

[54] **AUTOMOTIVE IGNITION CONTROL**

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

[58] Field of Search 123/148 E, 198 DB

[56] **References Cited**

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[57]

ABSTRACT

An ignition control system senses the time for igniting a fuel mixture in a cylinder from a signal generated by a pickup transducer on the distributor driveshaft. A current, limited to a selected maximum value, is drawn through the primary of an ignition coil by a power output circuit. The time during which this current stays at that maximum value is controlled to minimize both the power drain on the system and the operating temperature of the power output circuit. Structure is provided to protect the power output circuit from current surges flowing from the ignition coil when the power output circuit is turned off. Structure is also provided to turn off the output circuit when a voltage in excess of a given value is applied to the supply voltage. Additional structure is provided for dissipating energy stored in the ignition coil when a spark plug fails to fire.

12 Claims, 6 Drawing Figures

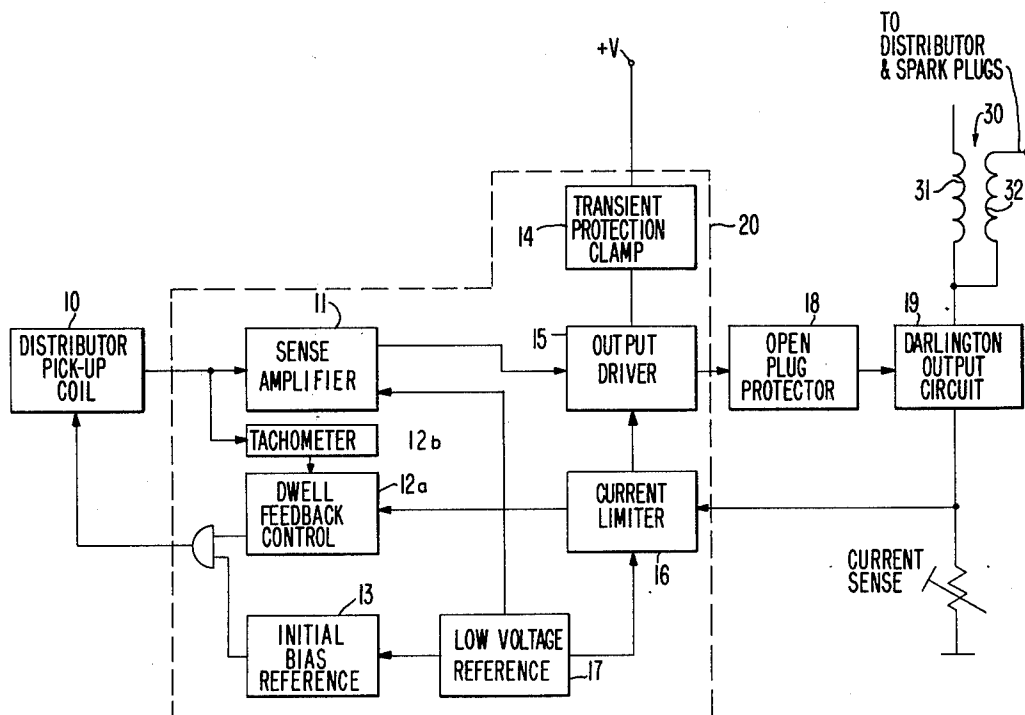
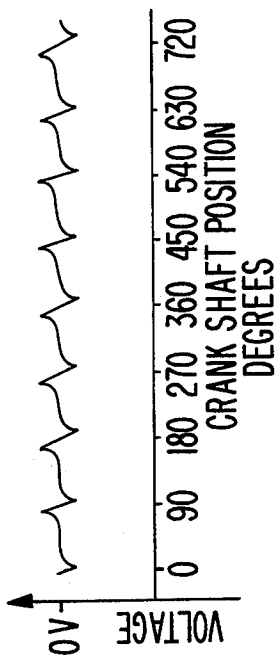
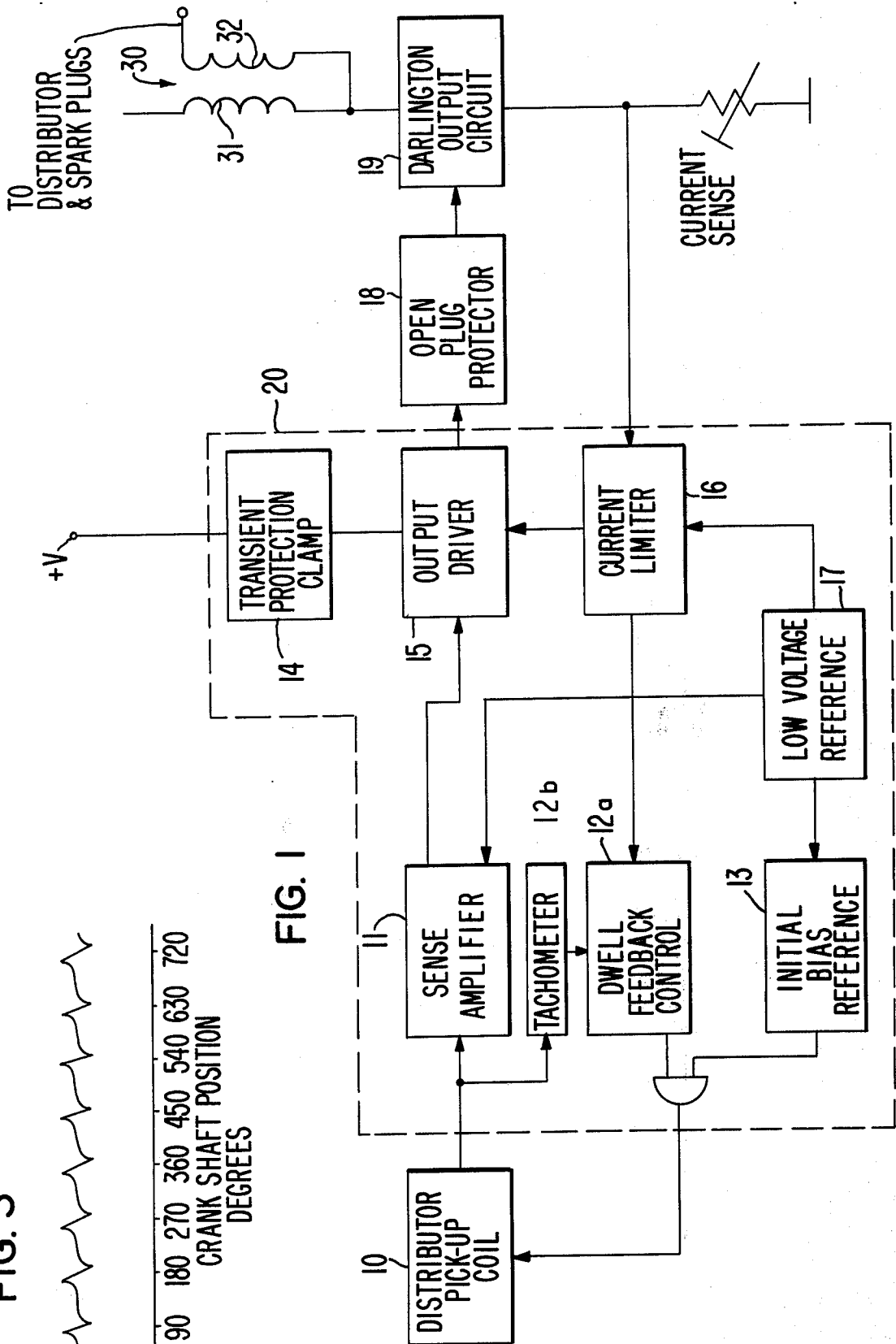


FIG. 3



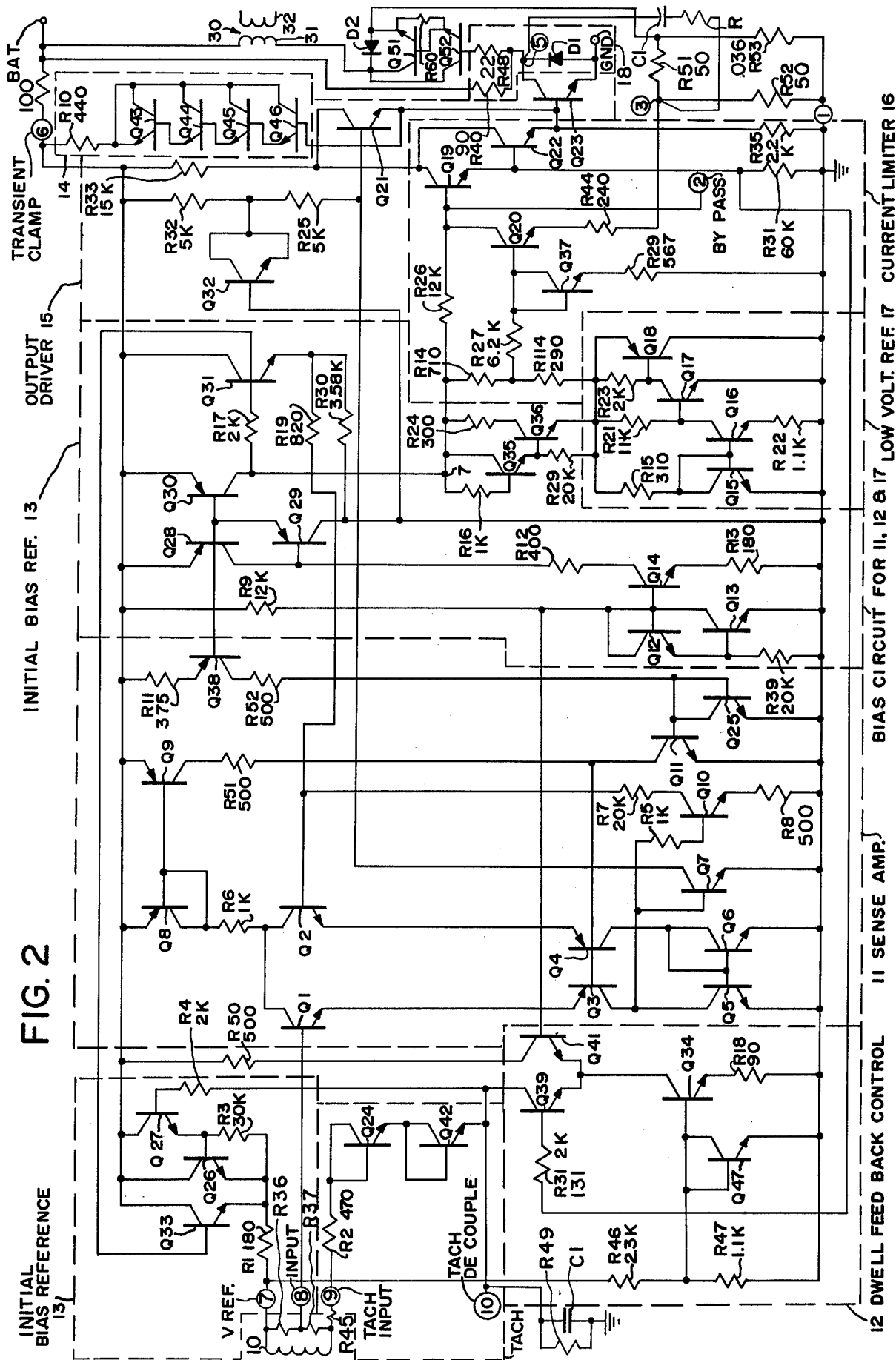


FIG. 4A

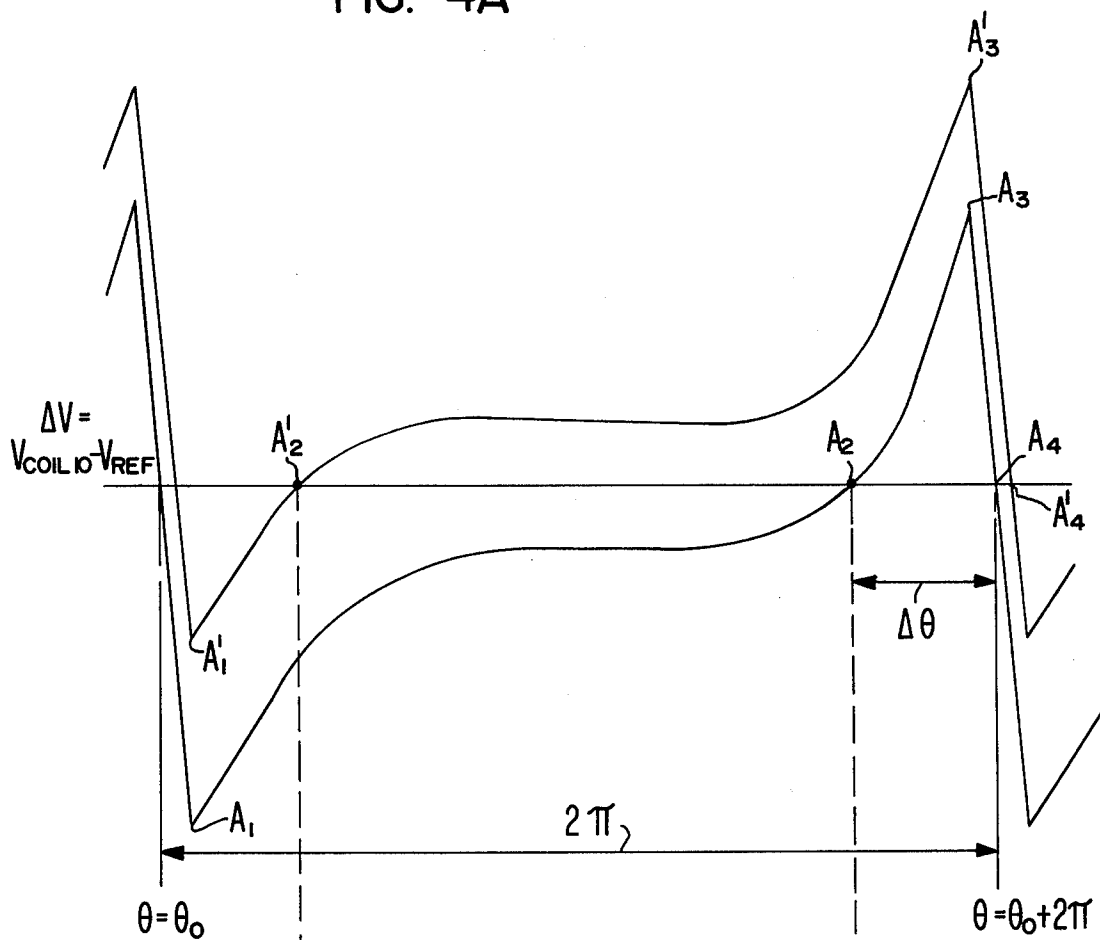


FIG. 4B

CURRENT
THROUGH
PRIMARY 31
AT LOW SPEEDS

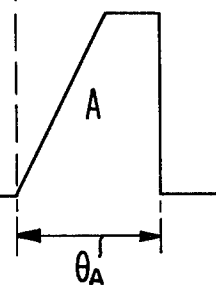
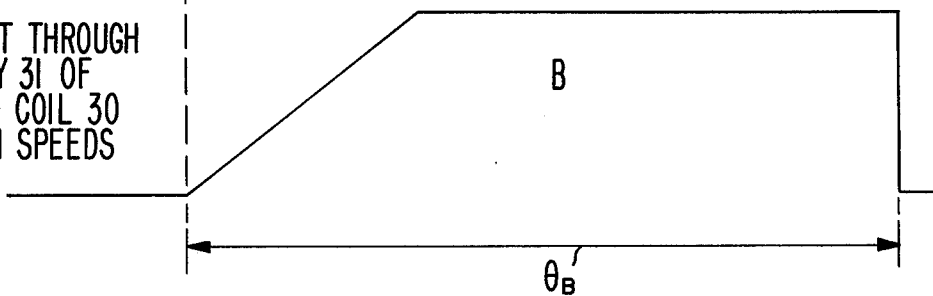


FIG. 4C

CURRENT THROUGH
PRIMARY 31 OF
IGNITION COIL 30
AT HIGH SPEEDS



AUTOMOTIVE IGNITION CONTROL

This is a continuation of application Ser. No. 241,752, filed Apr. 6, 1972, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to automotive ignition systems and in particular to an automotive ignition suitable for implementation using semiconductor technology.

2. Description of the Prior Art

The conventional ignition system commonly used today uses breaker points to periodically interrupt a current in the primary of an ignition coil. When the points are separated by, for example, the distributor camshaft, the current then flowing through the primary of the ignition coil discharges rapidly inducing a voltage in the secondary of the coil and through an appropriately connected spark plug, thereby igniting fuel in a cylinder. Although widely used, this system is less than ideal; the mechanical points wear and the current through the primary coil builds up to a level determined solely by the resistance of the output coil and ballast resistor and cannot be limited to a selected value. Therefore, the life of the spark plugs is reduced compared to what it would be if the discharge current was properly controlled.

Another type of ignition system is described in a paper entitled "Capacitor Discharge Ignition: The System Approach to Extended Ignition Performance and Life" presented at the Cleveland Section Meeting of the Society of Automotive Engineers, Inc., Dec. 1964, by James T. Hardin. Capacitor discharge ignition systems have been found superior to the conventional ignition system in the areas of extending spark life and firing fouled spark plugs.

SUMMARY OF THE INVENTION

This invention provides an ignition control system which is substantially maintenance free for a significantly longer portion of time than the typical mechanically-driven prior art ignition control system. Moreover, the system of this invention lends itself to significant manufacturing economies by eliminating the need for the ballast resistor and bypass relay actuated by the starter motor required in the conventional breaker-point ignition system.

According to this invention, an ignition control system suitable for use with an internal combustion engine comprises means for sensing an output signal indicating that the engine is approaching the time for ignition a fuel mixture in one cylinder, means for controlling a power output circuit to generate an increasing current through an ignition coil, means for detecting from an input signal the time for discharging said ignition coil, means for limiting the maximum current drawn by said power output circuit through said ignition coil, and means for protecting said power output circuit from current surges flowing from said coil through said power output circuit upon the cutting off of said power output circuit.

The circuit of this invention also uses a transient protection clamp for protection from system transients. In addition, the circuit provides means for limiting the maximum current drawn through the ignition coil by said power output circuit to a selected controllable value.

The ignition control system of this invention provides fail safe operation when the input pickup transducer becomes either open or short circuited. An external frequency compensation circuit allows the circuit to be stabilized for a variety of output coils. A feedback dwell control allows the on time of the power output circuit to be easily adjusted. (The loop gain of the circuit is a function of speed for the best stability and compensation.) The system operates over a wide range of temperatures and supply voltages. For example, the system operates from -40°C to 125°C and also operates on supply voltages ranging from about 4 to about 24 volts.

To provide some immunity from noise, the input stage has an hysteresis effect which prevents erroneously cutting off the power output and thus prevents misfiring of the engine. When a spark plug fails to fire, the circuit is protected and the energy in the ignition coil is dissipated through a resistor and a diode so that the next current pulse from the ignition control system starts from a zero and not a negative value of current. This prevents misfiring.

The circuit uses only one trim resistor and two external capacitors. The circuit can be formed on two semiconductor chips, one Linear Integrated Circuit chip containing the control circuitry (the "LIC chip"), and the other chip containing the power output circuitry (the "power chip"). The circuit is substantially immune to damage by external maintenance wherein leads from the circuit are accidentally shorted.

The system makes it possible to use a coil with a higher primary energy. This makes possible a longer discharge time through the secondary coil and therefore a longer burn time. This improves ignition performance and decreases the probability of a misfire for a given air/fuel ratio and engine. The probability of a misfire goes up as the spark time and fuel/air ratio go down.

DESCRIPTION OF THE DRAWING

FIG. 1 shows a schematic block diagram of the circuit;

FIG. 2 shows in more detail the circuitry of the LIC chip and the power output chip of FIG. 1;

FIG. 3 shows a waveform useful in explaining the operation of this invention; and

FIGS. 4a through 4c show the variation as a function of crank shaft angle θ in on-time of current through primary 31 (FIG. 1) as the output signal from pickup coil 10 (FIG. 1) increases in amplitude.

DETAILED DESCRIPTION

The ignition system of this invention is activated by signals from distributor pickup coil 10 (FIG. 1) mounted around, for example, a distributor shaft. In an eight cylinder, four cycle engine, distributor pickup coil 10 produces eight output pulses for every 720° rotation of the engine crank shaft. The particular waveform of the output signal from pickup coil 10 is specified according to the engine requirements. Typically a magnetic pickup is used in coil 10 to produce the required waveform although other sensing devices could also be used to produce the required signal. With a magnetic pickup, the amplitude of the output signal is proportional to engine speed. Thus as the number of pulses per second increase, so does the amplitude of the output signal.

The waveform in FIG. 3 shows the output voltage from pickup coil 10. This waveform is used to control the turning on and turning off of a Darlington power output circuit in a manner to be described.

FIG. 4a shows the amplitudes of the output signals from distributor pickup coil 10 over slightly more than one period of these signals for both low engine speeds (the bottom curve) and high engine speeds (the top curve). The pickup signal amplitude is approximately 0 volts $\theta = \theta_0 + \pi$. The ordinate in FIG. 4a represents the difference between the output voltage from coil 10 ($V_{coil\ 10}$) and a reference voltage (V_{ref}). Both of these voltages shift with engine speed but in such a way that the zero of this difference signal occurs at an earlier engine crankshaft position ($\Delta\theta$) as engine speed increases. The abscissa of these curves represents engine crankshaft position.

Referring to the bottom curve, at θ_0 the amplitude of the output signal from coil 10 drops sharply to a negative peak labeled A_1 , reached shortly after θ_0 and then climbs toward a positive amplitude. Approximately half way through the period (for an eight cylinder, four cycle engine a period represents 90° of crankshaft rotation), the output signal approaches tangentially the zero voltage level. Then as the engine cycle continues, the amplitude of the output signal from coil 10 goes positive at an increasing rate. At a given crankshaft angle, the amplitude of the output signal from coil 10 crosses a threshold voltage V_{ref} . At this point, labeled A_2 , the output signal from coil 10 turns on Darlington output circuit 19 (FIG. 1) which draws a current through primary 31 of ignition coil 30. This current remains on while the amplitude of the output signal from coil 10 increases to a maximum positive value, labeled A_3 , and then drops, very sharply in a substantially linear manner toward a peak negative voltage A_1 . While dropping, this amplitude passes the reference voltage V_{ref} at point A_4 . The level of the signal from coil 10 at which the current through the Darlington circuit 19 cuts off is, as will be explained in more detail later, beneath V_{ref} by an amount controlled by certain circuit parameters. (This hysteresis effect prevents a noise spike from turning on and off circuit 19 prematurely.) At this time the current through the primary 31 of coil 30 suddenly is cut off. This cut off generates a pulse in secondary 32 of coil 30 which creates a spark across the gap of a spark plug.

As will be seen later, the relative levels of the voltage V_{ref} and the output signal from pickup coil 10 change as a function of engine speed to vary the amount of time during which the current through primary 31 flows at its regulated value. In automobile terminology, the time during which current flows through primary 31, the "on-time," is known as "dwell angle."

FIG. 4b 4b the current through primary 31 at low engine speeds. The angle θ_A through which the crankshaft rotates while current is either building up or flowing at a steady state value through primary 31, represents a small portion of the period of the output signal from coil 10. However, as the engine speed increases, the portion of this period during which the current must flow through primary 31 increases to allow a minimum on-time for current through primary 31. FIG. 4c shows the portion θ_B of the period of the waveform in FIG. 4a during which the current flows through primary 31 at high engine speeds.

The LIC chip 20 (FIG. 1) contains the circuits 11 through 17 used to control the turn-on and turn-off of the Darlington output circuit 19 in response to the various operating conditions of the engine. A Darlington circuit is also known as a compound transistor as described on page 562 of "Pulse, Digital, and Switching Waveforms" by J. Millman and H. Taub, 1965, McGraw-Hill, Inc. As explained above, Darlington output circuit 19 is turned on when the signal from the pickup coil 10 goes above a reference threshold signal. This threshold signal is derived from one of two sources.

While the engine is operating at a low speed, an initial bias reference circuit 13 controls the turn-on and turn-off of the Darlington output circuit 19. Circuit 19 is turned on when the waveform from coil 10 rises above the threshold voltage produced by circuit 13 and is turned off when this waveform falls beneath this voltage. The turning on of circuit 19 causes a current to flow through the primary coil 31 of ignition coil 30. The turning off of the Darlington output circuit 19 induces a voltage pulse in the secondary winding 32 of coil 30 which fires the appropriate spark plug.

When the engine speed reaches a given value, a signal from dwell feedback control 12a turns on Darlington output circuit 19 when this signal rises above a reference level. This reference level increases as engine speed increases turning on the Darlington output circuit 19 at an earlier angle of crankshaft position. Circuit 19 thus turns on at a time sufficient to allow the current through the primary 31 and the Darlington output circuit 19 to build up to the desired level.

The current through primary 31 of the ignition coil 30 builds up in about 3 milliseconds. After the current through primary 31 reaches its desired value, the time that it remains at this desired value is reduced to a minimum so as to minimize power drain from the system. To do this, the current limiter 16 in the LIC chip 20 changes the reference voltage produced by tachometer 12b to a new value such that the current through primary 31 remains at its maximum value for at most a selected short period of time (see FIGS. 4b and 4c). Typically this time varies from a fraction of a millisecond to 30 milliseconds at low speeds. Some reasons for controlling this time are to limit the temperature of both the Darlington output circuit 19 and output coil 30, as well as to allow for the maximum plug burn time at any given engine RPM.

Protection devices, such as transient protection clamp 14, operate to turn off the Darlington output circuit 19 if the transient voltage rises above 28 volts. It does this by turning on output driver circuit 15 on the LIC chip 20. To limit the current in case of an over-voltage condition on LIC chip 20 current limiting resistors are placed in every current path. The circuit withstands transients to 80 volts.

If for some reason a spark plug is unable to fire, the energy contained in primary winding 31 must be dissipated. If it is not dissipated, at the beginning of the next firing cycle, the current in primary 31 will be initially negative and will not reach the maximum current necessary to fire the next spark plug. To prevent this from happening, open plug protecting circuit 18 comprising a series-connected resistor and diode is provided to dissipate this current. Circuit 18 also protects the output driver transistor in output circuit 19 from negative currents and voltages.

Removal of the pickup coil 10 results in the Darlington output circuit 19 not turning on. Thus the circuit is failsafe if for some reason pickup coil 10 is disconnected from the LIC chip 20. The circuit is also latch-up proof in that sense amplifier 11 is arranged so that the reference signal to amplifier 11 is always positive. Thus the normal state of the circuit is with no current through Darlington output circuit 19.

The low voltage reference circuit 17 has an output voltage of 1.4 volts and is designed so that this voltage does not vary with either temperature or supply voltage variations.

FIG. 2 shows in detail the circuit of FIG. 1. It should be noted that in the description that follows, a transistor is denoted by the letter Q followed by a number, transistors connected as diodes are designated by the letter Q followed by a number, a resistor by the letter R followed by a number, and other types of components by an identifying letter such as D for a diode, and C for a capacitor followed by a number.

Initially, when power is turned on and supplied through input lead 6 to the circuit, current flows through resistor R33 (output driver 15). The collector of Q21 is connected to R33. Simultaneously, current flows through R32 and R25 to the base of Q21. Thus Q21 turns on as does Q23 (both part of driver 15). The emitter of Q23 is coupled to ground. The base-emitter voltage drops of Q21 and Q23 hold the base of Q21 about 1.3 volts above ground.

Low voltage reference source 17 produces about a 1.4 volt reference voltage, which represents the sum of the base-emitter voltage drops of normally-on transistors Q17 and Q18. This reference voltage is then applied to the emitter of Q36 (initial bias reference 13). The base of Q36 is V_{BE} above its emitter voltage, (The term " V_{BE} " denotes the voltage drop, typically 0.6 to 0.7 volts, across a forward-biased base-emitter junction.) This base voltage is then applied to the emitter of Q35. The base of Q35 is similarly one V_{BE} above the base of Q36. The base voltage of Q35 is also applied to the base of Q31 which is thus $2V_{BE}$ above the 1.4 volts from reference source 17 or at about 2.6 volts. A pre-bias of about 2 volts is supplied to the base of Q2 (sense amplifier 11) which causes Q2, Q4, Q5 and Q6 to conduct.

A reference voltage of about 2 volts is thus provided on the emitter of Q33 (initial bias reference 13). This reference voltage provides a pre-bias to transistor Q34 (dwell feedback control 12) through resistors R1, R46 and R47 connected as a voltage divider. Q34 is connected together with resistor R18 and transistor Q47 as a current source. Q34's collector current is drawn from the two emitters of Q39 and Q41. Initially the current source comprising Q34 and Q47 draws its current through Q41. Q41 initially has 1.3 volts applied to its base via Q12 and Q13.

When the engine is cranked, the distributor pickup coil 10 (FIG. 1) produces a signal which is applied through input lead 8 to the base of transistor Q1 (sense amplifier 11). The waveform of the output signal from coil 10 is shown in FIG. 3. When this signal approaches the level of the voltage on the base of Q2, Q1 conducts. This turns on Q3, Q7 and Q10. Turning on Q10 reduces the voltage on the base of Q2. This turns off Q2, Q4, Q5 and Q6 thus increasing the current through Q3. This regenerative switching assures rapid turn-on of the

output Darlington transistor in a manner to be described shortly.

Transistor Q7 turns on and saturates in response to the turning on of Q1. The collector of Q7 is connected to the base of Q21 (output driver 15). The removal of the drive voltage on the base of Q21 when Q7 saturates, shuts off Q21. Q23 which has been saturated, thereby clamping the bases of Q51 and Q52 in circuit 19 at ground, shuts off when the emitter current of Q21 terminates.

When Q23 shuts off, current from the power supply battery is supplied through an external resistor to transistor Q51 and Q52 comprising the Darlington output power circuit 19 (FIG. 1) thereby turning on this circuit. The power output transistors Q51 and Q52 draw collector current through the primary 31 of the ignition coil 30.

The current through the Darlington output transistors is sensed at pin 3. A signal produced by a part of this current passing through external resistor R52 is fed back and used to shift the voltage on pin 3. As the output current increases, the voltage on pin 3 increases, thereby increasing the voltage on the emitter of Q20.

Before the Darlington output circuit drew current, current passed through Q20 (current limiter 16). As the emitter voltage on Q20 rises, Q20 conducts less current. A part of Q20's collector current, which passes through R26, now turns on Q19 and Q22. The emitter current current Q22 passes through R35 thereby raising the voltage on the base of Q23. Q23 now goes into a linear mode of operation and is turned on by the voltage drop across R35. The turning on of Q23 reduces the current to the Darlington output circuit thus completing the feedback loop. Equilibrium is attained when the current through Q20 is approximately equal to the current through Q37. The peak current which flows through primary 31 in response to turning on of Darlington output circuit 19 is determined by the values of resistors R51 through R53.

Transistors Q39 and Q41, connected with their emitters coupled to a common node, are part of the dwell feedback control 12. The input to Q39 is taken across R31 from the node between the base of Q22 and R31 in current limiter 16. The base of Q22 is $2V_{BE}$ above ground potential due to the base-emitter drops of Q22 and Q23. The base of Q41 in dwell feedback control 12 is held $2V_{BE}$ above ground by transistors Q12 and Q13 in bias reference circuit 13. Q12, connected as a diode, and Q13 get their current directly from the power supply through R9. When no current flows from the emitter of Q19 (in current limiter 16) to ground, the voltage drop across R31 is approximately zero and the base of Q39 is held at ground. However, as current begins to flow through resistor R31, the voltage on the base of Q39 rises. When this voltage rises above the voltage drop ($2V_{BE}$) across two forward-biased p-n junctions, Q39 turns on thereby supplying some of the current source Q34.

When the signal from the distributor pickup coil 10 (FIG. 1) starts to go negative as shown in FIG. 4a, the base voltage on Q1 (sense amplifier 11) goes negative. When this base voltage drops beneath the base voltage on Q2, Q1 shuts off. Hysteresis is provided to ensure that Q1 shuts off rapidly. This hysteresis is provided by the fact that when Q10 turns on, the base voltage on Q2 is dropped by an amount determined by the values of resistors R7, R8 and R19. Therefore the base voltage

on Q2 is lower than it was when Q1 turned on. This difference is typically 60 millivolts in one embodiment but could be other values, if desired.

The capacitor C1 external to the circuit has a voltage on it generated by the output signal from the distributor pickup coil 10. As the speed increases, the amplitude of this output signal increases and thus the charge on capacitor C1 increases.

During current limiting, Q19 (current limiter 16) is turned on. The turning on of Q19 results in a voltage drop across R31 and this voltage drop turns on Q22 and Q23. Therefore, the base voltage on Q22 is about 1.2 volts ($2V_{BE}$) above ground Q20 tends to turn off as a result of the reduction of its V_{BE} and its collector voltage goes up to turn on Q19 and Q22. Q23 turns on and reduces the drive to Darlington output circuit. Q22 and Q23 are sized such that $2V_{BE}$ at the bases of Q22 and Q39 is larger than $2V_{BE}$ at the base of Q41. Thus Q39 turns on and Q41 turns off. This turning on of Q39 results in the emitter current of Q39 passing through Q34 to ground. The collector voltage of Q34 previously had been at 0.6 or 0.7 volts. The collector current drawn by Q39 comes from capacitor C1 rather than from power supply input through pin 6.

As engine speed increases, the charge on capacitor C1 increases. Therefore, the base voltage on Q27 goes up. This drives up the voltage on pin 7. Consequently, the reference voltage to coil 10 (FIG. 1) increases and the output signal waveform from coil 10 shifts up in position relative to the reference signal. The result is an increase in the dwell angle of the circuit, that is, an increase in the portion of one cycle of distributor rotation during which current flows through primary 31 of ignition coil 10. When the current through the Darlington power circuit reaches a given value in response to a signal from the LIC chip 20, components provided in the dwell feedback control of LIC chip 20 operate to hold the current through the Darlington power circuit at that value as described above. At this point Q39 turns on drawing current from capacitor C1. The amount of this current is determined by current source Q34. The collector current drawn by transistor Q39 is supplied totally by charge from capacitor C1.

Note that Q39 only turns on when Q19 and Q22 turn on. These two latter transistors turn on only when the current through the Darlington output circuit 19 (FIG. 1) has reached a limiting value. Transistor Q39 reduces the reference voltage on capacitor C1 and thus controls the length of time that the output current stays in the limiting current condition. The turning on of transistor Q39 results in Q41 shutting off. When Q39 turns off, Q41 will turn on again because the base voltage on Q41 remains at about 1.2 volts even while off.

Transistor Q32 is an NPN transistor connected as a zener diode. This transistor comprises the current output driver circuit 15 (FIG. 1) and limits the base current to transistor Q21. Q32 is connected together with R32 and R25 to perform this function. R33 serves as common load for Q19 and Q22 as well as Q21.

The transient protection circuit 14 prevents transients from turning on the Darlington circuit 19. A transient of greater than 28 volts, which is the reverse breakdown voltage of the four series-connected zener diodes Q43 through Q46, breaks down the reverse-biased p-n junctions in these diodes and turns on Q23. Q23 saturates and clamps the output pin 5 to ground thereby preventing the Darlington output circuit from

turning on. It should be noted that if a transient occurs while the system is operating, Q23 will still saturate thereby momentarily clamping the output pin 5 to ground and shutting off the Darlington output circuit 19.

The diode D1 shown across the collector and emitter of Q23 in series with resistor R48 serves to dissipate the energy stored in the primary 31 of ignition coil 30 when for some reason a spark plug does not fire. If energy is stored in the coil 30 and the previous spark plug fails to fire, and Q23 turns off to energize the coil for firing the next spark plug, then negative current will begin to flow through the coil and diodes D1 and D2 will be forward biased. This in turn will discharge the energy stored in the coil, which prevents the failure of a spark plug to fire from resulting in negative current output through the Darlington output circuit on the next firing cycle.

Diode D₂ connected across the collectors of Q51 and Q52 and the emitter of Q52 is part of open plug protector circuit 18 (FIG. 1). D₂ discharges some of the energy in primary 31 due to a misfire. This diode is sometimes called a "free-wheeling" diode.

Transistors Q1 through Q6 are similar to the μ A741 input stage, a well-known device produced by Fairchild Camera and Instrument Corporation.

If pickup coil 10 open circuits, Q1 cannot be turned on and thus the circuit fails safely in a mode which prevents the generation of current through the Darlington output circuit 19. This feature is accomplished by the voltage drop across R1 developed by the voltage divider action between R1, R46 and R47. The emitter voltages of Q31 and Q33 are equal since their bases are driven from a common node. Since one input of the sense amplifier (base of Q2) is driven from the emitter of Q31, in order to change the state of the sense amplifier, or to turn Q1 on, the pickup coil 10 has to provide sufficient drive through R36 and R37 to overcome the voltage drop across R1. If the distributor pickup coil 10 short circuits, Q1 again stays off since the voltage at pin 7 of the LIC chip is connected to the input transistor Q1 through resistor R36 and the voltage at pin 7 is below the level of the base voltage of Q2.

Transistors Q3 and Q4 being PNP, have a base-collector breakdown voltage much higher than the reverse bias base-emitter breakdown of MPN transistors Q1 and Q2. Thus a transient overload of up to 80 or so volts can be withstood by the system without junction breakdown. This protection applies not only to transients but likewise to regular input signals from the distributor pickup coil 10.

It should be noted that the circuit shown in FIG. 2 will operate with a supply voltage of anywhere from 4 to about 24 volts although normally it operates at about 12 to 16 volts supply voltage. The time necessary for the current through Q51 and Q52 to reach a steady value is determined by the inductance-resistance ratio of the ignition coil 30. Typically the rise in this current is approximately linear. With a coil used in one embodiment, this current takes about 3 milliseconds to reach a limiting value (see FIGS. 4b and 4c).

It should also be noted that the circuit operates over a wide temperature range typically from -40°C to 125°C . The 1.4 volt reference supply for current limiting purposes enables a regulated output current at low supply voltages.

The reference voltage circuit 17 has a zero temperature compensation coefficient which makes the circuit useful over the above-mentioned temperature range. Changes in the ambient temperature are detected by changes in the V_{BE} of the transistors in current limiter 16, low voltage reference 17, and in initial bias reference 13, and in particular, transistors Q35 and Q36. R14 and R114 in the current limiter circuit 16 create the zero temperature compensation effect. The base of Q36 has a negative temperature coefficient while the node between resistors R15, R21 and R23 has a positive temperature coefficient at some voltage between these two nodes. R114 is approximately 290 ohms while R14 is about 710 ohms. The voltage at the node between these two resistors is approximately temperature insensitive. However, by varying the location of this node (varying the ratio of the resistance values of R14 and R114), either a positive or negative temperature coefficient can be obtained thereby compensating for a temperature coefficient external to the LIC circuit 20, for example, R53.

Only one trimming resistor is required for the circuit. Trimming resistor R51 is connected in the emitter circuit of the Darlington output stage. This resistor is varied to control the output current limiting value drawn by the Darlington output circuit 19. R51 is a thick film resistor and is in one embodiment laser trimmed.

The circuit uses only two external capacitors. Capacitor C1 is used to integrate the dwell time control voltage of the circuit, that is, the time during which the Darlington output circuit draws a limited current. Capacitor kC2 is connected to output pin 5 and provides stability in the circuit.

The system can be implemented using only two semiconductor chips. One chip is the basic LIC chip containing the sense amplifier tachometer 12, initial bias reference circuit 13, transient protection clamp 14, output driver 15, current limiter 16, low voltage reference 17, and open plug protection 18. The other chip contains the Darlington output circuit.

It should be noted that in one embodiment, the component C1 in FIG. 2 was 0.47 μ f, resistor R49 in parallel with C1 was 200K ohms, resistors R35, R37 and R45 were 7K, 10K and 24K ohms respectively, capacitor C2 was 0.022 μ f and resistor R connected between capacitor C2 and pin 3 was 1K ohm.

What is claimed is:

1. An ignition control system for use in an internal combustion engine having at least one means for igniting fuel, said system comprising:

- a. means for producing a control signal alternating in timed relationship with an engine;
- b. an energy storing ignition coil possessing a primary and a secondary side, said secondary side being cyclically coupled to said means for igniting in timed relationship with said engine;
- c. a power output circuit coupled to the primary side of said coil for drawing current through said coil;
- d. means coupled to said power output circuit and responsive to said control signal for switching said power output circuit off to discharge said coil through said means for igniting;
- e. means for limiting the maximum current drawn by said power output circuit through said ignition coil;
- f. means for dissipating energy stored in said coil when said energy fails to discharge through said means for igniting, said means for dissipating com-

prising at least one diode connected from a reference potential to the primary side of said coil, said diode coupled so as to conduct current when said primary side is at a selected lower potential than said reference potential; and

g. means for turning or maintaining OFF said power output circuit when said means for producing a control signal is either open-circuited or short-circuited.

2. A system as defined in claim 1 including means for protecting said system from supply voltage transients, said means for protecting comprising a plurality of zener diodes connected in series between a positive voltage supply for said ignition control system and said means coupled to said power output circuit, said diodes operative to switch said power output circuit off in response to a transient voltage spike greater than the breakdown voltage of said plurality of series-connected zener diodes.

3. An ignition control system for use in an internal combustion engine having at least one means for igniting fuel, said system comprising:

- a. means for producing a control signal alternating in timed relationship with an engine;
- b. an energy storing ignition coil having a primary and a secondary side, said means for igniting in timed relationship with said engine;
- c. a power output circuit coupled to the primary side of said coil for drawing current through said coil, said power output circuit comprising a pair of transistors, the collectors of which are coupled to the primary side of said coil and the emitters of which are coupled to ground potential, the emitter of one of said pair also being coupled to the base of the other of said pair;
- d. means for switching said power output circuit off to discharge said coil through said means for igniting in response to said control signal, said means for switching being coupled to the base of said one of said pair of transistors;
- e. means for limiting the maximum current drawn by said power output circuit through said ignition coil; and,
- f. circuit feedback means for varying as a function of engine speed the portion of each cycle during which said power output circuit draws current through said ignition coil.

4. Structure as in claim 2 including means for preventing a noise spike from changing the state of said power output circuit.

5. Structure as in claim 2 including means for minimizing the time that the current through said ignition coil remains at said maximum current level, thereby to minimize power drain and thus control the temperature of said power output circuit.

6. A system according to claim 3 including means for dissipating energy stored in said coil when said energy fails to discharge through said means for igniting, said means for dissipating comprising at least one diode connected from a reference potential to the primary side of said coil, said diode coupled so as to conduct current when said primary side is at a selected lower potential than said reference potential.

7. A system according to claim 3 wherein said means for limiting comprises:

- a. a constant current source;

- b. means for developing a voltage proportional to the current drawn by said power output circuit and the primary side of said coil;
 - c. a current limiting transistor having a base coupled to said constant current source and an emitter coupled to said means for developing a voltage;
 - d. transistor switching means coupled between the collector of said current limiting transistor and the base terminal of said one of said pair of transistors, wherein variations of the current drawn by said current limiting transistor in response to voltage from said means for developing a voltage effects operation of said transistor switching means to vary the current passing through said power output circuit and said coil until equilibrium is reached as a result of current being drawn by said current limiting transistor substantially equal to the current through said constant current source.
8. A system according to claim 7 wherein said circuit feedback means comprises:
- a. a first transistor having a collector coupled to a voltage source, an emitter coupled to one side of said means for producing a control signal, and a base terminal, said first transistor being disposed for supplying a reference potential for said means for producing a control signal;
 - b. means for storing a voltage coupled to said means for producing a control signal and the base terminal of said first transistor; and,
 - c. a second transistor having an emitter coupled to ground potential, a collector coupled to said voltage storage means and the base terminal of said first transistor, and a base terminal coupled to said transistor switching means, wherein the voltage reference level of said means for producing a control signal varies in accordance with voltage stored by said voltage storage means such that the reference voltage increases as a function of engine speed and decreases as a function of current drawn by said current limiting transistor.
9. A system in accordance with claim 3 including means for turning or maintaining OFF said power output circuit when said means for producing a control signal is either open-circuited or short-circuited.
10. An ignition control system for use in an internal combustion engine having at least one means for igniting fuel, said system comprising:
- a. means for producing a control signal alternating in timed relationship with an engine;
 - b. an energy storing ignition coil possessing a primary and a secondary side, said secondary side being cyclically coupled to said means for igniting in timed relationship with said engine;
 - c. a power output circuit coupled to the primary side of said coil for drawing current through said coil;
 - d. means coupled to said power output circuit and responsive to said control signal for switching said power output circuit off to discharge said coil through said means for igniting; and,
 - e. means for limiting the maximum current drawn by said power output circuit through said ignition coil, said means for limiting comprising:
 - 1. a constant current source;
 - 2. means for developing a voltage proportional to the current drawn by said power output circuit and the primary side of said coil;

- 3. a current limiting transistor having a base coupled to said constant current source and an emitter coupled to said means for developing a voltage;
 - 4. transistor switching means coupled between the collector of said current limiting transistor and the base terminal of said one of said pair of transistors, wherein variations of the current drawn by said current limiting transistor in response to voltage from said means for developing a voltage effects operation of said transistor switching means to vary the current passing through said power output circuit and said coil until equilibrium is reached as a result of current being drawn by said current limiting transistor substantially equal to the current through said constant current source.
11. An ignition control system for use in an internal combustion engine having at least one means for igniting fuel, said system comprising:
- a. a distributor pick-up coil for producing a control signal alternating in timed relationship with an engine;
 - b. an energy storing ignition coil possessing a primary and a secondary side, said secondary side being cyclically coupled to said means for igniting in timed relationship with said engine;
 - c. a power output circuit coupled to the primary side of said coil for drawing current through said coil, said power output circuit comprising a pair of transistors coupled as a compound-transistor;
 - d. circuit means coupled between said distributor pick-up coil and said power output circuit for switching said power output circuit off in response to said control signal to discharge said coil through said means for igniting;
 - e. current sense resistance means coupled between said power output circuit and ground potential for developing a voltage proportional to the current drawn by said power output circuit through said ignition coil;
 - f. a current limiter circuit coupled between said current sense resistance means and said circuit means for limiting the maximum amount of current drawn by said power output circuit through said ignition coil; and,
 - g. a dwell feedback control circuit coupled between said current limiter circuit and said distributor pick-up coil for varying the dwell angle as a function of engine speed during the portion of each cycle that said power output circuit draws current through said ignition coil.
12. An ignition control system for use in an internal combustion engine having at least one means for igniting fuel, said system comprising:
- a. a distributor pick-up coil for producing a control signal alternating in timed relationship with an engine;
 - b. an energy storing ignition coil possessing a primary and a secondary side, said secondary side being cyclically coupled to said means for igniting in timed relationship with said engine;
 - c. a power output circuit coupled to the primary side of said coil for drawing current through said coil, said power output circuit comprising a pair of transistors coupled as a compound-transistor;

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- d. circuit means coupled between said distributor pick-up coil and said power output circuit for switching said power output circuit off in response to said control signal to discharge said coil through said means for igniting; 5
- e. current sense resistance means coupled between said power output circuit and ground potential for developing a voltage proportional to the current drawn by said power output circuit through said ignition coil; 10
- f. a current limiter circuit coupled between said current sense resistance means and said circuit means for limiting the maximum amount of current drawn by said power output circuit through said ignition coil; 15
- g. a dwell feedback control circuit coupled between said current limiter circuit and said distributor pick-up coil for varying the dwell angle as a function of engine speed during the portion of each cycle that said power output circuit draws current 20

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- through said ignition coil;
- h. means for dissipating energy stored in said ignition coil when said energy fails to discharge through said means for igniting, said means for dissipating comprising at least one diode connected from a reference potential to the primary side of said ignition coil, said diode coupled so as to conduct current when said primary side is at a selected lower potential than said reference potential; and,
- i. means for protecting said system from supply voltage transients, said means for protecting comprising a plurality of zener diodes connected in series between a positive voltage supply for said system and said circuit means, said diodes operative to switch said power output circuit off in response to a transient voltage spike greater than the breakdown voltage of said plurality of series-connected zener diodes.

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