during the period of transformer action as the ignition coil primary winding energizing current builds up. This induced voltage by transformer action is of a sufficient magnitude to maintain the arc across any of the fired spark plugs. Furthermore, the primary winding was designed to have a sufficient inductance value, which, with a predetermined magnitude of energizing current, for exapmle 25 amperes, will provide sufficient stored energy to charge the total output capacitance to the desired output potential, for example 30 kilovolts, if the arc does not strike and to maintain the arc initiated across each spark plug for a duration at least as long as the period between successive energizations thereof; that is, for the period of each of the successive logic 0 output signals of control monostable multivibrator circuit **50**. With this arrangement, the arc across any of the fired spark plugs is maintained during the entire period of the timing signal, as illustrated by curve H of FIG. **2**, to provide substantial arc power.

The ignition signal, curve A of FIG. **2**, is shown to be of a longer duration than the timing signal, curve C of FIG. **2**. It is to be understood that these curves are illustrative of possible signal durations as the ignition signal may be of a shorter duration than the timing signal at higher engine speeds while the timing signal duration is constant at all engine speeds.

Diode **91** is included for the purpose of preventing the potential upon junction **92** from becoming greater than the potential across lead **15** and point of reference or ground potential **5** and diode **93** is included to prevent negative polarity spikes from occuring upon junction **92** to prevent damage to comparator circuit **25**. Diode **94** is included for the purpose of removing negative polarity spikes from lead **67** to prevent damage to comparator circuit **75**. Resistors **95** and **96** provide "pull-up" potential for respective comparator circuits **25** and **75**.

As the output signal of comparator circuit **25** has substantially vertical leading and trailing edges corresponding to the times that ignition distributor breaker contacts **7** are operated to the electrical circuit open and closed conditions, respectively, and is, consequently, of a duration equal to the time that ignition distributor breaker contacts **7** are operated to the elec-

trical circuit open condition, the logic 1 output signal of comparator circuit **25**, curve B of FIG. **2**, may be employed as the timing signal. This embodiment is schematically set forth in FIG. **4**, wherein circuit elements the same as in FIG. **1** are assigned the same characters of reference, which sets forth the portion of the circuit of FIG. **1** which is changed by this embodiment. Output terminal **39** of signal shaper circuit **25** is connected directly to the cathode electrode of diode **69** and monostable multivibrator circuit **40** is retriggerable in a manner to be later explained. The remainder of the circuit operates exactly the same way as herein previously described, so long as the timing signal output of comparator circuit **25** is present upon the cathode electrode of diode **69** and monostable multivibrator circuit **40** is in the alternate state. With this embodiment, however, the duration of the timing signal would be equal to the time that ignition distributor breaker contacts **7** are operated to the electrical circuit open condition. Consequently, the lobes of the distributor cam, not shown but well known in the automotive art, are designed to maintain ignition distributor breaker contacts **7** operated to the electrical circuit open condition for a predetermined number of degrees of engine crankshaft rotation which, at any engine speed, is the time ignition spark energy is to be supplied to the spark plugs. Therefore, as engine **8** rotates the distributor cam to operate the ignition distributor breaker contacts **7** to the electrical circuit open and closed conditions, each time breaker contacts **7** are operated to the electrical 1 open condition, a logic **1** timing signal corresponding to a spark plug of engine **8** is produced across output terminal **39** of comparator circuit **25** and point of reference or ground potential **5** in timed relationship with and during each revolution of the crankshaft of engine **8** and for a duration of time corresponding to the period of time ignition spark energy is to be applied to the spark plug to which it corresponds. For example, and without intention of interference of a limitation thereto, should it be desired that ignition spark energy be applied to each of spark plugs **1S**, **2S**, **3S** and **4S** of engine **8** for a period of **45** crankshaft degrees, each one of the four lobes of the ignition distributor cam would be designed to maintain ignition distributor breaker contacts **7** open for **45** degrees of crankshaft rotation of engine **8**. With this embodiment, therefore, the timing signal would not be of a constant duration regardless of engine speed, as with the embodiment employing an arc-duration monostable multivibrator circuit, but would be of a length of time proportional to engine speed, being longest with minimum engine speed and decreasing in duration with increasing engine speed. The R-C time constant of the charge circuit of capacitor **44**, therefore, would be designed to insure that monostable multivibrator circuit **40** remains in the alternate state for a period of time longer than the longest timing signal. To prevent monostable multivibrator circuit **40** from timing out and returing to the stable state during alternate timing signals at high engine speeds, circuitry is provided through which this circuit is retriggered by each timing signal. Each positive polarity timing signal supplies base-emitter drive current for NPN transistor **60** through capacitor **47** and resistor **48**. While base-emitter drive current is being supplied to transistor **60**, capacitor **44** discharges through the collector-emitter electrodes thereof. When capacitor **47** has become charged, base-emitter drive circuit is no longer supplied to transistor **60**, consequently, this device extinguishes and capacitor **44** begins to charge through circuitry previously described. The time constant of capacitor **47**, resistor **48** and resistor **49** is selected to be of a duration only long enough to permit capacitor **44** to discharged. Diode **59** prevents reverse potential from damaging transistor **60** when capacitor **47** discharges at the conclusion of each timing signal.

With this embodiment, monostable multivibrator circuit **40** establishes a maximum arc-duration limit in the event movable contact **11** of switch **13** is closed to stationary contact **12** while engine **8** is not in the running mode and ignition distributor breaker contacts **7** are operated to the elecrical circuit open condition. Under these conditions, without this limit circuitry, the system would continue producing a spark so long as switch **13** remains closed. As has been previously brought out, the R-C time constant of the charge circuit for capacitor **44** is designed to insure that monostable multivibrator circuit **40** remains in the alternate state for a period of time longer than the longest ignition signal. Therefore, in the absence of a series of timing signals, this device times out and returns to the stable state and the logic 0 output signal thereof provides a forward anode-cathode bias for diode **61**. While diode **61** conducts at this time, the potential upon junction **66** is of an insufficient magnitude to cause Zener diode **64** to break down and conduct in a reverse direction. Consequently, switching transistor **30** is maintained extinguished.

In the two embodiments just described, the ignition signals appearing across junction **24** and point of reference or ground potential **5** are produced in response to the operation of ignition distributor breaker contacts **7** to the electrical circuit open condition. In FIG. **5**, wherein circuit elements the same as in FIG. **1** have been assigned the same characters of reference, an alternate method for producing the required ignition signals by a magnetic pick-up type distributor is set forth. Magnetic pick-up type distributors of this type are well known in the automotive art and are comprised of a rotor member **110** rotated by the associated internal combustion engine within the bore of a pole piece **112** which is magnetized by an annular permanent magnet, not shown. As rotor member **110** is rotated by the engine, an alternating current signal is induced in pickup coil **114**, as shown, which is filtered by the resistor **115** and capacitor **116** filter circuit combination and supplied through input resistor **29** to the positive polarity input terminal of comparator circuit **25**. When the signals induced in pickup coil **114** are of a magnitude less positive than the comparison signal present upon junction **38**, a logic 0 signal appears upon the output terminal **39** of comparator circuit **25**, as shown, and when these signals are of a magnitude more positive than the comparison signal upon junction **38**, a logic 1 signal appears upon the output terminal **39** of comparator circuit **25**, as shown, until the potential induced in the pickup coil **114** reduces to a magnitude less positive than the comparison signal upon junction **38**. Comparator circuit **25**, therefore, functions as a signal shaper circuit which produces an output signal of a square waveform having substantially vertical leading and trailing edges and of a duration of time equal to the period of time the signals induced in pickup coil **114** are of a magnitude greater than the comparison potential upon junction **38**. Consequently, with this embodi-

ment, comparator circuit **25** functions as it does in the embodiments previously described except that in this embodiment it is responsive to an alternating current ignition signal rather than a direct current ignition signal. Output terminal **39** may be connected to the input terminal of arc-duration monostable multivibrator circuit **40**, or, alternatively, it may be connected directly to the cathode electrode of diode **61**, in which event the output signal thereof is the timing signal.

It is apparent from the curves of FIG. **2** that from the beginning of the timing signal, curve C, to the initiation of the ignition spark which occurs at the beginning of arc current, curve G, there is a fixed time delay equal to the time period required for the ignition coil primary winding energizing current to reach a predetermined magnitude. The fixed time delay between the beginning of the timing signal and the initiation of the spark results in a retardation of the spark, as is well known in the automotive art. This spark retard is compensated for by the initial distributor tiiming and the use of the proper spark advance curve. For example, a spark retard of 0.5 milliseconds between the beginning of the timing signal and the initiation of the ignition spark requires a distributor spark advance compensation of 3° per 1000 engine rpm.

While specific electric circuit elements, logic circuit elements, transistor types, electrical circuits and electrical polarities have been set forth in detail in this specification, it is to be specifically understood that alternate electrical circuit elements, logic circuit elements, transistor types, electrical circuit elements and compatible electrical polarities may be substituted therefor without departing from the spirit of the invention.

While a preferred embodiment of the present invention has been shown and described, it will be obvious to those skilled in the art that various modifications and substitutions may be made without departing from the spirit of the invention which is to be limited only within the scope of the appended claims.

What is claimed is:

1. An internal combustion engine ignition system comprising in combination with a source of direct current potential and an ignition distributor having an electrical contact rotated in timed relationship with the engine through which ignition spark potential is applied to the spark plugs of the engine individually; a first monostable multivibrator circuit for producing a timing signal corresponding to each spark plug of said engine in timed relationship with and during each revolution of the crankshaft of said engine of a duration corresponding to the period of time ignition spark energy is to be applied to the said spark plug to which it corresponds; an ignition coil having a magnetic core, a primary winding which, during the buildup of the flow of an energizing current therethrough, produces a magnetic flux in said core and a secondary winding, connected to said electrical contact of said distributor, in which an ignition spark potential of sufficient magnitude to initiate an arc across the spark gap of each of said spark plugs is induced upon the interruption of the flow of energizing current through said primary winding, said primary winding having an inductance value which, with a predetermined magnitude of energizing current, will provide sufficient stored energy to maintain the arc initiated across each spark plug spark gap for a predetermined duration of time and said ignition coil having a primary to secondary winding turns ratio such that, during the buildup of energizing current through said primary winding, a potential sufficient magnitude to maintain the arc initiated across each spark plug spark gap is induced in said secondary winding; an ignition coil primary winding energizing circuit through which energizing current flows from said source of direct current potential through said ignition coil primary winding; an impedance element included in said ignition coil primary winding energizing circuit for producing an electrical potential signal of a magnitude proportional to the magnitude of said flow of energizing current; a second monostable multivibrator circuit for producing a plurality of control signals during each said timing signal, each in response to said electrical potential signal of a predetermined magnitude; and means reponsive to said timing signal for establishing and to each of said control signals for interrupting said ignition coil primary winding energizing circuit.

2. An internal combustion engine ignition system comprising in combination with a source of direct current potential and an ignition distributor having an electrical contact rotated in timed relationship with the engine through which ignition spark potential is applied to the spark plugs of the engine individually; a first monostable multivibrator circuit for producing a timing signal corresponding to each spark plug of said engine in timed relationship with and during each revolution of the crankshaft of said engine of a duration corresponding to the period of time ignition spark energy is to be applied to the said spark plug to which it corresponds; an ignition coil having a magnetic core, a primary winding which, during the buildup of the flow of an energizing current therethrough, produces a magnetic flux in said core and a secondary winding, connected to said electrical contact of said distributor, in which an ignition spark potential of sufficient magnitude to initiate an arc across the spark gap of each of said spark plugs is induced upon the interruption of the flow of energizing current through said primary winding, said primary winding having an inductance value which, with a predetermined magnitude of energizing current, will provide sufficient stored energy to maintain the arc initiated across each spark plug gap for a predetermined duration of time and said ignition coil having a primary to secondary winding turns ratio such that, during the buildup of energizing current through said primary winding, a potential of sufficient magnitude to maintain the arc initiated across each spark plug spark gap is induced in said secondary winding; an ignition coil primary winding energizing circuit through which energizing current flows from said source of direct current potential through said ignition coil primary winding; an impedance element included in said ignition coil primary winding energizing circuit for producing an electrical potential signal of a magnitude proportional to the magnitude of said flow of energizing current; an electrical potential comparator circuit reponsive to said electrical potential signal of a predetermined magnitude for producing an output signal; a second monostable multivibrator circuit for producing a plurality of control signals during each said timing signal, each in response to said output signal of said potential comparator circuit; and an electrical switching device of the type operable to electrical circuit closed and open conditions in response to electrical signals responsive to said timing signal for establishing and to each of said control signals for interrupting said ignition coil primary winding energizing circuit.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,892,219

DATED : July 1, 1975

INVENTOR(S) : Mark E. Preiser et al

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

Column 1, line 44, "is" should be -- in --.
Column 3, line 21, "collectoremitter" should be -- collector-emitter --;
line 25, "circiut" should be -- circuit --.
Column 4, line 26, "contracts" should be -- contacts --;
line 31, "distirbutor" should be -- distributor --;
line 39, "Breifly" should be -- Briefly --;
line 60, "circut" should be -- circuit --;
line 64, "circiut" should be -- circuit --.
Column 8, line 55, after "stable" insert -- state --.
Column 9, line 6, after "As" insert -- the --;
line 14, delete "curve" (first occurrence).
Column 11, line 31, delete "1" and insert -- circuit --;
line 39, delete "of" (first occurrence) and insert -- or --;
line 67, delete "circuit" and insert -- current --.
Column 12, line 6, change "discharged" to -- discharge --.
Column 13, line 20, "tiiming" should be -- timing --.
Column 14, line 3, after "potential" insert -- of --;
line 42, after "plug" insert -- spark --;
line 56, change "repon" to -- respon --.

Signed and Sealed this

ninth Day of December 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks