United States Patent [19]

Brennan

[11] **3,885,720**

[45] **May 27, 1975**

[54] **METHOD AND SYSTEM FOR CONTROLLING COMBUSTION TIMING OF AN INTERNAL COMBUSTION ENGINE**

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[73] Assignee: **Mobil Oil Corporation**, New York, N.Y.

[22] Filed: **Jan. 10, 1973**

[21] Appl. No.: **322,393**

Related U.S. Application Data

[63] Continuation of Ser. No. 109,878, Jan. 26, 1971.

[52] **U.S. Cl.... 123/148 E**; 123/117 R; 123/146.5 A

[51] **Int. Cl.** **F02p 5/04**

[58] **Field of Search**..... 123/32 EA, 119 R, 148 E, 123/140 MC, 117 A

[56] **References Cited**

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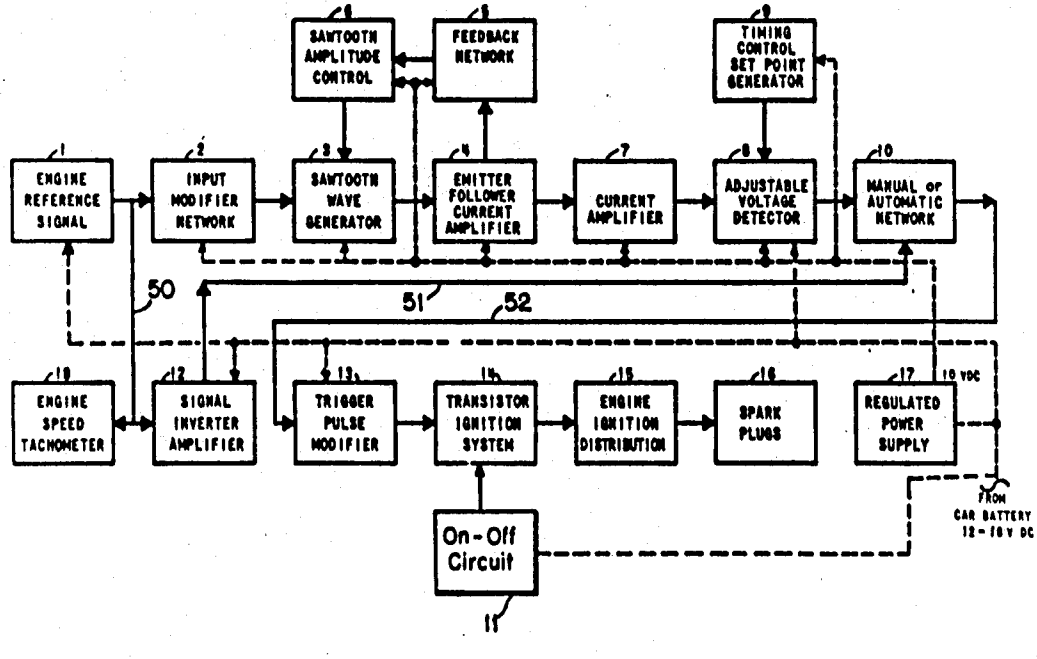
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Primary Examiner—Charles J. Myhre
Assistant Examiner—Cort Flint
Attorney, Agent, or Firm—Charles A. Huggett; Carl D. Farnsworth

[57] **ABSTRACT**

The specific disclosure provides for controlling ignition timing of an internal combustion engine by triggering a sawtooth wave generator to generate a sawtooth signal having a frequency equal to the firing frequency of the engine. A feedback network maintains the amplitude of the sawtooth wave signal at a constant level in response to the frequency of the sawtooth wave signal. A voltage detector adjustable to an ignition timing set point detects the set point voltage during the generation of each sawtooth and provides an ignition trigger signal for firing the engine upon each detection of the set point voltage. Another voltage detector may be provided which is adjustable to a fuel injection timing set point for detecting a fuel injection set point voltage during the generation of each sawtooth and for providing a fuel injection trigger signal upon each detection of the fuel injection set point voltage.

14 Claims, 23 Drawing Figures



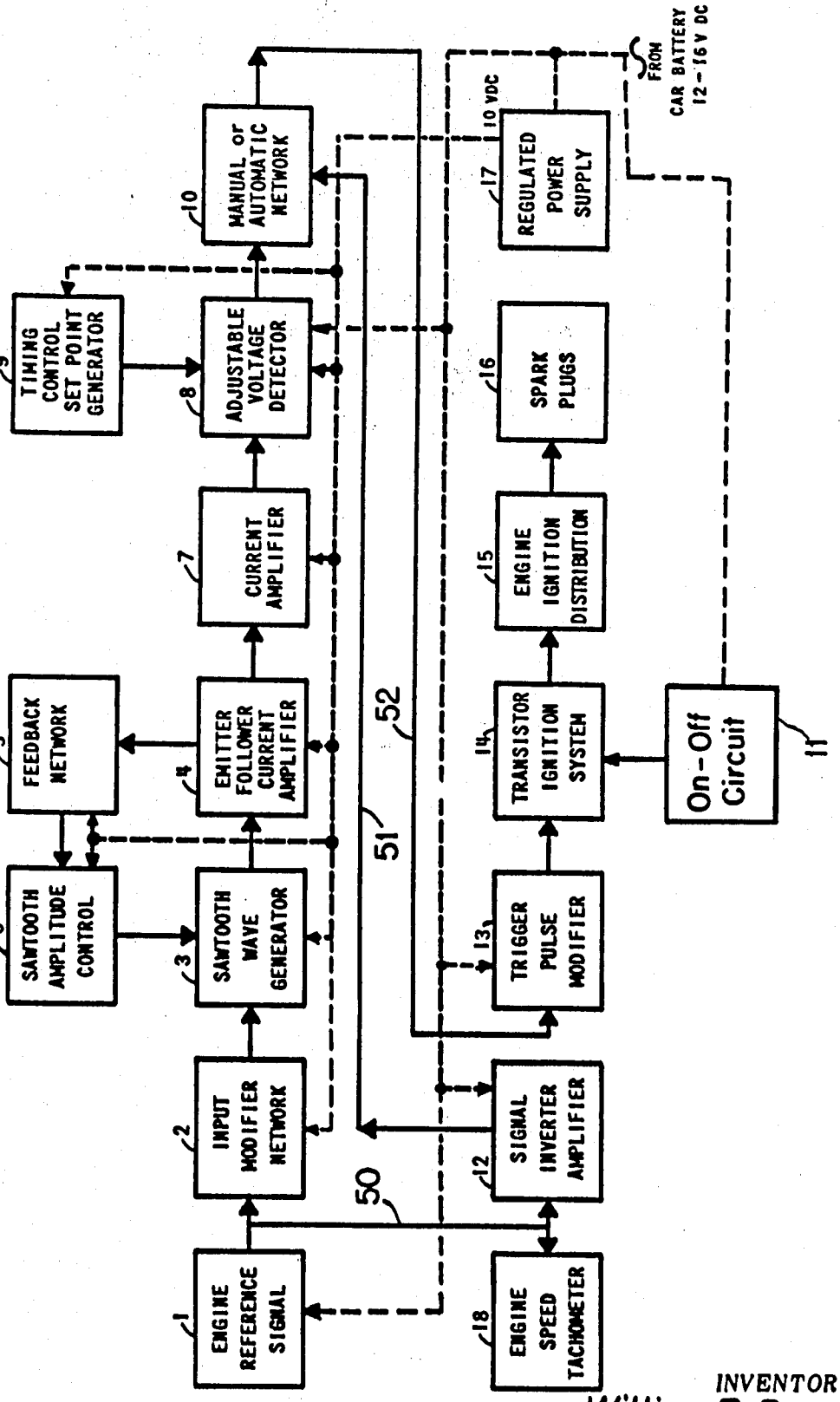


FIG. 1

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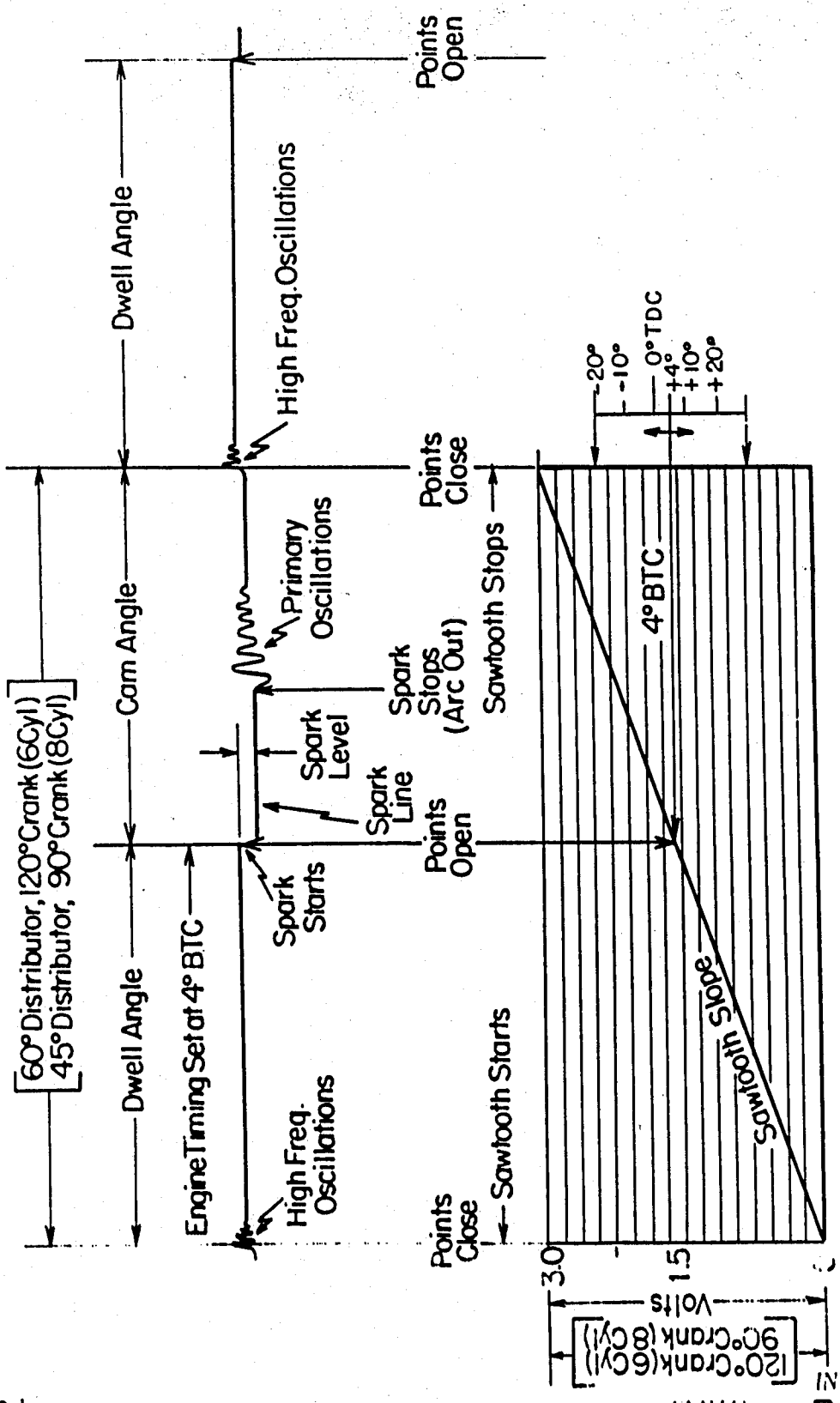


FIG. 2

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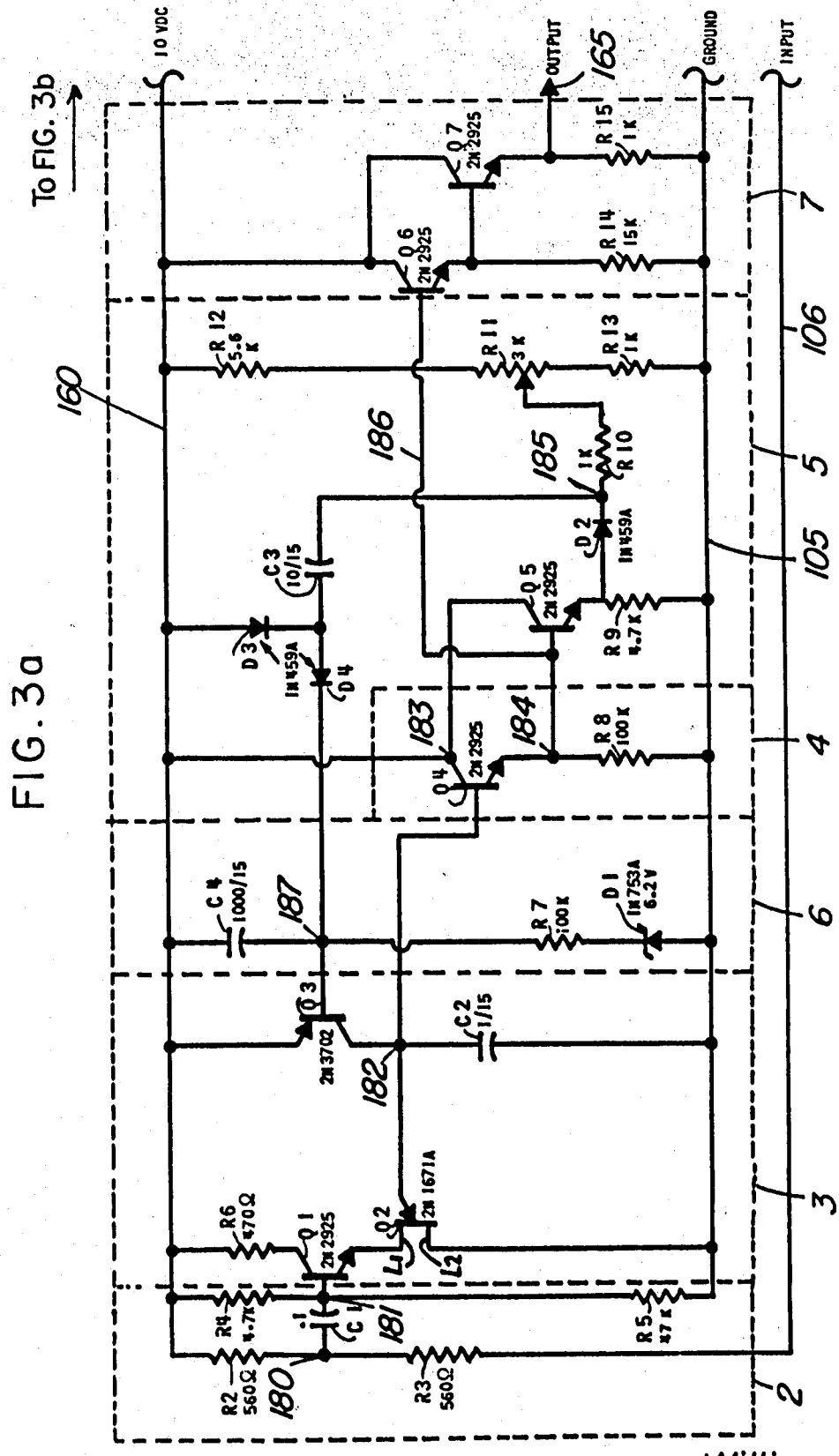


FIG. 3a

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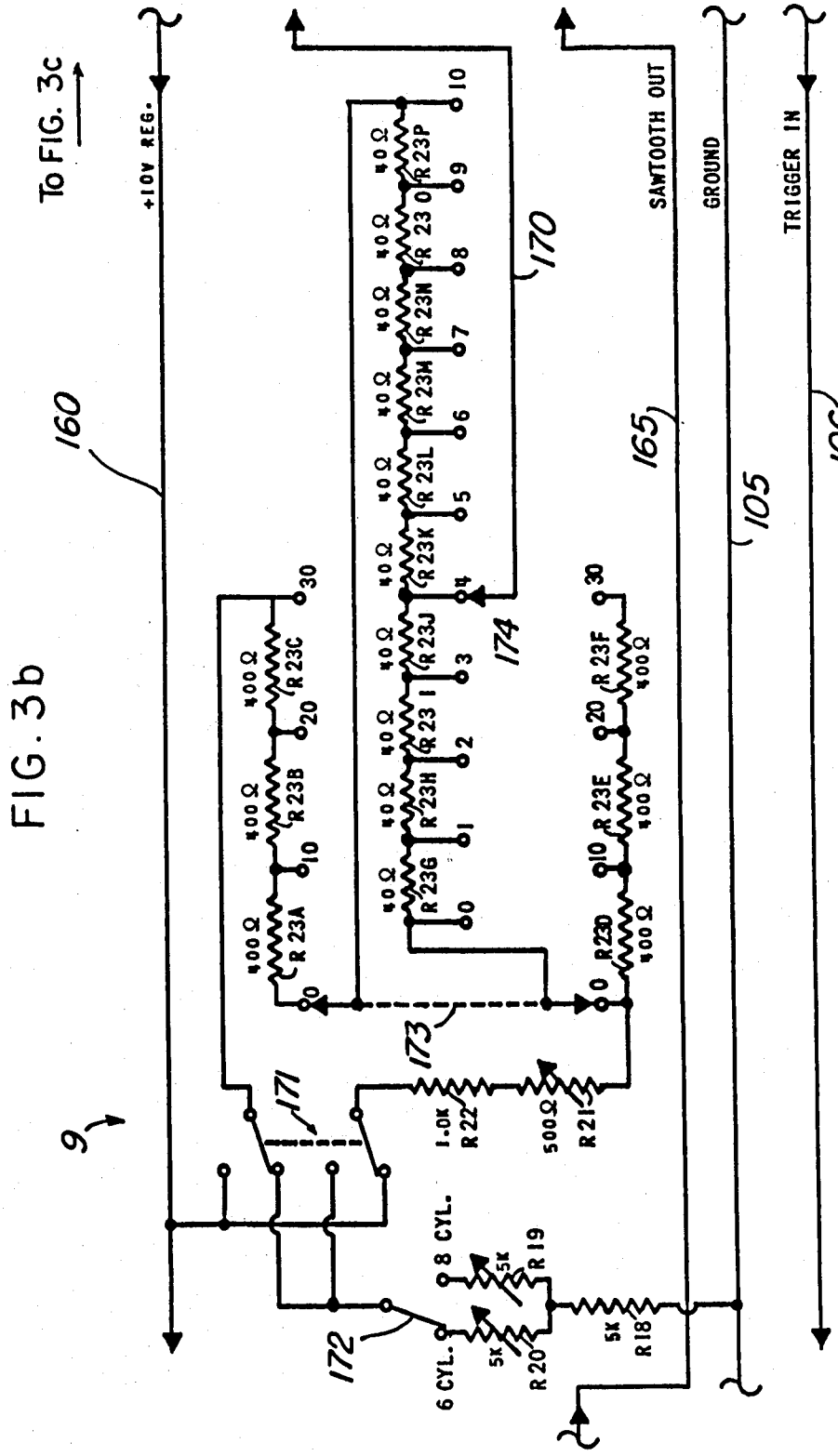


FIG. 3b

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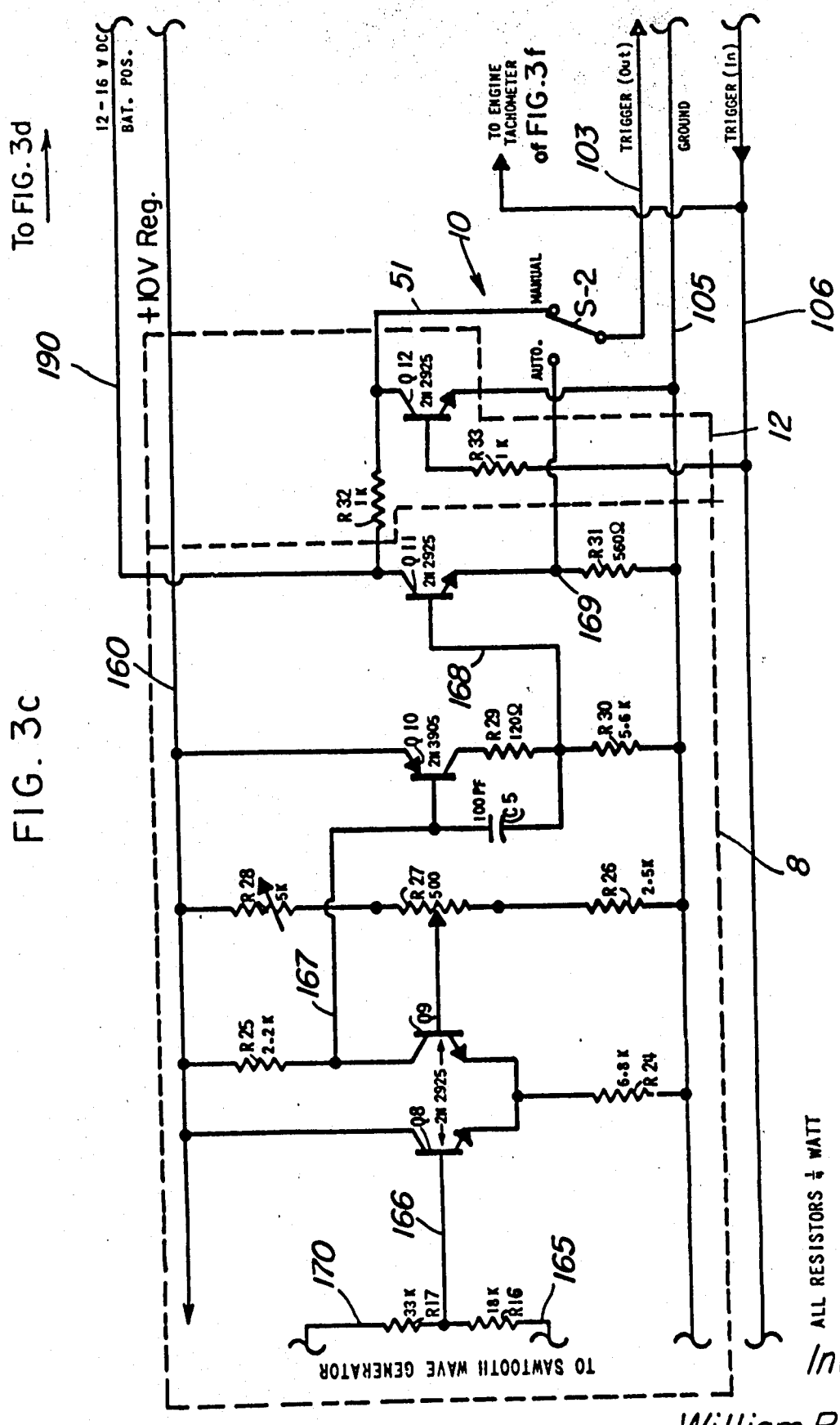


FIG. 3c

Inventor

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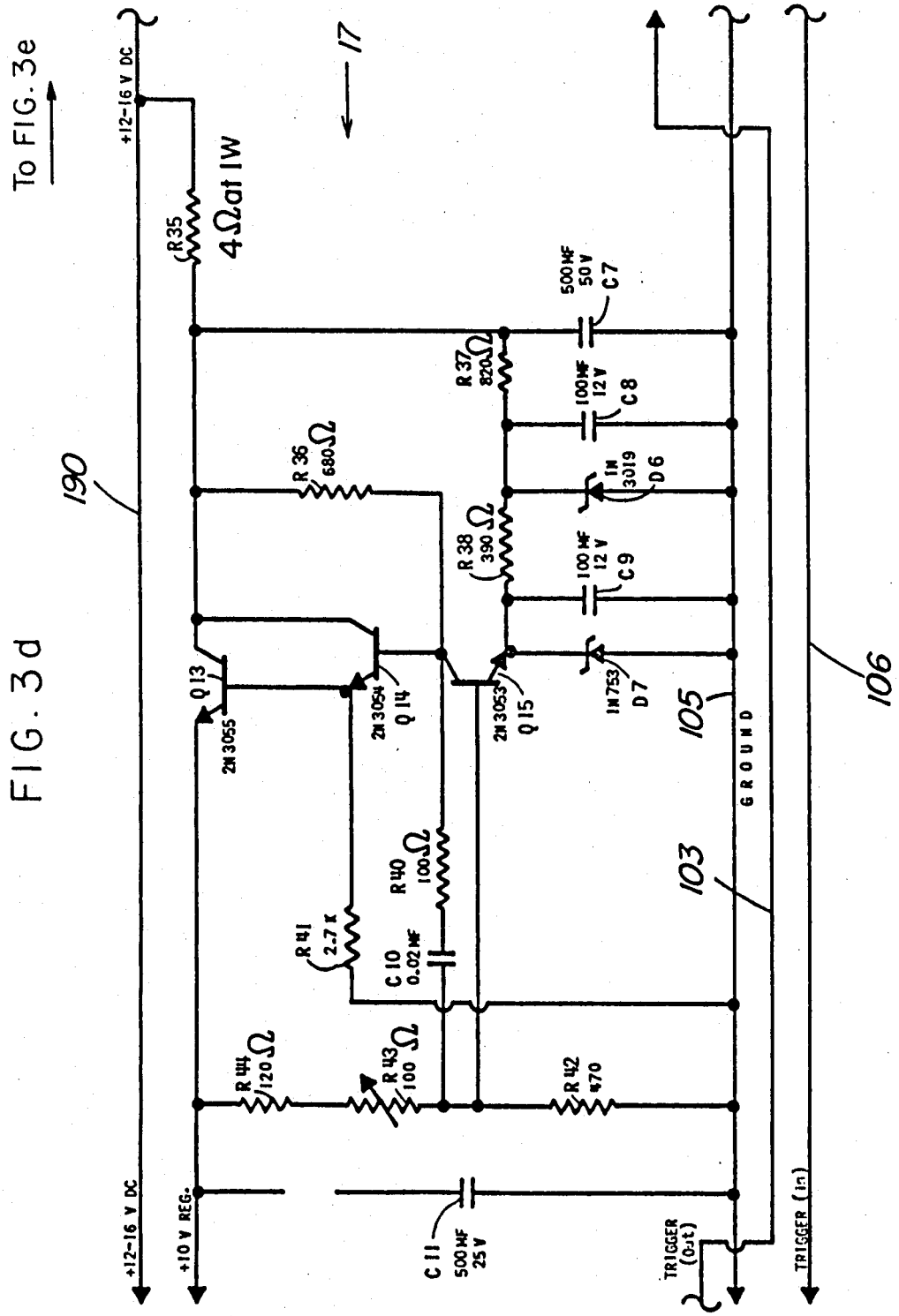


FIG. 3d

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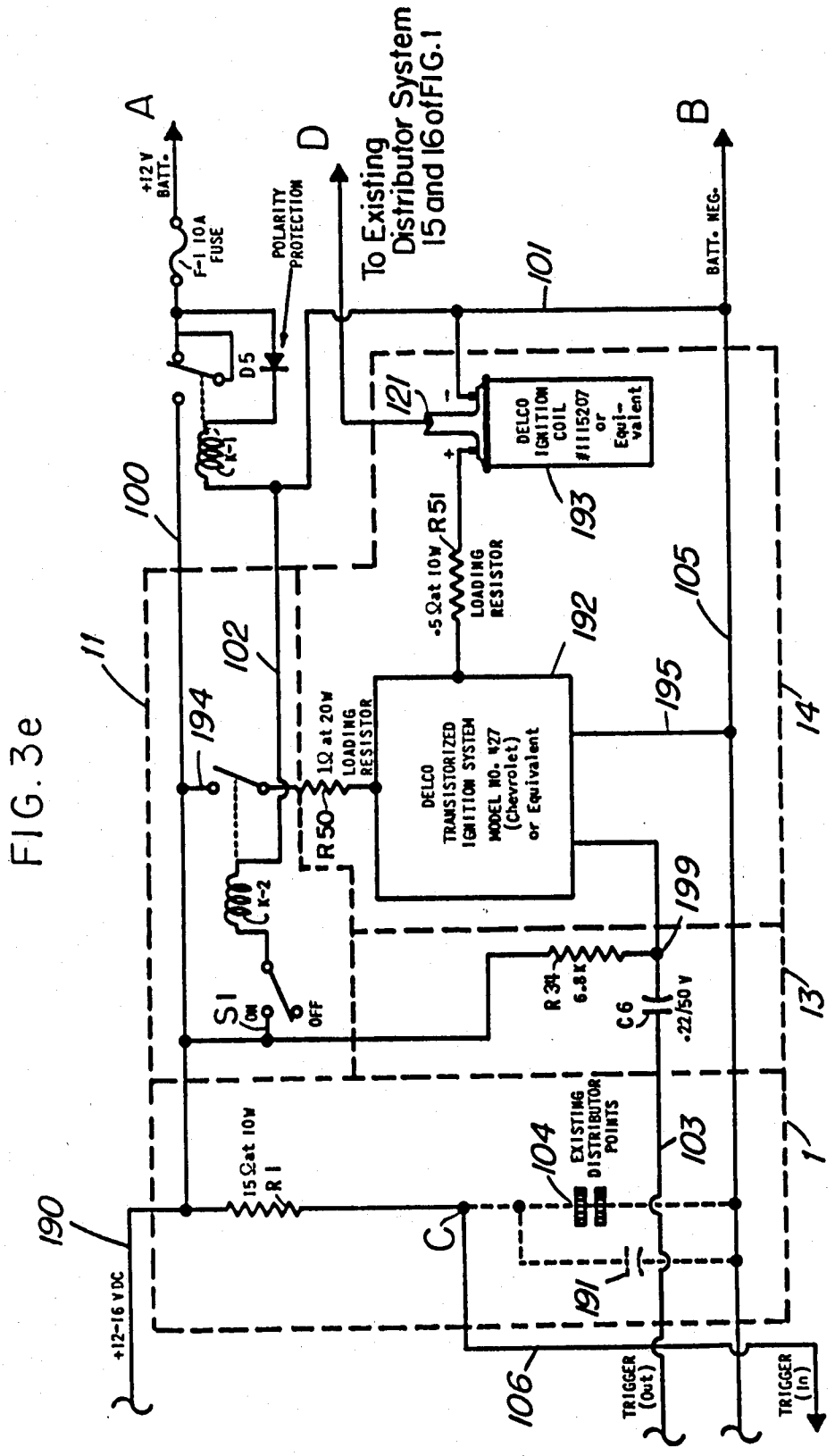


FIG. 3e

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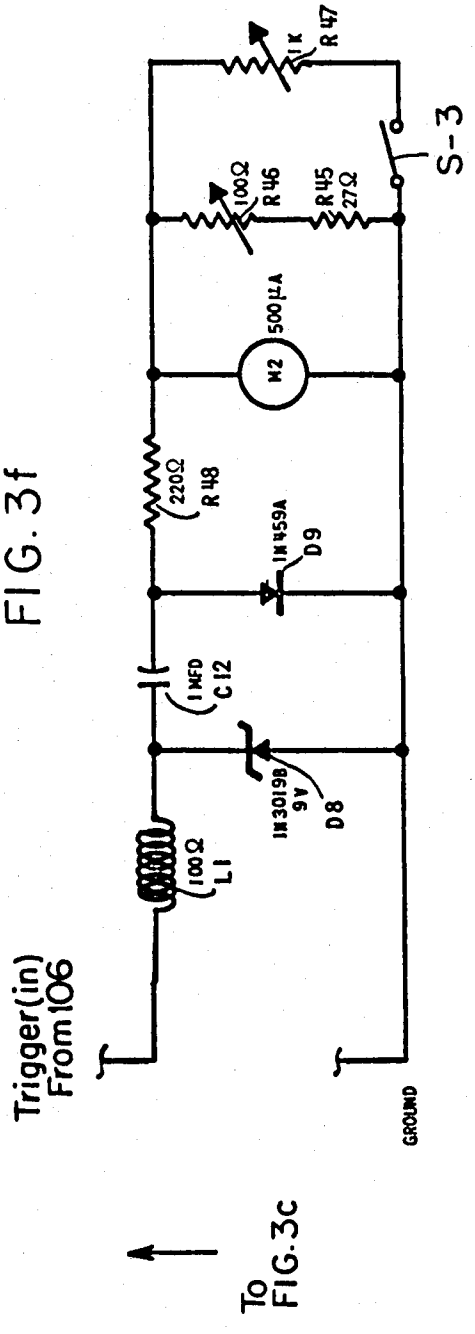


FIG. 3f

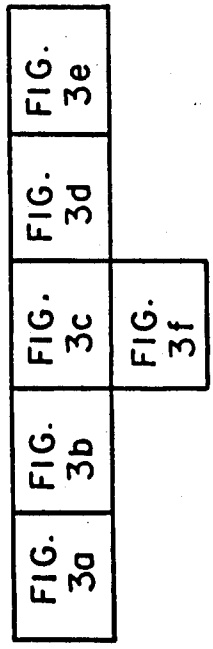


FIG. 4

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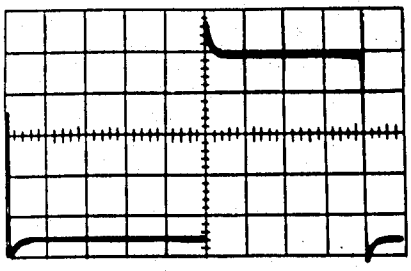


FIG. 5a

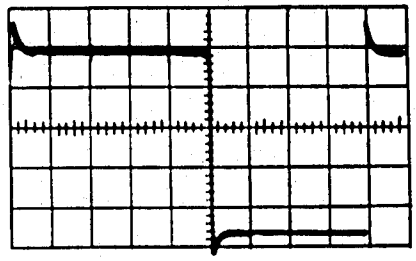


FIG. 5b

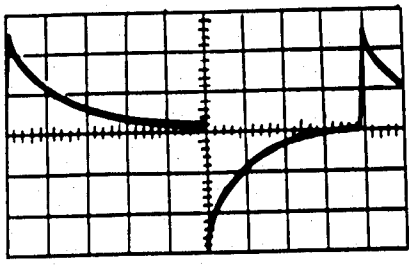


FIG. 5c

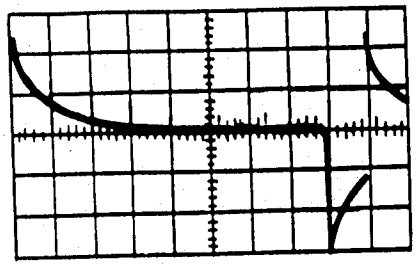


FIG. 5d

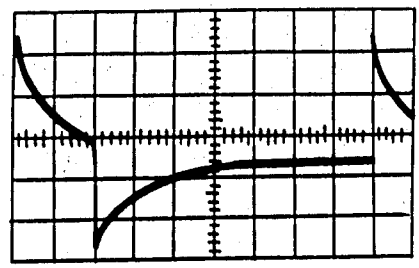


FIG. 5e

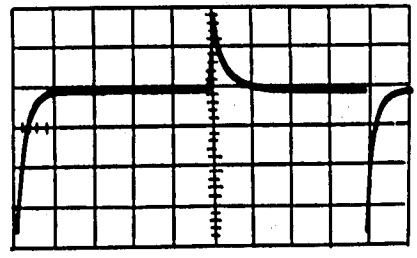


FIG. 5f

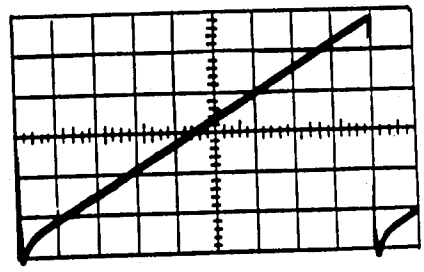


FIG. 5g

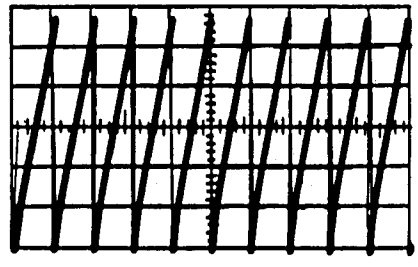


FIG. 5h

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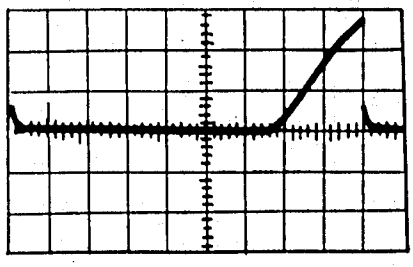


FIG. 5i

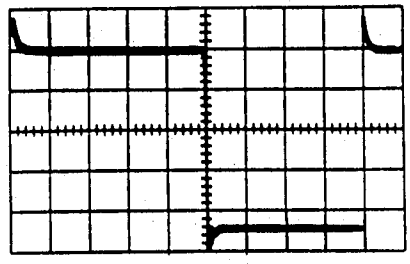


FIG. 5m

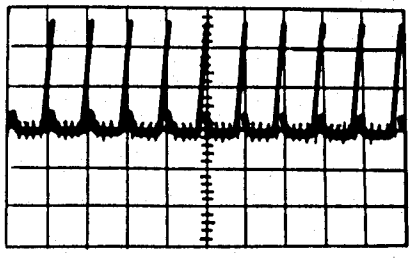


FIG. 5j

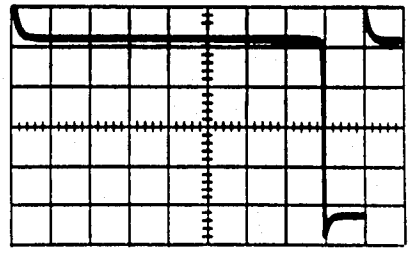


FIG. 5n

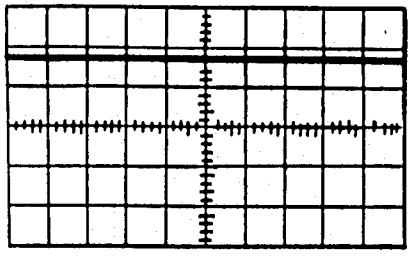


FIG. 5k

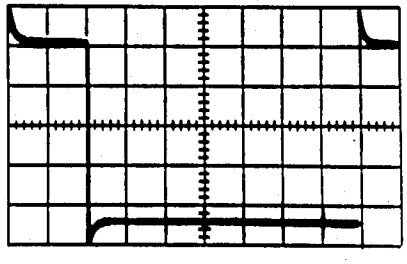


FIG. 5o

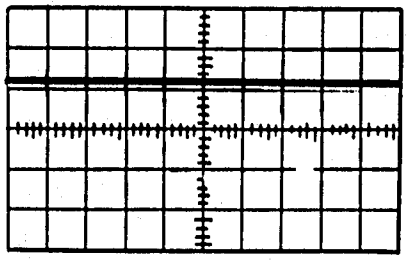


FIG. 5l

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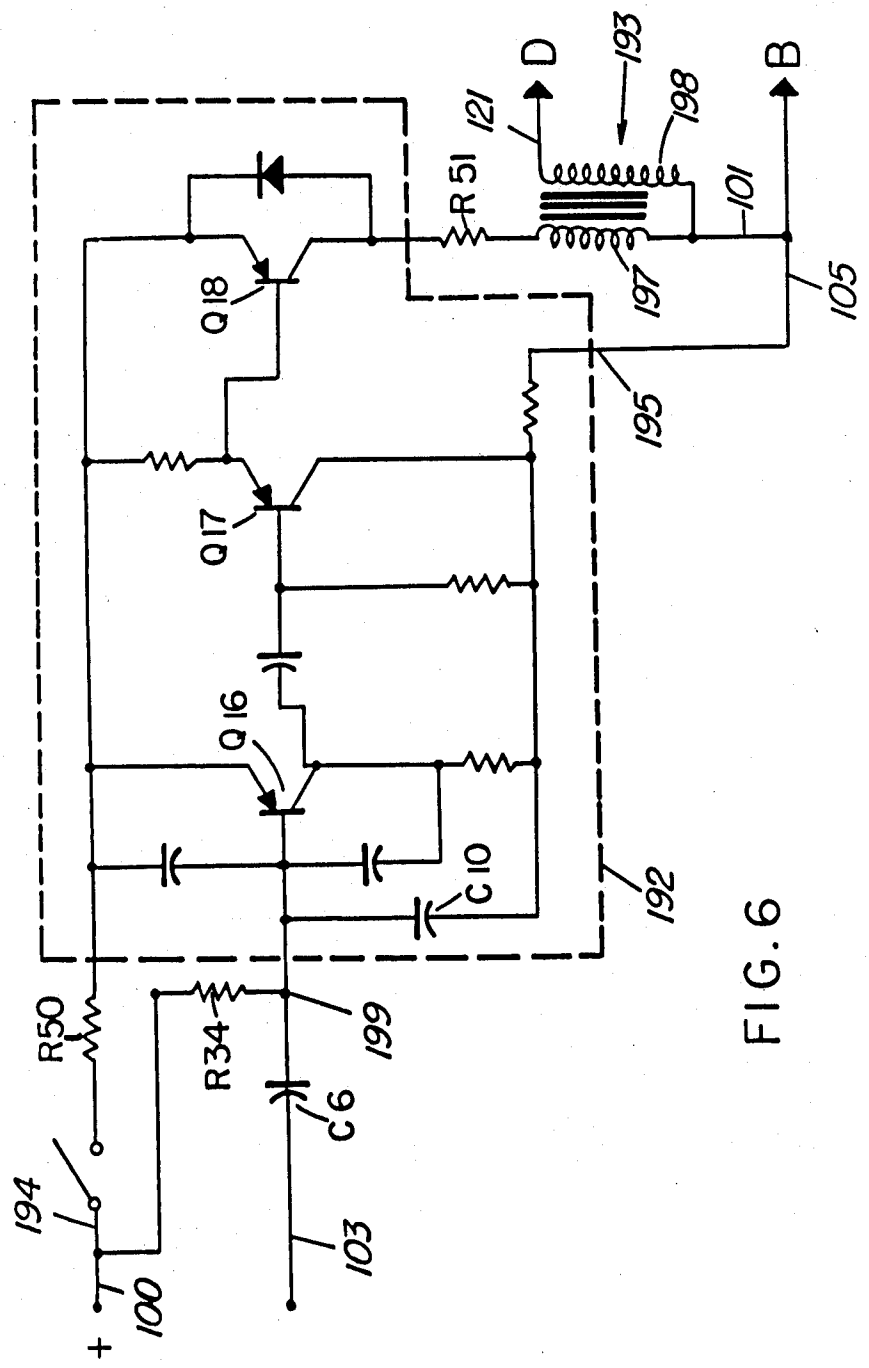


FIG. 6

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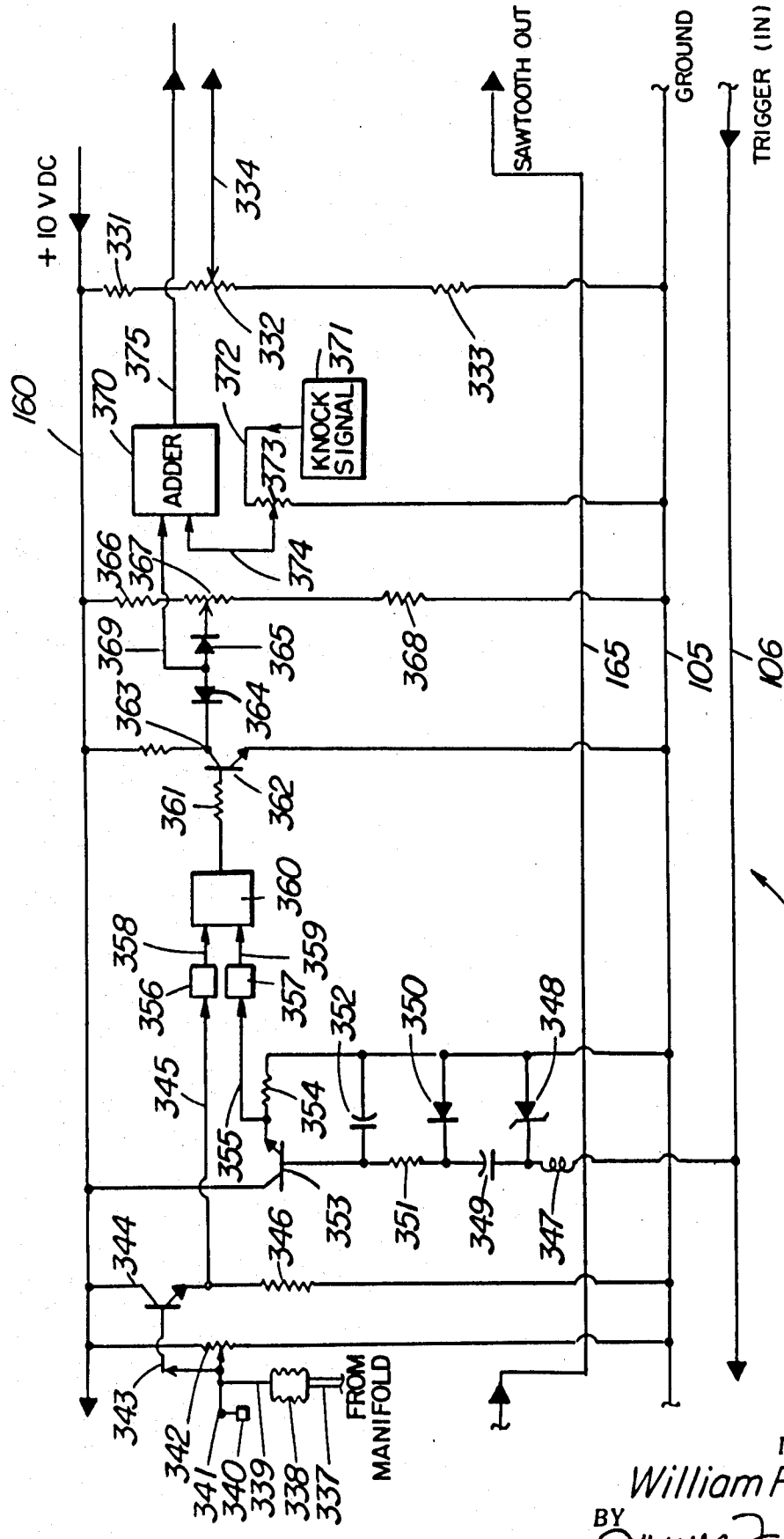


FIG. 7

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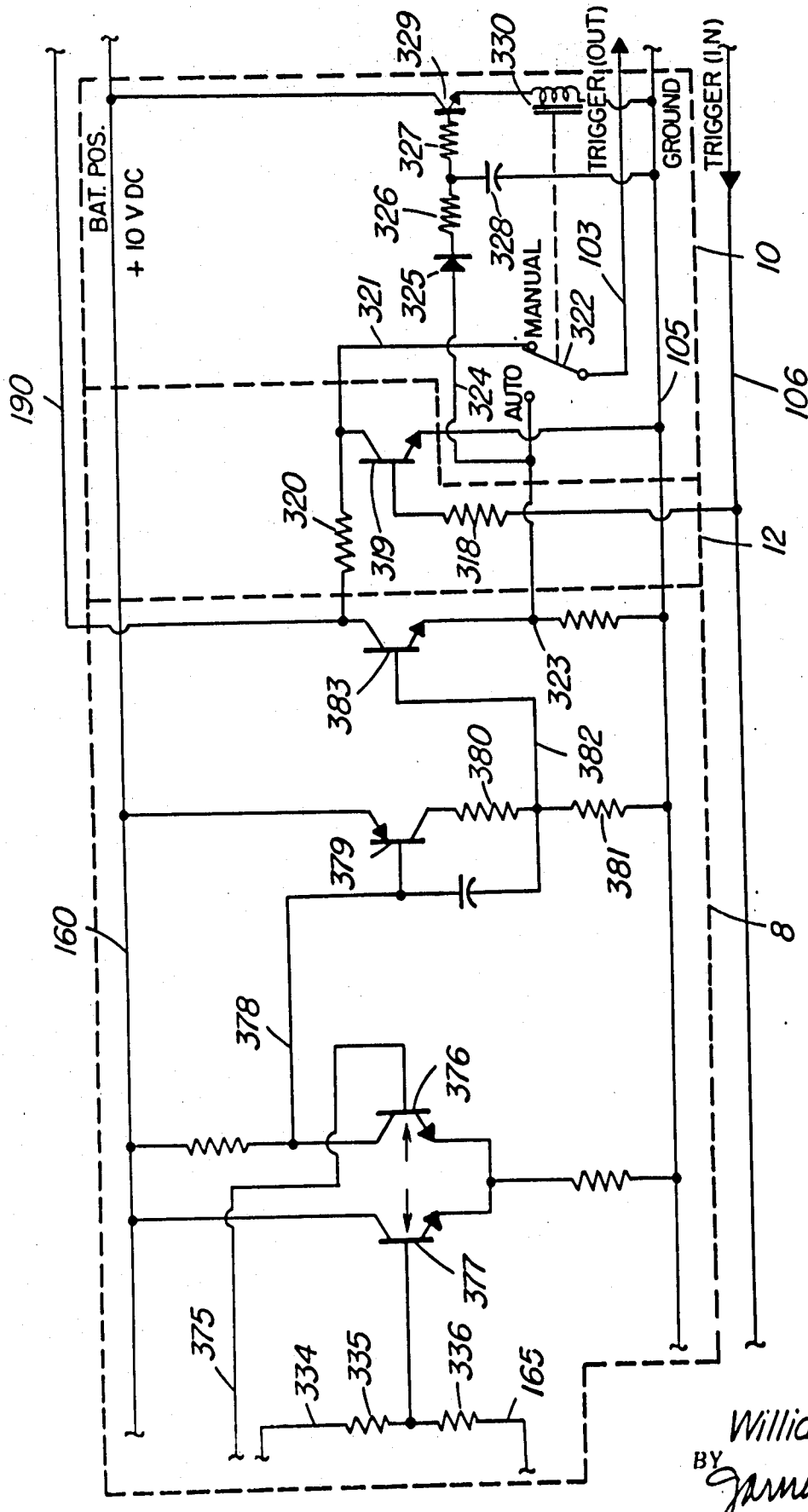


FIG. 8

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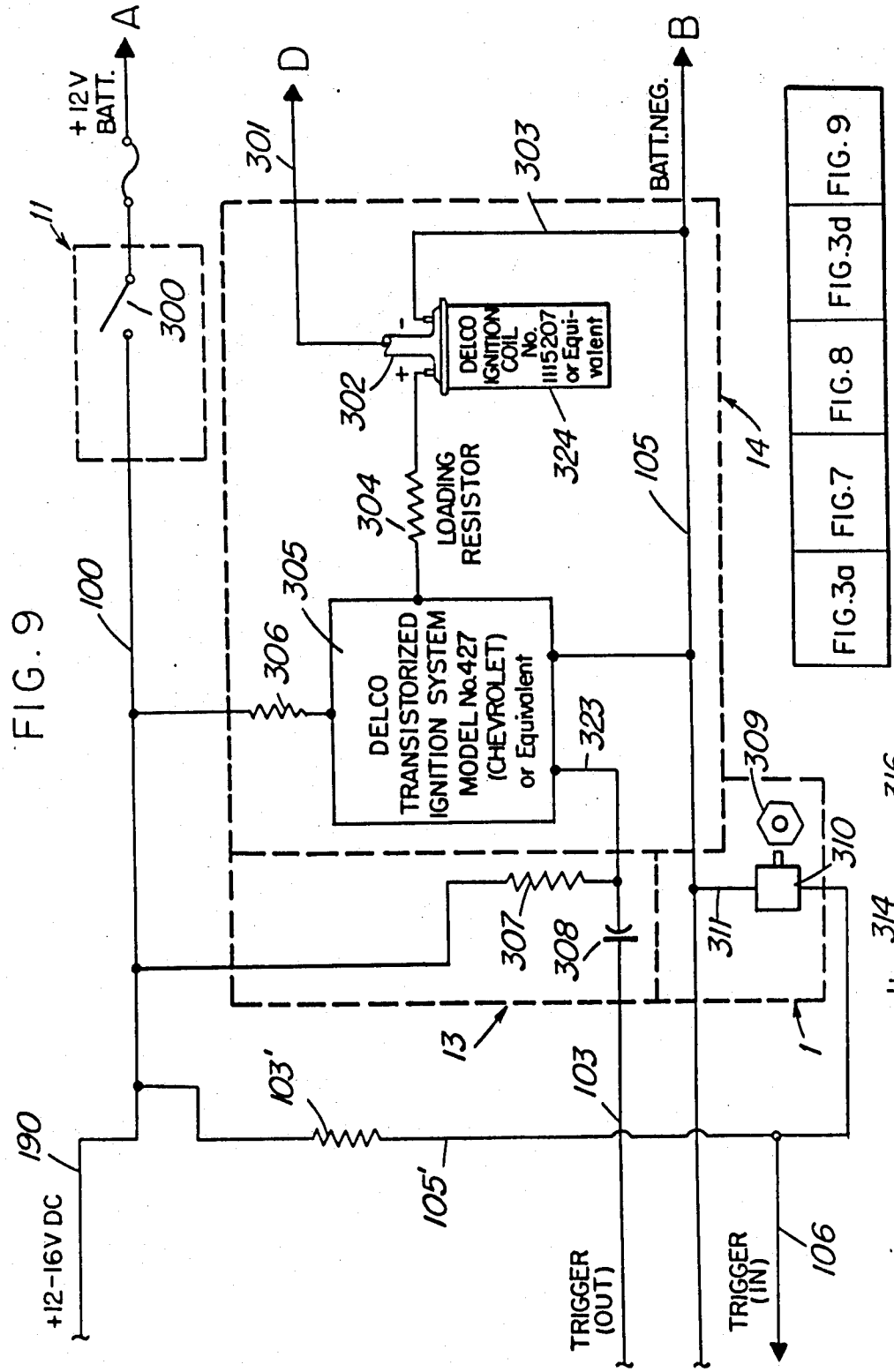


FIG. 9

FIG. 10

FIG. 11

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FIG. 12

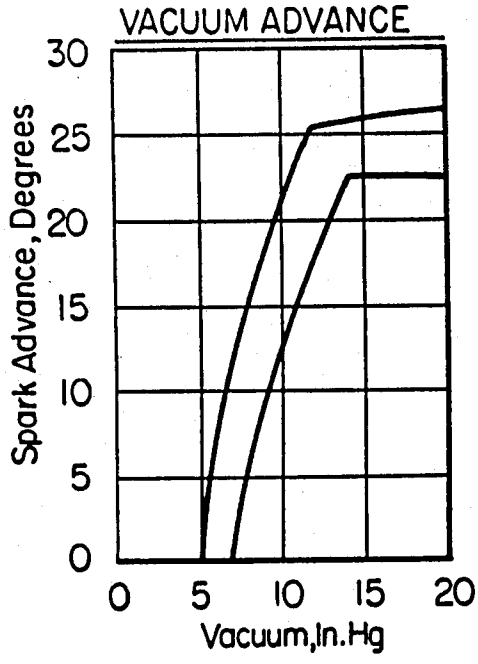
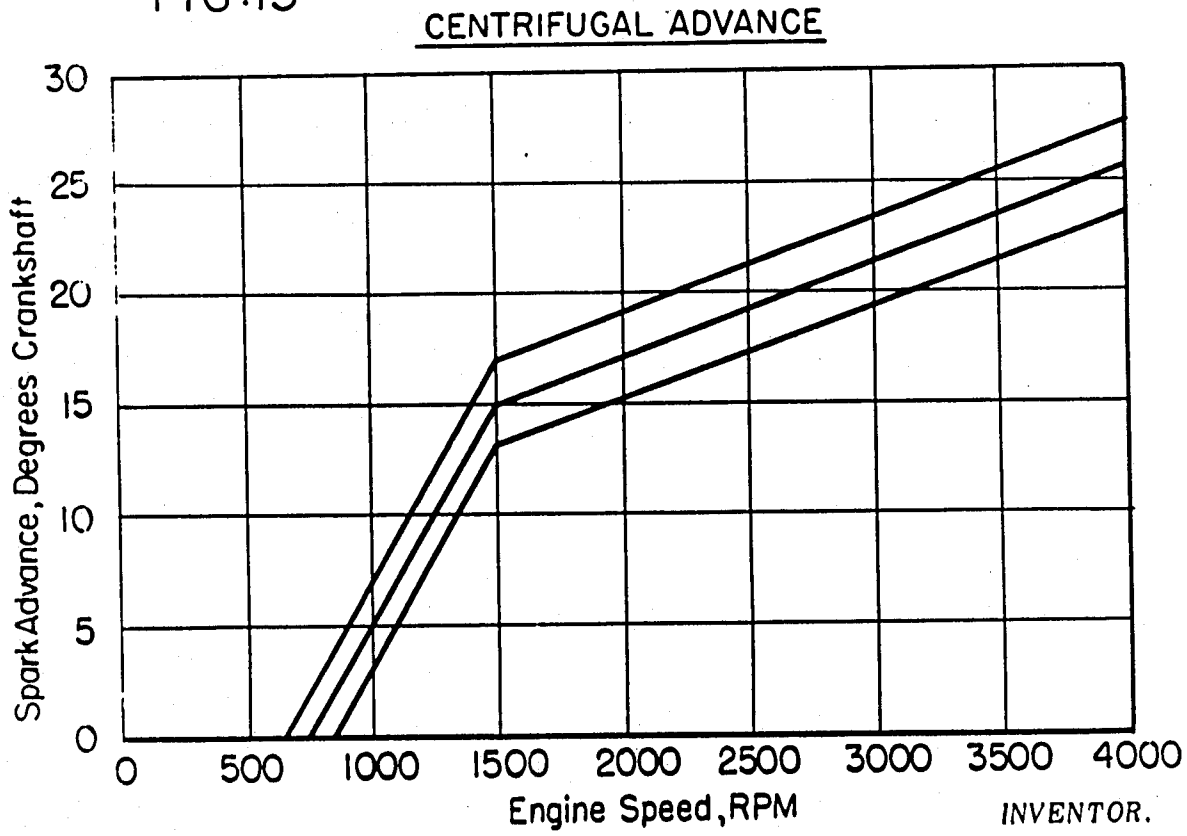


FIG. 13



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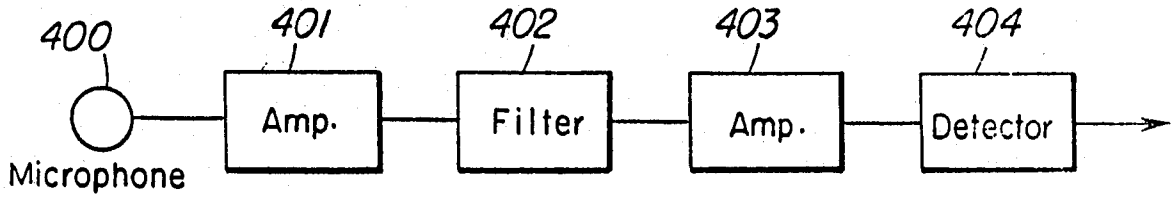


FIG. 14

FIG. 15

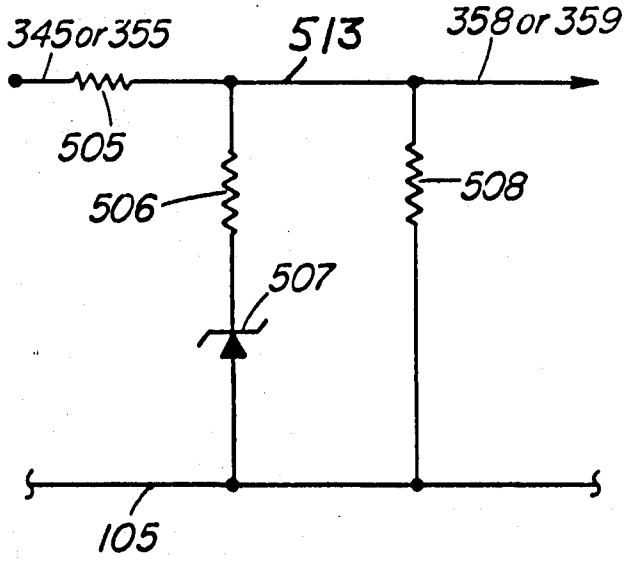
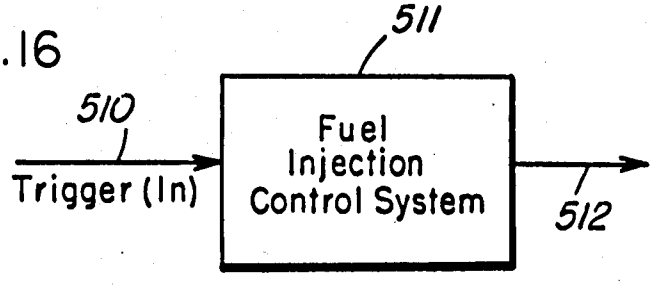


FIG. 16



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METHOD AND SYSTEM FOR CONTROLLING COMBUSTION TIMING OF AN INTERNAL COMBUSTION ENGINE

This is a continuation, of application Ser. No. 109,878, filed Jan. 26, 1971.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an engine combustion timing control system and method. More particularly, the present invention relates to a method and system for controlling spark ignition and/or fuel injection timing of an internal combustion engine.

2. Description of Prior Art

Internal combustion engines generally function by mixing fuel and air, compressing the mixture in a chamber, igniting the compressed mixture, and using the expansion of gases resulting from the heat of combustion to drive a piston which, in turn, causes a crankshaft to rotate. It is common to provide an ignition system for generating an electrical impulse which is timed in relation to rotation of the crankshaft to jump a gap inside the combustion chamber and produce a spark which ignites the mixture.

An ignition system supplies electrical energy for igniting fuel in each engine cylinder at the proper time during the engine cycle. In a conventional ignition system, a storage battery supplies the primary electrical energy which must be amplified to furnish a proper spark at each spark plug gap. The amplification is accomplished in a step-up transformer or coil having a primary winding connected in a primary circuit including the battery, and a secondary winding in which a high voltage is induced by continuous opening and closing of the circuit including the primary winding. The opening and closing of the primary circuit is generally accomplished by cam actuated breaker points. The cam is driven by a camshaft which is generally geared to rotate at one-half engine speed. The cam is customarily located at the lower portion of a distributor. The upper portion of the distributor includes another rotary switch driven by the engine that distributes the high voltage electrical energy induced in the secondary winding to the spark plugs of the engine in a proper engine firing order.

The conventional ignition system has certain characteristics which have become of increasing concern to engine designers as engine power and speed have increased. The secondary voltage output of the coil is limited at high engine speeds as a result of a time element involved in opening and closing the coil circuits. Further, the breaker points are subjected to the full primary current flow, and, therefore, are subject to burning and erosion which will require corrective maintenance from time to time. Transistorized ignition systems were developed to meet this concern. A transistorized ignition system generally acts as an amplifier and a switch.

There are many types of transistorized ignition systems. For example, a contact-controlled ignition system retains the conventional breaker points. In the contact-controlled system, the transistor circuit receives full current from the battery and directs a very small part as a control medium through the distributor points. The main output of the transistor circuit is applied to the primary of the ignition coil when the

breaker points close. The subsequent breaker point opening causes a collapse of the field about the primary of the coil to induce a high voltage in the secondary of the coil. The subsequent electrical energy distribution to the engine spark plugs is the same as in the conventional ignition system.

A variation of the foregoing contact-controlled transistorized ignition system includes a capacitor which is constantly supplied by energy from the battery. When the contact points are opened, the transistor circuit causes the capacitor to discharge to the primary of the coil. Since there is no current flow and thus no magnetic field in the coil prior to discharge of the capacitor, the discharge of the capacitor to the primary establishes a magnetic field which induces the required high voltage in the secondary of the coil. Thus, this particular system produces secondary voltage upon the closing of the breaker points rather than upon the opening of the breaker points.

A still further transistorized system is a magnetic-impulse system which replaces the breaker points with a small magnetic or pulse generator. In this system, a pole in the shape of a disc is mounted about the lower portion of the distributor and has a number of projections thereupon equal to the number of pistons. The disc is rotated within a stationary pole having an equal number of inwardly directed projections. When the projections of the stationary and rotating pole pieces are in-line, a magnetic field is established which induces a voltage in a pickup coil. The induced voltage triggers the transistor circuit to permit the electrical energy of the battery to be applied to the primary of the coil. As the projections separate, the field collapses and a small voltage of reverse polarity is again induced in the pickup coil. The voltage having the reverse polarity again triggers the transistor circuit to cause a collapse of the primary coil and thereby develop a high secondary voltage in the secondary of the coil.

An interval of time elapses between the jumping of the gap by the spark and full expansion of the gases with combustion. Ignition is therefore timed during each engine cycle to provide for the development of maximum pressure as a result of the expansion of the gases with combustion. By maintaining ignition timing at an optimum setting, the mixture is more completely burned to thereby minimize hydrocarbon emissions from the engine.

Ignition timing is commonly called spark advance when the spark is timed to be generated before the top dead center position of the piston, and is commonly called spark retard when the spark is generated after the piston passes through the top dead center position.

Ignition timing of an engine will vary with engine design and with engine operation. Specifically, a change in engine speed requires a concurrent change of ignition timing to achieve maximum power output.

It is common to use a device known generally as a "mechanical advance" which balances centrifugal force against spring tension by a series of weights, levers, and springs to provide a device sensitive to engine speed that will vary the ignition timing in response to changes in engine speed. These devices are affected by an alteration of the balance of forces caused by any change in weight due to dirt, grease or wear, and any change in spring tension due to temperature change or wear. They are also affected in their movement by dirt, grease, or the lack of it, and wear, and by any change

in consistency of the grease due to a change in temperature.

It is also common to use a device known generally as a "vacuum advance" which generally consists of a spring supported diaphragm connected to the intake manifold which will vary the ignition timing in response to the variation of the differences between the intake manifold pressure and atmospheric pressure. These devices operate on the assumption that a measurement of the variance between intake manifold pressures and atmospheric pressures will accurately reflect the pressures and temperatures within the combustion chamber. However, since the pressures and temperatures within the combustion chambers are not being measured directly, this provides only an approximation. These devices are furthermore subject to the same problems in moving as are the "mechanical advance" devices, and are additionally affected by leaks in the pressure sensitive system.

Under normal combustion, ignition will cause a rapid progressive burning wherein the flame front spreads out from the igniting spark to the more remote sections of the combustion chamber. As the flame front progresses during the burning period, the temperature and pressure in the combustion chamber rises considerably. The ensuing compression of the unburned part of the mixture by the expansion of the burning gases raises the temperature and pressure of the unburned mixture which may cause auto-ignition. In this phenomenon, the mixture which is ignited spontaneously does not burn progressively, but practically explosively with the result that rapid pressure waves are produced. The colliding wave fronts produce sounds which are generally known as combustion knock or detonation. Combustion knock or detonation generally occurs during rapid acceleration at low to medium speeds.

Combustion knock or detonation is to a large extent controlled by the anti-knock quality or octane number of the fuel. The anti-knock quality or octane number of the fuel may be controlled by adjusting the feed stock and/or control variables in a refinery process, and by the use of additives such as tetraethyl-lead. However, the trend at this time is to minimize or avoid the use of additives such as tetraethyl-lead.

Engine mechanical and operating factors also exert a considerable influence upon combustion knock. The tendency to knock increases slightly at lower speeds and mechanical-transmission cars and at higher speeds in automatic-transmission cars, at higher torque, as the spark timing is advanced, when the engine is overheated, when hot dried intake air is used, and at low altitudes. An increase in compression ratio by combustion-chamber deposit accumulations can also increase knocking tendencies.

Combustion knock or detonation produces inefficient and incomplete combustion of the fuel mixture, and therefore increases hydrocarbon emissions.

SUMMARY OF THE INVENTION

In a preferred embodiment of the invention, the timing of a combustion cycle of an internal combustion engine having a rotatable power shaft is controlled by a system comprising means responsive to the rotation of the power shaft for generating sequential input trigger signals having a frequency proportional to the speed rotation of the shaft. A sawtooth waveform generator responsive to the input trigger signal generates sequential sawtooth waveforms where each of the waveforms has a duration corresponding to a predetermined number of degrees of power shaft rotation having an amplitude changing as a function of time. The maximum amplitude of the waveform is maintained at a substantially constant level for all engine speeds by varying the instantaneous rate of change of the amplitude as a function of engine speed. A set point signal is generated corresponding to a predetermined angle of rotation and the set point signal is compared to amplitude of the waveform. When the amplitude of the waveform is detected as having a level equal to the set point signal so as to correspond to a predetermined angle of rotation of the power shaft, a trigger signal is generated. By adjusting the set point signal, the timing of the engine trigger signal may be adjusted to correspond with different predetermined angles of rotation without adjusting the duration of the sawtooth waveforms corresponding to a predetermined number of degrees.

In accordance with one important aspect of the invention, the amplitude of the waveform is maintained at a substantially constant level at all engine speeds by feedback means which vary the rate of change of amplitude as a function of engine speed.

In accordance with another important aspect of the invention, the instantaneous rate of change in amplitude is varied in response to a control signal having a magnitude representing the speed of the rotation of the power shaft. The control signal is then applied to a semiconductor device to control the current flow path to a charged storage means.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows in block diagram form a specific embodiment of the invention for controlling ignition timing of an engine;

FIG. 2 shows an output curve of a component of a specific embodiment of the invention which is used as a basis for controlling ignition timing of an engine;

FIG. 3*a* through 3*f* show a circuit of a specific embodiment of the invention for adjusting ignition timing of an engine;

FIG. 4 shows in block diagram form the manner in which FIGS. 3*a* through 3*f* are arranged;

FIGS. 5*a* through 5*o* show curves generated at specific points in the circuit of FIGS. 3*a* through 3*f*;

FIG. 6 shows a transistorized ignition system circuit suitable for use in the specific embodiment of FIGS. 3*a* through 3*f*;

FIG. 7 shows a circuit suitable for use as a timing control set point generator in another specific embodiment of the invention which provides for automatic ignition timing control of an engine;

FIG. 8 shows circuit components suitable for use as an adjustable voltage detector, a manual or automatic network, and a signal inverter amplifier in the embodiment for automatic ignition timing control of an engine;

FIG. 9 shows circuit components suitable for use as an engine reference signal generator, detector pulse modifier and a transistor ignition system in the embodiment for automatic ignition timing control of an engine;

FIG. 10 shows in block diagram form the arrangement of FIGS. 7, 8 and 9 with 3*a* and 3*d* as the embodiment for automatic ignition timing control of an engine;

FIG. 11 shows an engine reference signal generator suitable for use in the disclosed embodiments;

FIG. 12 shows a vacuum advance curve for a specific vehicle;

FIG. 13 shows a centrifugal advance curve for the specific vehicle;

FIG. 14 shows in block diagram form a knock signal generator suitable for use in the automatic timing control embodiment;

FIG. 15 is a circuit suitable for use as a curve shaper; and

FIG. 16 shows in block diagram form another specific enbodiment of the present invention wherein the automatic ignition timing control system is used as a basis for generating an input signal for a fuel injection control system.

DESCRIPTION OF SPECIFIC EMBODIMENTS

FIG. 1 shows in block diagram form an electronic engine ignition timing control system as a specific embodiment of the present invention. With reference to FIG. 1, the engine is started by operating an on-off circuit 11 to the on position and operating the manual or automatic network 10 to the manual position. The engine is then cranked with any known starter system (not shown). An engine reference signal generator 1 generates a reference or trigger signal during each engine piston cycle which serves as a basis for firing a spark plug.

In a more specific embodiment a positive square wave reference or trigger signal is generated at the ignition distributor breaker points between each opening and closing of the points. However, a transistor ignition system 14 used in the more specific embodiment requires a negative triggering pulse to generate electrical energy for application through an engine ignition distribution system 15 to fire the spark plugs 16. Consequently, the embodiment of FIG. 1 provides for applying the trigger signal from the engine reference signal generator by a line 50 to a signal inverter amplifier 12 wherein the trigger signals are inverted and applied by a line 51, the manual or automatic network 10 in the manual mode, and a line 52 to a trigger pulse modifier 13. The trigger pulse modifier 13 generates negative trigger pulses in response to the positive trigger signals applied thereto for application to the transistor ignition system 14 which, in turn, acts to fire the spark plugs 16 through the engine ignition distribution system 15.

After the engine is started, the manual or automatic network 10 is moved to the automatic mode. In the automatic mode, the engine reference signal generator 1 applies its reference output signal to an input modifier network 2. The input modifier network 2 generates a peaked trigger pulse in response to a negative excursion of the reference signal applied thereto, and applies the peaked trigger pulse to a sawtooth wave generator 3. The sawtooth wave generator 3 generates a sawtooth wave in response to each trigger pulse applied thereto. The sawtooth wave output of the generator 3 is applied to an emitter follower amplifier 4 wherein the sawtooth wave is current amplified.

The current amplified sawtooth signal is applied to a feedback network 5 wherein the sawtooth signal is clipped at a predetermined level, and the clipped portion of the sawtooth signal is rectified and fed as an output signal to a sawtooth amplitude control 6. The sawtooth amplitude control 6 acts to control the rate of generation of the sawtooth by the sawtooth generator in response to the frequency of the sawtooth such that the output of the sawtooth wave generator 3 is maintained at a constant amplitude.

Since the sawtooth wave generator 3 is triggered as each piston reaches a predetermined position in its cycle, for example, when the distributor points close, the length of each sawtooth output of the sawtooth wave generator 3 is proportional to the time elapsed between successive pistons in firing order reaching the predetermined position, for example, the time between successive closing of the distributor points, irrespective of engine speed. Further, since the sawtooth wave generator 3 generates a constant amplitude sawtooth output regardless of speed, it is apparent that the engine will fire at the same voltage level during each generation of the sawtooth as determined by the ignition timing of the system.

The emitter follower amplifier 4 also applies the current amplified sawtooth to another current amplifier 7 which acts to generate a sawtooth output sufficiently strong to minimize the possibility of distortion of the signal. The current amplified sawtooth output signal from the amplifier 7 is applied to an adjustable voltage detector 8. The adjustable voltage detector 8 also has applied thereto a signal from a timing control set point generator 9.

Since a particular timing setting will cause the engine to fire at the same voltage level on the sawtooth, the sawtooth wave is used as a basis for adjusting the ignition timing control of the engine. This is accomplished by adjusting the timing control set point generator 9 to a particular set point which acts to apply a set point signal to the adjustable voltage detector 8 to determine the voltage level detected by the adjustable voltage detector 8.

In a more specific embodiment, the adjustable voltage detector 8 generates a negative square wave signal upon sensing the voltage level during the generation of each sawtooth as determined by the setting of the timing set point generator 9. The negative square wave output of the adjustable voltage detector 8 is applied through the manual or automatic network 10 which is in the automatic mode to the trigger pulse modifier 13 by way of the line 52. In response to the output of the detector 8, the trigger pulse modifier 13 generates peaked negative trigger signals which are applied to the transistorized ignition system 14 to thereby trigger the ignition system 14 to provide high voltage distribution to the spark plugs 16 through the distributor 15. Thus, the sawtooth voltage level detected by the detector 8 determines the ignition timing of the engine.

The embodiment of FIG. 1 also provides for applying the output of the engine reference signal generator 1 to an engine speed tachometer 18 for monitoring the speed of the engine. Further, FIG. 1 applies a positive voltage from the battery of the vehicle as indicated by the dashed line leading therefrom to the engine reference signal generator 1, the signal inverter amplifier 12, the trigger pulse modifier 13, the adjustable voltage detector 8, and a regulated power supply 17. The regulated power supply 17 supplies a suitable regulated power to the input modifier network 2, the sawtooth wave generator 3, the emitter follower amplifier 4, the feedback network 5, the sawtooth amplitude control 6 the current amplifier 7, the adjustable voltage detector 8, and the timing control set point generator 9.

In a spark ignition engine, a distributor shaft is typically geared to a crank shaft at a 1-to-2 ratio. Thus, as shown in FIG. 2 successive point closings will occur during each 60° rotation of the distributor shaft or 120° rotation of the crank shaft for a 6-cylinder engine. In an 8-cylinder engine, successive point closings will occur at each 45° rotation of the distributor shaft or 90° rotation of the crank shaft. As the points close, high frequency oscillations will be generated at the output of the ignition coil for a short period of time. When the points open as determined by the ignition timing, an ignition coil discharges to apply a high voltage to a spark plug as determined by the distribution system. This spark level will cause the spark plug gap to be bridged and will be maintained for a period of time as shown in FIG. 2. The spark will then stop and primary oscillations will occur in the ignition coil output. This voltage level will be maintained until the points close which will again cause high frequency oscillations in the output of the ignition coil.

As shown in FIG. 2, a more specific embodiment of the invention which will be described hereinafter with reference to FIGS. 3*a* through 3*f*, provides for beginning the generation of a sawtooth wave when the points close and continuing the generation of the sawtooth wave until the points again close. In a typical ignition system, a high voltage is applied to a spark plug when the points open to thereby disconnect the primary of an ignition coil and cause electrical energy to be discharged through the secondary coil to the center tap of a distributor. Ignition timing or the time during each cycle when the contacts are open is generally determined by the relative position of a cam lobe which is driven by the distributor shaft. If the cam lobe is positioned such that the spark is generated before a piston reaches top dead center, it is termed spark advance, and conversely, if the spark is generated after the piston reaches top dead center, the timing is termed spark retard.

In the more specific embodiment, the ignition coil of the vehicle is disconnected from the center tap of the distributor, and a transistorized ignition system which includes an ignition coil is connected to the distributor.

Although the coil is disconnected from the center tap of the distributor, the more specific embodiment uses existing vehicle points in the engine reference signal generator 1 to provide a reference or trigger signal to the sawtooth wave generator 3 to begin the generating of a sawtooth wave when the points close. At the next closing of the points, the sawtooth wave generator terminates the generation of a wave and begins generating a new sawtooth. Thus, as shown in FIG. 2, the sawtooth wave is generated between two successive closings of the points. By adjusting the timing control set point generator 9 to cause the adjustable voltage detector 8 to detect a voltage along the slope of the sawtooth, a trigger signal is generated and applied to the trigger pulse modifier 13 for triggering the transistor ignition system 14. Thus, the invention provides for total timing adjustment during any point in time during an engine cycle. For example, in an 8-cylinder engine wherein successive point closings occur during each 90° rotation of the crank shaft, the timing may be adjusted to 45° advance or 45° retard. However, it will be understood that in a typical engine the usable advance-to-retard timing range will be determined by the design of the engine, and that there generally occurs a point during the rise of a piston before which ignition will cause the piston to move downwardly rather than to continue its upward rise. Similarly, during the downward movement of a piston, there will be a point in time when the valves will open and thus require that the ignition occur prior to this time.

In a conventional vehicle such as a 1970 Ford having an 8-cylinder engine, the normal practical maximum advance is 30° and the typical practical retard maximum is 20°. This operating range is reflected on the right ordinate of the sawtooth wave in FIG. 2.

The specific embodiment of FIGS. 3*a* through 3*f* provides a system for adjusting ignition timing which may be used to determine road octane ratings. To determine road octane ratings, a specific vehicle is operated on a plurality of fuels having known octane numbers, and the ignition timing of the vehicle is adjusted while operating on each of the fuels until the engine begins to knock. Knock will generally occur by advancing the timing. A curve is plotted with points defined by a timing to cause knock, and by an octane number. With this curve, the vehicle is operated on unknown fuels and the timing is adjusted until knock occurs. The curve is then entered with the timing setting to determine the octane number of the unknown fuel. As a general rule, the curves thus generated are substantially linear.

The knock of an engine may be determined by placing a microphone inside the vehicle near the fire wall which separates the interior of the vehicle from the engine. The operator of the vehicle may have a headset which is connected to the microphone, and thus will be able to hear the engine as it begins to knock. Skilled operators may be able to hear the beginning of knocking from inside the vehicle without the aid of a microphone.

FIGS. 3*a* through 3*f* show a detailed circuit arrangement for controlling the ignition timing of an engine to determine the timing point at which knock occurs. As shown in FIG. 4, FIGS. 3*a* through 3*e* are arranged end-to-end and FIG. 3*f* is connected to FIG. 3*c*.

Referring to FIG. 3*e*, the circuit is attached to the ignition system of the vehicle by connecting points A and B to the positive and negative battery terminals, respectively. Point C represents a connection at the distributor breaker point terminal, and point D represents a connection to the distributor high voltage input terminal.

When points A and B are connected as shown, current will flow from point B at the negative terminal of the battery through a coil of a relay K–1, a diode D–5, a fuse F–1 to point A at the positive terminal of the battery. Current flow through the coil of the relay K–1 acts to move the switch arm of the relay K–1 to the position not shown in FIG. 3*e*, and thereby connect a line 100 to the positive terminal of the battery. The diode D–5 provides polarity protection for the circuit by preventing current flow through the relay K–1 in the event that the points A and B are connected to the negative and positive terminals, respectively, of the battery.

FIG. 3*e* shows the engine on-off circuit 11 as comprising an on-off switch S–1 connected in series with a coil of a single pole relay K–2. To start the engine, the switch S–1 is closed to permit current flow from the point B at the negative terminal of the battery along a line 101, a line 102, the coil of the relay K–2, the closed switch S–1, the line 100, the contact arm of the relay K–1 (in the position not shown), the fuse F–1 and to

the point A at the positive terminal of the battery. Current flow through the coil of the relay K-2 acts to close its contact arm to thereby connect the line 100 through a loading resistor R-50 to the transistor ignition system 192.

The transistor ignition system 192 may be any commercially available system such as that manufactured by Delco under Model No. 427. The output of the transistor ignition system 14 is applied through a loading resistor R-15 to the input of an ignition coil of the vehicle. When the Delco Model No. 427 is used, a suitable ignition coil is that manufactured by Delco as Part No. 1115207. The output terminal 121 of the coil is connected through the point D to the high voltage input terminal of the distributor of the vehicle.

The reference signal generator 1 is shown in FIG. 3*e* as including a resistor R-1 connected in series with the existing distributor points 104 of the vehicle through the point C and between the line 100 and a line 105 connected to the negative terminal of the battery through the point B. When the points 104 are closed, the voltage at C is ground, and when the points open, the voltage at C is approximately 12 volts. Thus, between successive closings of the distributor points a positive square wave pulse will be generated whenever the points open. FIG. 5*a* shows an oscilloscope wave shape at point C where the timing is at top dead center.

The square wave signal developed at point C is applied along a line 106 to the signal inverter amplifier 12 shown in FIG. 3*c*. The inverter amplifier 12 includes a transistor Q-12, a resistor R-32, and a resistor R-33. The output of the signal inverter 12 is applied along the line 51 to the manual-automatic network 10 which includes a three position switch S-2. When the engine is being started, the switch S-2 is placed in the manual position as shown in FIG. 3*c*.

When a voltage on the line 106 is at ground, the voltage at the base of the transistor Q-12 is also at ground and thus the transistor Q-12 is turned off. Accordingly, the voltage at the collector of the transistor Q-12 is at +12 volts as sensed through the resistor R-32 which is connected to a line 190, which, in turn, is connected to the positive terminal of the battery. When the positive square wave signal is generated on the line 106, it is applied through the resistor R-33 to the base of the transistor Q-12 to turn the transistor Q-12 on and thus cause current to flow from the ground 105 through the emitter and the collector of the transistor Q-12, through the resistor R-32 to the line 190 connected to the positive terminal of the battery. When this occurs, the voltage at the collector of the transistor Q-12 decreases, and accordingly causes a negative square wave, such as shown in FIG. 5*b*, to be applied through the switch S-2 along a line 103 to the trigger pulse modifier 13 shown in FIG. 3*e*.

The trigger pulse modifier 13 includes a capacitor C-6 and a resistor R-34. As shown in FIG. 3*e*, the capacitor C-6 normally has 12 volts impressed thereacross. When the voltage to the left of the capacitor C-6 goes negative as a result of the inverted wave form applied thereto from the switch S-2 (FIG. 3*c*), a negative wave is developed to the right of C-6 for application to the ignition system 14. The pulse developed to the right of the capacitor C-6 is a negative sharp peaked pulse, such as shown in FIG. 5*c*, which acts to trigger the transistor system 14, which, in turn, removes power from the primary of the ignition coil 120 to cause the ignition coil to discharge through the secondary and thus apply a pulse at terminal 121 to the center tap of the distributor.

FIG. 5*c* shows timing at point 199 at 0° or top dead center. FIG. 5*d* shows timing at point 199 at 30° retard and FIG. 5*e* shows the output of the trigger pulse modifier 13 at 30° advance.

After the engine is started, the manual-automatic network 10 is moved to its automatic mode by operating the switch S-2 (FIG. 3*c*) to the automatic position. In this mode, adjustment of the timing control set point generator 9 (FIG. 3*b*) will cause the adjustable voltage detector 8 (FIG. 3*c*) to detect a predetermined voltage along the sawtooth slope and thus serve to adjust the ignition timing of the system.

In the automatic mode, the engine reference signal is applied from point C of FIG. 3*e* along the line 106 to the input of the input modifier network 2 which is shown in FIG. 3*a* as including a voltage divider network including resistors R-2 and R-3, resistors R-4 and R-5, and a capacitor C-1.

In the specific embodiment shown, the resistors R-2 and R-3 are equal, and thus only half of the reference signal is impressed across the capacitor C-1. The right side of the capacitor C-1 is initially at a positive 10 VDC as a result of being connected through the resistor R-4 to the line 160 which, in turn, is connected to the regulated power supply 17.

As the square wave pulse applied to the input modifier network 2 goes negative, a negative peaked pulse is generated at the right of the capacitor C-1 at point 181. This occurs whenever the points close as shown in FIG. 5*f*. This negative peaked pulse is applied to the sawtooth wave generator 3 which in FIG. 3*a* includes transistors Q-1, Q-2 and Q-3.

The transistor Q-1 is normally turned on as a result of the positive 10 VDC applied to its base through the resistor R-4. Terminal L-1 of the transistor Q-2 is normally at a higher potential than terminal L-2 of the transistor Q-2 because Q-1 is turned on.

The application of the negative peaked pulse from the capacitor C-1 to the base of the transistor Q-1 acts to turn the transistor Q-1 off to thus cause the potential at the terminal L-1 of the transistor Q-2 to diminish to the firing level of transistor Q-2. At this time, the capacitor C-2 is discharged very rapidly through the terminal L-2 of the transistor Q-2. However, the capacitor C-2 is immediately placed into a charged state as a result of the regulated VDC voltage impressed across the transistor Q-3 and the capacitor C-2. Therefore, the capacitor C-2 begins to linearly charge. The capacitor C-2 continues to charge until the next negative peaked pulse is generated at the point 181 to the right of the capacitor C-1 for application to the base of the transistor Q-1.

The sawtooth wave developed at a point 182 of FIG. 3*a* is applied to the emitter follower amplifier 4 which comprises a transistor Q-4. The transistor Q-4 acts to current amplify the sawtooth wave applied to the base of the transistor Q-4. The current amplification is proportional to the value of a resistor R-8. The transistor Q-4 also acts to isolate the capacitor C-2 by preventing the capacitor C-2 from bleeding. The current amplified sawtooth wave developed at point 183 from the emitter of the transistor Q-4 is applied to the feedback network 5. FIG. 5*g* shows a sawtooth wave for 500 RPM and FIG. 5*h* shows a sawtooth wave for 5,000 RPM. The

feedback network 5 is shown in FIG. 3*a* as including a transistor Q–5.

The sawtooth wave is applied from the point 184 to the base of the transistor Q–5 where it is again current amplified across a resistor R–9. The feedback network also includes resistors R–11, R–12 and R–13 which form a voltage divider network. The resistor R–11 is a potentiometer which is moved to a suitable position such that a predetermined DC voltage is applied to a point 185 between a diode D–2 and a resistor R–10. The DC voltage applied to the point 185 acts to clip the sawtooth wave developed at point 185 to thus generate a series of peaked pulses the amplitude of which is determined by the level of the DC voltage at the point 163. FIG. 5*i* shows a clipped peak with engine at 500 RPM, and FIG. 5*j* shows clipped peaks with engine at 5,000 RPM.

The feedback network also includes a rectifier circuit including diodes D–3 and D–4. The rectifier circuit including the diodes D–3 and D–4 rectifies the clipped portions of the sawtooth, and applies the rectified signal to the sawtooth amplitude control 6 which in FIG. 3*a* includes a capacitor C–4, a resistor R–7 and a zener diode D–1.

In the specific embodiment, C–4 has a 6.2 volt applied at its lower side as determined by the particular zener diode D–1 shown in FIG. 3*a*. The rectified signal applied to the lower end of the capacitor C–4 at point 187 controls the voltage potential across the capacitor C–4. The potential across the capacitor C–4 is reflected between the base of the transistor Q–3 and the emitter of Q–3 connection to the line 160. An increase in potential between the base and the emitter of the transistor Q–3 reduces its resistance and thereby permits a greater rate of current flow therethrough to charge the capacitor C–2. Thus, the capacitor charge rate will be determined by the number of peaks applied to the rectifier comprising the diodes D–3 and D–4. The number of peaks per unit time applied to the rectifier comprising the diodes D–3 and D–4 is determined by the speed of the engine as reflected by the firing rate of the spark plugs. Thus, as the engine increases in speed, the engine reference signal generator 1 will cause a greater number of pulses to be generated which number of pulses is reflected by an equivalent number of sawtooth waves generated by the sawtooth wave generator 3 which are then clipped in the feedback network 5 and the clipped portions are applied to the rectifier comprising the diodes D–3 and D–4 which generates a rectified signal for the sawtooth amplitude control 6 to control the charging rate of the capacitor C–2 of the sawtooth wave generator 3. In this matter, the amplitude of the sawtooth as developed at the point 182 of FIG. 3*a* is maintained at a constant level.

By way of an example FIGS. 5*k* and 5*l* show signals developed at the point 187 at engine speeds of 500 RPM and 5,000 RPM, respectively. The signal of FIG. 5*l* for the higher engine speed is lower than that of FIG. 5*k*. Accordingly, the potential between the base and the collector of the transistor Q–3 is higher when the engine is operated at a higher speed to thereby increase the charge rate of the capacitor C–2.

The output from the emitter follower amplifier 4 is applied to a 2-stage current amplifier 7 which comprises transistors Q–6 and Q–7 and resistors R–14 and R–15. The amplified sawtooth wave developed at the point 184 of FIG. 3*a* is applied along a line 186 to the base of the transistor Q–6 through the amplifying two-stage amplifier comprising the transistors Q–6 and Q–7, and is fed as an output along a line 165 to an adjustable voltage detector 8 which is shown in FIG. 3*c*.

With reference to FIG. 3*c*, the adjustable voltage detector 8 includes transistors Q–8, Q–9 and Q–10, and resistors R–16, R–17 and R–24 through R–30, and a capacitor C–5. The base of the transistor Q–9 is kept at a positive potential as determined by the setting of an adjustable resistor R–27 which acts to maintain the transistor Q–9 turned on. The transistor Q–8 is in an off state at the beginning of the sawtooth wave and will be turned on during the generation of each sawtooth as determined by a voltage from the timing control set point generator 9, to be described in more detail hereinafter, which is applied by a line 170 across a resistor R–17 to the base of the transistor Q–8. The sawtooth input is applied by the line 165 across a resistor R–16 to the base of the transistor Q–8. As the sawtooth input voltage increases it is added to the timing control set point voltage applied to the base of the transistor Q–8 by the line 170. The sawtooth signal will trigger the transistor Q–8 at a level as determined by the timing control set point voltage. When the transistor Q–8 is turned on, the voltage at its emitter increases to turn off the transistor Q–9. When the transistor Q–9 is turned off, the voltage at the collector of Q–9 will increase to apply an increase voltage along a line 167 to the base of the transistor Q–10. The increase in voltage on the line 167 to the base of the transistor Q–10 acts to turn the transistor Q–10 off. When the transistor Q–10 is in an on state, current will flow therethrough across a voltage divider network including resistors R–29 and R–30 to apply a positive voltage along a line 168 to the base of the transistor Q–11. The transistor Q–11 acts as a current amplifier to strengthen the output signal developed at a point 169 which is used as an ignition firing signal. When the transistor Q–10 is turned off, the transistor Q–11 is off to change the potential of the point 169 to ground.

Thus, it can be seen that the trigger signal will be generated at the point 169 at the point in time during the development of each sawtooth wave across the resistor R–16 when the sum of the sawtooth voltage and the timing set point voltage applied by the line 170 across the resistor R–17 reaches a level sufficient to turn the transistor Q–8 on. Top dead center is calibrated in the voltage detector by adjusting the resistor R–27 to thereby preset the operating level of the transistor Q–9.

FIG. 5*m* shows a signal developed at point 169 for top dead center timing; and FIGS. 5*n* and 5*o* show point 169 signals for 30° retard and 30° advance, respectively.

The timing set point signal developed across the resistor R–17 (FIG. 3*c*) may be generated by a variable resistor or a voltage divider network. A suitable voltage divider network is shown in FIG. 3*b*. With reference to FIG. 3*b*, when a switch 171 is in the position shown, the network is in timing retard mode, and when the switch 171 is in the position not shown, it is capable of advancing ignition timing. As described with reference to FIG. 2, the period of the sawtooth signal is indicative of 90° movement of the crankshaft of an 8-cylinder engine, and of 120° movement of a 6-cylinder engine. Accordingly, the voltage divider network of FIG. 3*b* is designed to be adjustable between total resistance values such that movement of the ganged switch arm 173 from

the position shown to the terminals indicated as 10, 20 and 30 will act to include or remove resistances R-23A through R-23F from the circuit, and thereby provide adjustments of 10° increments of timing dependent upon the position of switch 171. The resistances R-23G through R-23P provide 1° increments of timing adjustment by movement of the contact arm 174 along the contact points indicated as 0 through 10. With the contact arms 171, 173 and 174 in positions shown, the voltage divider network provides a signal on the line 170 indicative of 4° retard.

A switch 172 is operable to include one of two variable resistances R-19 for a 6-cylinder engine, and R-20 for an 8-cylinder engine in the network. The resistors R-19 and R-20 are adjusted to ratio the network such that movement of the contact arm 173 will provide 10° increments of change in time setting. The resistances R-18, R-21 and R-22 are provided to complete the circuit. R-21 is adjustable such that the total resistance between R-21 and R-22 is 1.2K for the specific values of resistances shown in FIG. 3*b*.

The trigger signal generated at point 169 of FIG. 3*c* is applied through the switch S-2 which is in the automatic position and along the line 103 to the trigger pulse modifier 13 shown in FIG. 3*e*. The RC circuit including the capacitor C-6 and the resistor R-34 will develop a narrow negative pulse such as that shown in FIG. 5*c* for triggering the transistor ignition system 14.

The transistorized ignition circuit 192 is shown in greater detail in FIG. 6. With reference to FIG. 6, the Delco model No. 427 circuit was modified by substituting a capacitor C-10 for a 15 K resistor. The RC circuit consisting of the capacitor C-6 and the resistor R-34 applies the negative pulse having a constant period to the base of a transistor Q-16. As the negative peaked pulse increases in voltage, it acts to turn on the transistor Q-16 to thereby raise the potential at the collector of Q-16. As the potential increases at the collector of the transistor Q-16, the potential at the base of a transistor Q-17 is turned on, the potential at the emitter of the transistor Q-17 is thereby lowered and the potential at the base of a transistor Q-18 is also reduced to turn the transistor Q-18 off. When the transistor Q-18 is turned off, power is removed from the primary 197 of the ignition coil 193 to cause the primary coil 197 to discharge, and the secondary 198 to apply a high voltage on the line 121 to the existing distributor of the vehicle for distribution to a specific spark plug.

A suitable regulated power supply source is shown in FIG. 3*d*. With reference to FIG. 3*d*, the vehicle battery voltage as developed on the line 190 and which may vary between 12 and 16 VDC is applied across a voltage dropping resistor R-35 to a series pass compound transistor circuit consisting of a pair of NPN transistors Q-13, Q-14. The resistor R-35 is also connected to a resistor R-36 which, in turn, is connected to the base of the transistor Q-14 and the collector of an amplifier transistor Q-15.

The resistor R-35 is also connected to a series-parallel circuit consisting of capacitors C-7, C-8, and C-9 a pair of zenor diodes D-6, D-7, and a pair of resistors R-37, R-38. The series-parallel circuit is connected to the emitter of the amplifier transistor Q-15 and supplies a reference voltage to the emitter of the transistor Q-15. The base of the transistor Q-13 and the emitter of the transistor Q-14 are connected to a resistor R-41 which, in turn, is connected to ground. The base of the transistor Q-14 and the collector of the transistor Q-15 is connected to a resistor R-40 which, in turn, is connected to a capacitor C-10. The capacitor C-10 is connected to a voltage dividing network R-42, R-43, R-44. The base of the transistor Q-15 is also connected to the voltage dividing network R-42, R-43, R-44. The circuit shown in FIG. 3*d* develops a regulated +10 VDC across a capacitor C-11 as the output of the circuit.

FIG. 3*f* provides an engine speed tachometer which is used in this specific embodiment to insure that the engine is operated at the same engine speed at which the road octane curves were generated. The input to FIG. 3*f* is the trigger signal from point C of FIG. 3*e* which is applied from line 106 through a coil L-1 which acts to round off the edges of the square wave input. The rounded off wave is then developed across a zener diode D-8 which limits the amplitude of the signal to a predetermined value, e.g., 9 volts. The signal is limited to a predetermined value less than the normal operating voltage of the battery because battery voltage will normally vary during vehicle operation.

The signal is then passed through a capacitor C-12 to block DC voltage. The signal is then applied across a rectifier network including a diode D-9 and a resistor R-8 to remove negative pulse excursions. The rectified signal is then applied across an microammeter M-2 which provides a current reading indicative of engine speed. Specifically, an increase in engine speed will cause a greater number of rectified pulses to be applied to the meter M-2 to thereby increase its reading. Loading resistors R-45, R-46, R-47 are provided for the meter M-2. When the system is used with a 6-cylinder engine, a switch S-3 is in the position shown to load the meter M-2 with only the resistors R-45, R-46. When the system is used with an 8-cylinder engine, the switch S-3 is closed to place the resistor R-47 in the circuit.

The invention functionally described with reference to FIG. 1 is also suitable for automatic adjustment of ignition timing during normal operation of a vehicle. In this embodiment, the timing control set point generator 9 (FIG. 1) is responsive to engine manifold pressure and engine speed for generating a timing set point signal. The timing control set point generator for this embodiment is shown in FIG. 7, and additionally include a circuit for preventing engine knock. The adjustable voltage detector 8 (FIG. 1), the manual or automatic network 10 (FIG. 1), and the signal inverter amplifier 2 for the automatic timing control system embodiment is shown in FIG. 8. FIG. 9 shows a suitable engine reference signal generator 1 (FIG. 1), on-off circuit 11 (FIG. 1), a trigger pulse modifier 13 (FIG. 1), and transistor ignition system 14 (FIG. 1) for the automatic embodiment. The disclosed automatic specific embodiment of FIGS. 7 through 9 are used in combination with FIG. 3*a* which includes the input modifier network 2, the sawtooth wave generator 3, the emitter follower current amplifier 4, the feedback network 5, the sawtooth amplitude control 6, and the current amplifier and with the regulated power supply 17 as shown in FIG. 3*d*. FIGS. 3*a* and 3*d* are arranged end-to-end with FIGS. 7 through 9 as shown in FIG. 10.

With reference to FIG. 9, the system is connected to a vehicle by joining points A and B with the positive and negative terminals of the battery, respectively. Point B is connected to the center tap of a distributor. The on-off circuit 11 function is carried out by a switch

300 which may be the ignition switch. The engine reference signal generator 1 is shown in FIG. 9 as comprising an existing cam lobe 309 which is driven by the distributor shaft and acts to actuate a microswitch 310 whenever the periphery surface of the cam lobe changes direction. The cam lobe will have a number of surfaces equal to the number of pistons in the engine. The microswitch 310 is connected by a line 311 to the negative terminal of the battery by the line 105 and to the positive terminal by line 105' which includes a resistor 103'. The microswitch 310 generates an output square wave signal which is applied to the trigger (in) line 106.

Alternatively, the trigger (in) signal may be generated by a system such as that shown in FIG. 11 wherein a disc 313 is mounted on a distributor shaft 316 and has a number of holes 317 formed in the periphery thereof equal to the number of cylinders. A magnetic pickup 314 is arranged with respect to the disc 313 such that the magnetic pickup 315 generates a trigger whenever one of the holes 317 is sensed by the magnetic pickup 314. The magnetic pickup 314 applies the trigger signal through an amplifier 135 for application to the trigger (in) line 106.

In each of the signal generating embodiments, the switch is actuated such that a positive square wave is generated between successive actuations. The cam lobe 309 or the disc 313 is synchronized with engine rotation such that top dead center of a piston cycle will occur between successive actuations and preferably at approximately mid-point in time between successive actuations.

The signal generated by the engine reference signal generator 1 of FIG. 9 is applied by the line 106 to the signal inverter amplifier 12 shown in FIG. 8. The signal inverter 12 of FIG. 8 operates in the same manner as the signal inverter of FIG. 3*c*. Specifically, when the voltage on the line 106 is at ground, the voltage at the base of a transistor 319 is also grounded to thus maintain the transistor 319 in an off state. When the transistor 319 is in an off state, the voltage at the collector of the transistor 319 is at +12 volts as sensed through a resistor 312 which is connected to the line 190 and thereby to the positive terminal of the battery. When the positive square wave is generated on the line 106, it is applied through a resistor 318 to the base of a transistor 319 to turn the transistor 319 on and thus cause current flow therethrough. As current flows through the transistor 319, the voltage at the collector of the transistor 319 decreases to apply a negative square wave pulse along a line 321 to the manual or automatic network 10 which includes a switch 322. When the vehicle engine is not running, the switch 322 is in a position shown, i.e., in its manual or start position. In this state, the negative square wave pulse is applied through the switch 322 to the trigger out line 103 to the trigger pulse modifier 13 shown in FIG. 9.

The trigger pulse modifier 13 includes a resistor 307 and a capacitor 308 which operates in the same manner as the trigger pulse modifier described with reference to FIG. 3*e* in that a negative peaked pulse is generated on a line 323 for application to the transistor ignition system 14 which includes a transistorized ignition system 305 connected by a loading resistor 306 to the line 100, and by a loading resistor 304 to the primary terminal of an ignition coil 324. The transistor ignition system 14 operates in the same manner as that described with reference to FIG. 3*e* in that high voltage pulses are applied from the center terminal 302 of the coil 324 along a line 301 to the distributor of the vehicle for application to the spark plugs of the engine.

While the engine is cranking and after it is started, the adjustable voltage detector 8 of FIG. 8 will generate as an output at point 323 pulses such as that shown in FIGS. 5*m* through 5*o* dependent upon the setting of the timing control set point generator 9 to be described hereinafter. The pulses thus generated at the point 323 are applied by a line 324 through a diode 325 which acts to clip the negative excursions. The thus rectified wave is applied through a resistor 326 to charge a capacitor 328. The capacitor 328 is connected by a resistor 327 to the base of a transistor 329. When the charge on the capacitor reaches a predetermined value, the voltage at the base of the transistor 329 will correspondingly be increased to turn the transistor 329 on. When this occurs, current will flow through the coil of a relay 330 to cause the arm of the switch 322 to move from the manual or start state shown in FIG. 8 to the automatic position.

At this time, the adjustable voltage detector 8 of FIG. 8 will apply a trigger (out) signal by way of the line 103 to the trigger pulse modifier 13 of FIG. 9, in accordance with the setting of the timing control set point generator 9 shown in FIG. 7.

With reference to FIG. 7, a voltage divider network comprising resistors 331 and 333 and a variable resistor 332 is connected between the regulated voltage line 160 and the negative terminal of the battery by way of the line 105. The resistor 332 is preset at a factory or during engine maintenance to a setting to provide an ignition timing reference. For example, the resistor 332 may be indicative of a range of settings between zero degree and +12°. A voltage indicative of the timing reference setting is applied by a line 334 to a resistor 335 of FIG. 8. The voltage thus applied across the resistor 335 acts to off-set the sawtooth voltage generated by the system shown in FIG. 3*a* and applied to the adjustable voltage detector 8 of FIG. 8 by the line 165 and across a resistor 336.

As described hereinabove, ignition timing is a dynamic variable in that a varying timing is necessary to provide optimum operation of the engine at different engine speeds and loads. Accordingly, the timing control set point generator 9 of FIG. 7 provides for adjusting the timing set point in response to engine vacuum and engine speed. The specific embodiment also provides for sensing the beginning of engine knock and adjusting the timing to avoid engine knock.

With reference to FIG. 7, a bellows 338 which may be a standard vacuum diaphragm used on a vehicle is connected to the engine manifold by a conduit 337. The bellows 338 acts to drive rheostat arm 342 by a line 339 to move the rheostat 342 to a position indicative of manifold pressure. The rheostat 342 is pivoted at a point 341 and fixedly secured at a point 340. The rheostat applies a voltage indicative of the engine vacuum along a line 343 to the base of a transistor 344. The voltage indicative of engine vacuum applied to the base of the transistor 344 acts to control the current flow through a resistor 346 and thereby apply a signal on a line 345 which is indicative of the vacuum level.

A signal indicative of engine speed is generated in a manner similar to that described with reference to FIG. 3*f*. With reference to FIG. 7, the trigger signal on the

line 106 is applied through a coil 347 which acts to round off the edges of the square wave input. The rounded off wave is then developed across a zener diode 348 which limits the amplitude of the signal to a predetermined value, for example, 9 volts. The signal is then passed through a capacitor 349 to block DC voltage. The signal is then applied across a rectifier network including a diode 350 and a resistor 351 to remove negative pulse excursions. The rectified signal is used as a source of charge for a capacitor 352 which applies a voltage to the base of a transistor 353 to control current flow therethrough. The level of current flow through the transistor 353 is indicative of engine speed and develops a signal across a resistor 354 indicative of engine speed which is applied to a line 355.

Typical vehicles do not have linear curves relating spark advance to manifold pressure and engine speed. For example, FIGS. 12 and 13 show curves for a Chevrolet 327 V-8 1965 car. These curves were extracted from "Distributor Spark Advance Curves for 1965 U.S. Passenger Cars," Ethyl Corporation, Detroit, Mich., and show the non-linearity of typical curves. Therefore, the voltages on the lines 345 and 355 must be shaped to correspond to the curves for a specific vehicle. Accordingly, the signals on the lines 345 and 355 are applied to curve shapers 356 and 357, respectively, wherein output signals indicative of spark settings are generated in accordance with the respective vacuum and engine speed inputs. The output signals are applied by lines 358 and 359 to an adder scaler 360 wherein a signal is generated indicative of optimum time setting for the particular vacuum and engine speed operation of the vehicle.

The voltage output of the adder scaler 360 is applied through a resistor 361 to the base of a transistor 362 to control current flow therethrough. An inverted signal indicative of the optimum time setting is developed at a point 363 and applied to a high-limit and underride network comprising a pair of diodes 364, 365 and a voltage divider including resistors 366, 367, 368. The resistor 367 is adjusted to a predetermined value, for example, 4 volts, such that the voltage on a line 369 will not rise above the predetermined value. As the voltage through the diode 364 rises above the predetermined value, the voltage through the diode 365 dominates to prevent further rise of the voltage. This feature is provided to prevent the spark timing of the vehicle from being advanced past a predetermined value should such be considered necessary. The voltage indicative of the optimum timing in response to vacuum and engine speed applied on line 369 is applied to an adder circuit 370. A knock signal generator 371 is also shown in FIG. 7 and applies a signal, when knock is first sensed, on a line 372 to develop a signal across a resistor 373. The signal indicative of knock is applied by a line 374 to the adder 370 to be added with the optimum timing signal applied along the line 369. By adding the two signals, the signal output of the adder on the line 375 acts to retard timing and thus avoid knocking in the engine. The signal on the line 375 is applied to the adjustable voltage detector 8 shown in FIG. 8.

With reference to FIG. 8, a transistor 377 will be turned on during the generation of each sawtooth signal applied across the resistor 366 from the circuit of FIG. 3*a* at a level determined by the adjustment of the resistor 322 (FIG. 7) and resultant signal applied to the adjustable voltage detector 8 by the line 334 and developed across the resistor 335. A transistor 376 is maintained in an on state by the timing reference signal applied to its base by the line 375 and will operate at a level as determined by the value of the voltage on the line 375. As the sawtooth input applied to the resistor 336 increases through the voltage level as determined by the voltage developed across the resistor 335, the transistor 377 will be turned on. When the transistor 377 is turned on, the voltage at the emitter of the transistor 377 increases during the generation of the sawtooth. As the voltage at the emitter of the transistor 377 increases through the voltage level at the emitter of the transistor 376, the transistor 376 is turned off.

When the transistor 376 is turned off, the voltage at the collector of the transistor 376 increases to apply a voltage along a line 378 to the base of a transistor 379. The increase in voltage on the line 378 acts to turn the transistor 379 on. When the transistor 379 is turned on, the current will flow therethrough across a voltage divider network including resistors 380 and 381 to apply a positive voltage along a line 382 to the base of a transistor 383. The transistor 383 acts as a current amplifier to strengthen an output signal developed at a point 323 which is past through the switch 322 in the position not shown to the line 103 as a trigger output signal.

The trigger output signal on the line 103 is applied to the trigger pulse modifier 13 of FIG. 9. With reference to FIG. 9, the trigger pulse modifier 13 which includes the resistor 307 and the capacitor 308 operates to generate a negative peaked pulse which is applied by the line 323 to the transistor ignition system 305 to trigger the ignition system and apply a high voltage pulse from the center terminal 302 of the coil 324 along the line 301 to the distributor of the vehicle for application to the spark plugs of the engine.

Thus the automatic timing system of FIG. 7 provides for firing or triggering the spark plugs at a point in time during each piston cycle as determined by the manifold pressure and the engine speed. Further, the automatic system provides for preventing knock by retarding engine timing whenever engine knock is sensed. By operating the engine at optimum timing and by preventing knock, more complete combustion of the fuel applied to the engine is obtained to thereby reduce hydrocarbon emmissions.

Traver et al. U.S. Pat. No. 2,340,714, which is incorporated herein by reference, discloses a system suitable for the knock signal generator 371 of FIG. 7. A solid state version of the Traver et al. system is preferable when used with the automatic ignition timing control embodiment of the present application. The Traver et al system is shown in block diagram form in FIG. 14. With reference to FIG. 14, a microphone 400 is situated in the vehicle to detect knock and other noises and converts the detected sounds to electrical signals which are applied to an amplifier stage 401. The amplifier stage 401 applies the amplified electrical signals to a band pass filter 402. The filter 402 is tuned to pass a frequency band which will give the best discrimination between the sound of engine knock and of other engine noises. The output of the filter 402 is applied through another amplifier stage 403 to a detector 404. The detector 404 acts to detect signals generated in response to combustion knock or detonation which signals have a higher amplitude than signals generated in response to other engine noise.

As discussed above, the knock signal generator 371 generates a signal upon first detecting engine knock. The knock signal is added to the optimum timing signal applied to the adder 370 to thus retard engine timing and thereby avoid engine knock. If it is desired to avoid engine knock caused only by acceleration, ignition timing may alternatively be retarded by increasing the capacitance of the capacitor C–4 or inserting a resistor between the point 187 and the diode D–4 of FIG. 3*a*. In this alternative embodiment, the adder 370 and the knock signal generator 371 of FIG. 7 would not be required. By increasing the capitance of the capacitor C–4 or by inserting a resistor as described, the time constant for charging the capacitor C–4 is increased such that the output of the amplitude control 6 becomes sluggish in that the voltage developed at the point 187 will be lower than necessary to maintain a constant amplitude sawtooth output from the sawtooth wave generator during acceleration. Since the amplitude of the sawtooth wave is decreased, the slope of the sawtooth is also decreased. The decrease in the slope of the sawtooth causes the set point voltage as determined by the voltage developed across the resistor 335 (FIG. 8) to be attained later than if the sawtooth was maintained at a constant amplitude. Accordingly, the adjustable voltage detector 8 (FIG. 8) generates an output trigger on the line 103 at a later time in the engine cycle to thereby retard the ignition timing.

Combustion knock also occurs when a heavy load is placed on the engine, for example, when climbing a hill. To retard engine ignition timing and thereby minimize the possibility of combustion knock when a load is suddenly placed on the engine, the bellows 338 and rheostat 342 arrangement of FIG. 7 may be duplicated and placed in the FIG. 3*a* circuit between the point 187 and the diode D–4 such that the resistance of the rheostat will be increased as a result of a decrease in manifold pressure to thereby increase the time constant of charging the capacitor C–4. As described above, when the time constant of charging the capacitor C–4 is increased, the amplitude of the sawtooth output of the sawtooth generator 3 is decreased to thereby retard engine timing.

There are commercially available transducers suitable for monitoring the manifold pressure of the engine and providing a resistance output indicative of the monitored pressure. These transducers may be used in place of the bellows 338 and rheostat 342 arrangement of FIG. 7 and in place of the bellows and rheostat combination discussed in the preceding paragraph.

A circuit suitable for the curve shapers 356, 357 of FIG. 7 is shown in FIG. 15. With reference to FIG. 15, the input signals on the lines 345 or 355 (FIG. 7) are applied as an input to its respective curve shaper which generates an output signal on the lines 358 or 359, respectively (FIG. 7). The input signal is applied across a loading resistor 505 to a line 513. A resistor 506 and a zener diode 507 are connected between the line 513 and the ground 105. A resistor 508 is connected in parallel with the resistor 506 and the zener diode 507. The circuit is designed such that all the current will flow through the resistor 508 at low engine vacuum or low engine speed before the point at which the slopes of the vacuum advance and centrifugal advance curves change. Specifically, below 1,500 RPM engine speed for the curves of FIG. 13 all current will flow through the resistor 508 to develop a signal on the lines 358 or 359 indicative of spark advance as determined by the slope of the curve below 1,500 RPM. The zener diode 507 is chosen to being conducting current at a signal indicative of 1,500 RPM and thereby cause the signal developed on the line 358 or 359 to fall on the portion of the curve which has a smaller slope at a point as determined by the engine speed at or above 1,500 RPM.

The invention is also suitable for generating a trigger or actuating signal for a fuel injection system such as the Conelec Fuel Metering System manufactured by Conelec, Inc., Elmira, N.Y., and described in a Society of Automotive Engineers paper entitled *The Conelec Fuel Metering System*, Detroit Section Junior Activity, Spring Technical Session, Rackham Educational Memorial, Apr. 22, 1968.

FIG. 16 shows in block diagram form an embodiment for generating a trigger or actuating signal for a fuel injection system. An adjustable voltage detector which is a duplicate of the adjustable voltage detector 8 shown in FIG. 8, is connected to the automatic ignition timing control system of FIG. 10 such that it also receives the optimum timing control set point signal from the line 375 (FIG. 7). Another input to the duplicate adjustable voltage detector is a timing reference signal which is generated by a voltage divider network such as that shown by resistors 331, 332, 333 of FIG. 7. The other input to the duplicate adjustable voltage detector is the sawtooth wave developed on the line 165 (FIG. 7). The duplicate adjustable voltage detector will operate in the same manner as the detector 8 of FIG. 8, but, as determined by the timing reference signal thereto, will generate a trigger or actuating signal on a line 510 a few milliseconds prior to the generation of the trigger (out) signal on the line 103 (FIG. 8). The trigger or actuating signal on line 510 is applied to a fuel injection control system 511, such as the Conelec system, which, in turn, generates output control signals on a line 512 for controlling the injection of fuel and air to the cylinders in proper firing order a few milliseconds prior to respective ignition firing signals being applied to the cylinders.

It is apparent that the present invention is also suitable for generating a fuel injection timing signal for controlling fuel injection to a Diesel engine. It is well known that the Diesel or compression ignition engine utilizes the high temperature of highly compressed air to ignite the injected fuel charge. Therefore, the fuel must be injected into the combustion chamber within a precisely defined period of time.

As discussed above, FIGS. 12 and 13 are typical curves for a specific vehicle and indicate that the vacuum and centrifugal advance will occur, as a general rule, between the two outermost curves. FIG. 13 shows a center curve which is indicative of an average centrifugal advance performance for a specific vehicle. The output of the curve shaper of FIG. 15 for the early portion of the vacuum advance curve shown in FIG. 12 will be a linear approximation of the early portion of that curve.

The regulated power supply of FIG. 3*d* is not absolutely necessary for use in the embodiments described with reference to FIGS. 7 through 9 for automatic control of combustion timing by the generation of ignition timing and/or injection timing signals. A vehicle battery will provide a sufficiently stable voltage for the system when used as an automatic combustion timing system. However, it is preferable to use a regulated power sup-

ply with the embodiment of FIGS. 3*a* through 3*f* when it is used as a testing instrument for determining road octane rating.

The present invention is suitable for adjusting or controlling ignition timing of an internal combustion engine such as those having two or four cycles, and one or more cylinders. The invention is also suitable for controlling ignition timing of rotary combustion engines such as the Wankel engine.

Further, the invention is suitable for controlling fuel injection timing of an internal combustion engine which operates under the Otto principle, or of a Diesel engine.

Thus, there has been disclosed a method and a system for controlling combustion timing of an internal combustion engine by controlling ignition and/or fuel injection timing. The engine has at least one combustion chamber which may take the form of the volume defined by the area between a piston and a cylinder head and walls, or the volume defined by the area between each surface of the rotor of a rotary engine and the portion of the housing where combustion occurs. Combustion in the chambers acts to drive a power shaft such as the crankshaft of an Otto engine or the shaft driven by the rotor in a rotary combustion engine.

Although the specific embodiments provide for the use of the distributor shaft as a basis for generating reference signals indicative of the rotational angle of the power shaft, it is apparent that any part of the engine which moves in synchronization with the power shaft may alternatively be used as means for generating reference signals indicative of angular position of the power shaft.

The disclosed method and system also provides for generating signals indicative of rotation of the power shaft through a predetermined number of degrees, each of the power shaft rotation signals being generated for at least a time range during which combustion is initiatable by ignition and/or fuel injection trigger signals in a different one of the combustion chambers. The specific embodiments provide for successively generating sawtooth signals such as shown in FIG. 5*h* as power shaft rotation signals. However, it is apparent that the power shaft rotation signals may take any form which changes in a detectable manner as a function of time.

Further, the power shaft rotation signals may be spaced such that they are generated only during a part of the time range during which combustion is initiatable in each of the combustion chambers. For example, the sawtooth wave described with reference to the specific embodiments may be generated during only the compression stroke to provide a capacity for ignition timing limited to advancing the timing.

I claim:

1. A system for controlling the timing of the combustion cycle in an internal combustion engine having a rotatable power shaft, said system comprising:

means responsive to rotation of said power shaft for generating sequential input trigger signals having a frequency proportional to the speed of rotation of said power shaft;

a waveform generator responsive to said input trigger signals for generating sequential sawtooth waveforms, each of said sawtooth waveforms having a duration corresponding to a predetermined number of degrees of power shaft rotation and having an amplitude changing as a function of time;

feedback means responsive to said waveform generator for maintaining the maximum amplitude of said sawtooth waveforms at a substantially constant level for all engine speeds by varying the rate of change of the amplitude as a function of engine speed such that a given instantaneous magnitude of each sawtooth waveform corresponds to a predetermined angular position of the power shaft regardless of engine speed;

means for generating a set point signal corresponding to a predetermined angle of rotation of said power shaft;

means for detecting when the amplitude of each of said sawtooth waveforms reaches a level defined by said set point signal so as to correspond to a predetermined angle of rotation of said power shaft;

means responsive to said detecting means for generating an engine trigger signal corresponding in time to a predetermined angle of rotation of said power shaft; and

means for adjusting said set point signal so as to adjust the timing of said engine trigger signal to correspond with a different predetermined angle of rotation of said power shaft.

2. The system of claim 1, wherein the instantaneous amplitude of each of said wave forms corresponds to a unique angle of rotation.

3. The system of claim 1, wherein said wave form generator comprises:

a capacitor means; and

a current source for charging said capacitor means during said predetermined number of degrees of power shaft rotation to generate said wave forms.

4. The system of claim 1, wherein said feedback means comprises:

means for clipping said signals representing the charge on said capacitor means above a predetermined level; and

means responsive to the clipped portions of said signals representing the charge on said capacitor means to control the rate of charge of said capacitor means such that said power shaft rotation signals have a unique instantaneous amplitude for a given instantaneous angle of rotation for all engine speeds.

5. The system of claim 1, wherein said means for adjusting said set point signal is manually adustable.

6. The system of claim 1, wherein said means for adjusting said set point signal is automatically adjustable in response to at least one engine parameter.

7. The system of claim 1, including means for initiating sparking in said engine in response to said engine trigger signal.

8. The system of claim 7, wherein said means for adjusting said set point signal is automatically responsive to combustion knock.

9. The system of claim 8, wherein said means for adjusting said set point signal is automatically responsive to engine speed.

10. The system of claim 7, wherein said means for adjusting said set point signal is manually adjustable.

11. The system of claim 10, further comprising switch means for adjusting the duration of said wave forms to permit the system to be used with engines having different numbers of combustion chambers.

12. The system of claim 10, further comprising means initiating fuel injection into at least one combus-

tion chamber of said engine in response to said engine trigger signal.

13. A system for controlling the timing of the combustion cycle of an internal combustion engine having a rotatable power shaft, said system comprising:

means responsive to rotation of said power shaft for generating sequential input trigger signals having a frequency proportional to the speed of rotation of said power shaft;

a waveform generator responsive to said input trigger signals for generating sequential sawtooth waveforms, each of said sawtooth waveforms having a duration corresponding to a predetermined number of degrees of power shaft rotation and having an amplitude changing as a function of time such that a given instantaneous magnitude of each sawtooth waveform corresponds to a predetermined angular position of the power shaft regardless of engine speed;

means for maintaining the maximum amplitude of said sawtooth waveforms at a substantially constant level for all engine speeds by varying the instantaneous rate of change of the amplitude as a function of engine speed;

means for generating a set point signal corresponding to a predetermined angle of rotation;

means for detecting when the amplitude of each of said sawtooth waveforms reaches a level defined by said set point signal so as to correspond to a predetermined angle of rotation of said power shaft;

means responsive to said detecting means for generating an engine trigger signal corresponding in magnitude to a predetermined angle of rotation of said power shaft; and

means for adjusting said set point signal so as to adjust the timing of said engine trigger signals to correspond with a different predetermined angle of rotation without adjusting said duration of said sawtooth waveforms corresponding to said predetermined number of degrees.

14. A system for controlling the timing of the combustion cycle of an internal combustion engine having a rotatable power shaft, said system comprising;

means responsive to rotation of said power shaft for generating sequential input trigger signals having a frequency proportional to the speed of rotation of said power shaft;

a sawtooth waveform generator comprising charge storage means and a semiconductor device acting as a current flow path for changing the charge on said charge storage means, said waveform generator being responsive to said input trigger signal for generating a series of sequential waveforms at the output of said charge storage means having a duration corresponding to a predetermined number of degrees of power shaft rotation and having an amplitude continuously changing as a function of time such that a given instantaneous magnitude of each sawtooth waveform corresponds to a predetermined angular position of the power shaft regardless of engine speed;

sawtooth waveform control means for generating a control signal having a magnitude representing the speed of rotation of said power shaft and applying said control signal to said semiconductor device to control the current flow path for changing the charge of said charge storage means so as to maintain the maximum amplitude of the sawtooth waveforms at a substantially constant level for engine speeds by varying the instantaneous rate of change of charge as a function of engine speed;

means for generating a set point signal corresponding to a predetermined angle of rotation;

means for detecting when the amplitude of each of said sawtooth waveforms reaches a level defined by said set point signal so as to correspond to a predetermined angle of rotation of said power shaft;

means responsive to said detecting means for generating an engine trigger signal corresponding in time to a predetermined angle of rotation of said power shaft; and

means for adjusting said set point signal so as to adjust the timing of said engine trigger signal to correspond with a different predetermined angle of rotation.

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