United States Patent [19]

Farr

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[45] **Oct. 1, 1974**

[54] **IGNITION CIRCUIT WITH AUTOMATIC SPARK ADVANCE**

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[73] Assignee: **Tecumseh Products Company,** Tecumseh, Mich.

[22] Filed: **Mar. 9, 1972**

[21] Appl. No.: **233,377**

Related U.S. Application Data

[60] Division of Ser. No. 882,355, Dec. 15, 1969, Pat. No. 3,661,132, which is a continuation of Ser. No. 684,052, Nov. 17, 1967, abandoned.

[52] **U.S. Cl.** ..... **123/148 E,** 123/149 D, 123/149 R, 123/148 E

[51] **Int. Cl.** **F02p 3/06**

[58] **Field of Search** ..... 123/148 E, 149 R, 149 D, 123/149 C, 148, 149

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Primary Examiner—Laurence M. Goodridge
Assistant Examiner—Cort Flint
Attorney, Agent, or Firm—Barnes, Kisselle, Raisch & Choate

[57] **ABSTRACT**

A solid state capacitor discharge ignition system for use in a single-cylinder engine having a magneto for an electrical energy source wherein the capacitor is discharged through a silicon controlled rectifier in response to trigger signals generated by a trigger assembly mounted on the rotor and stator of the magneto. The trigger assembly generates at least two discrete spaced pulses at running and cranking speeds, and the spacing between the two pulses corresponds to a desired shift in the engine timing between cranking and running speeds. The trigger assembly, the silicon controlled rectifier and the circuit connection therebetween are such that both pulses are applied to the controlled rectifier at all engine speeds; but the retarded ignition pulse is effective at cranking speeds and the advance pulse is effective at running speeds.

4 Claims, 15 Drawing Figures

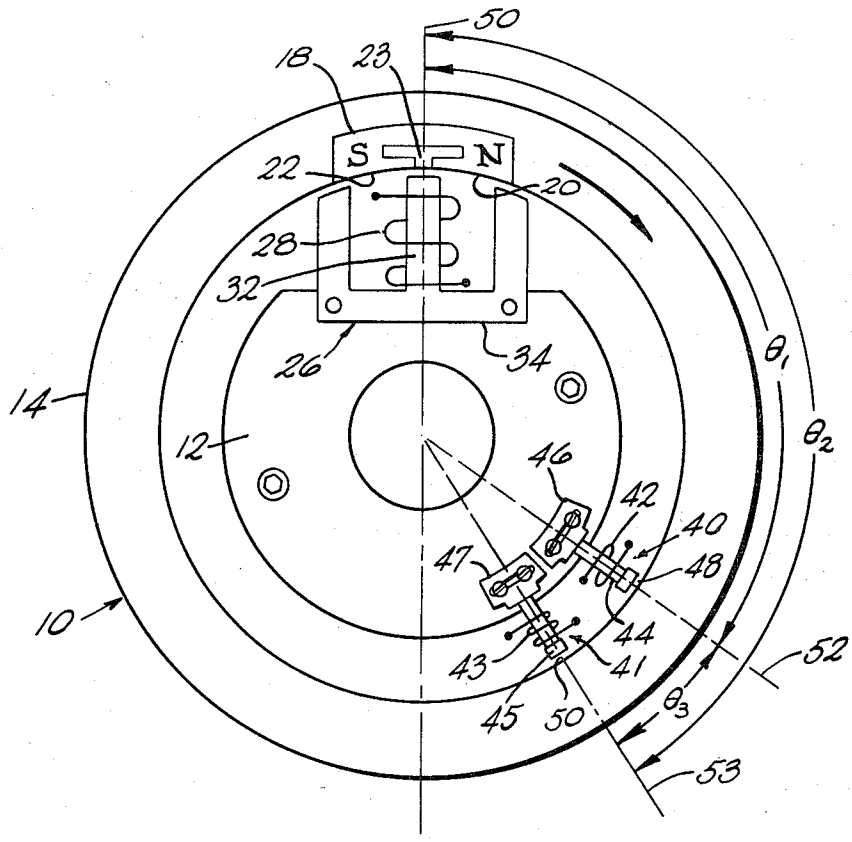
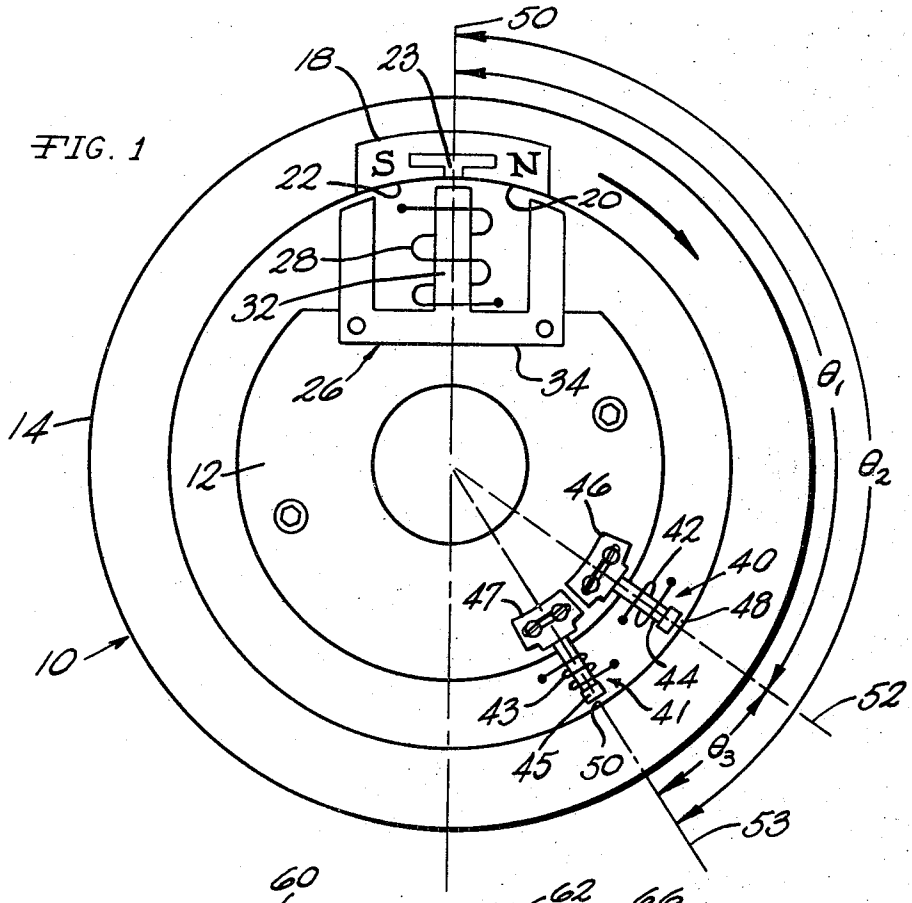


FIG. 1



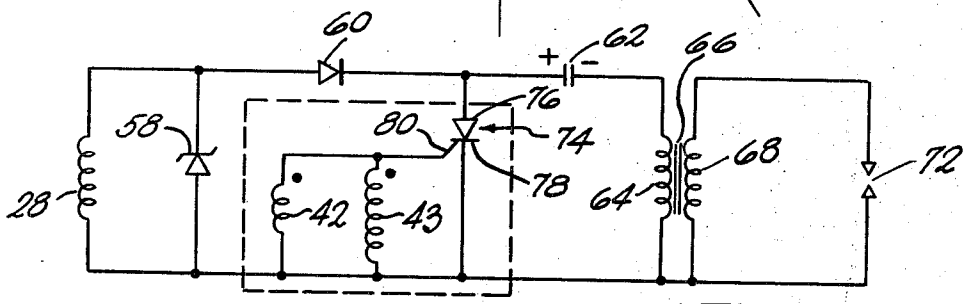


FIG. 2

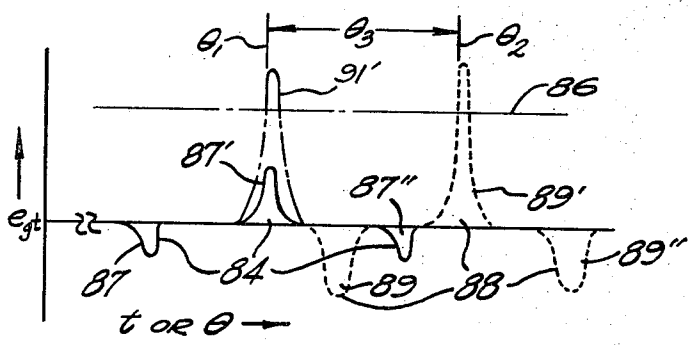


FIG. 3

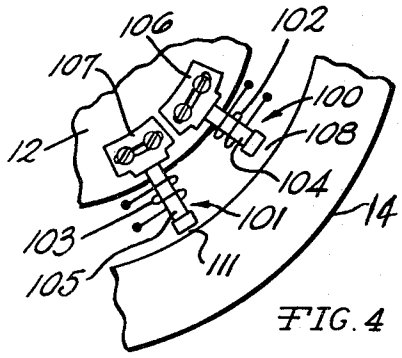


FIG. 4

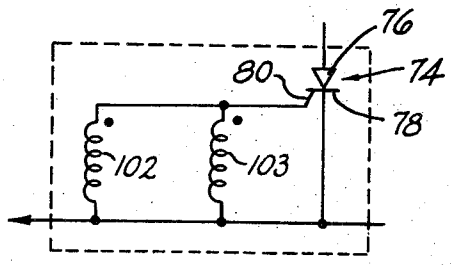


FIG. 5

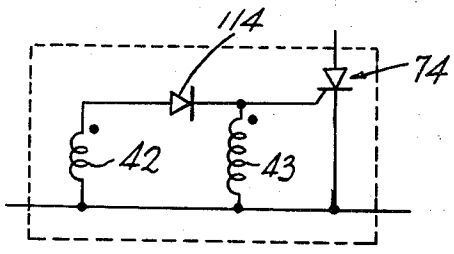


FIG. 6

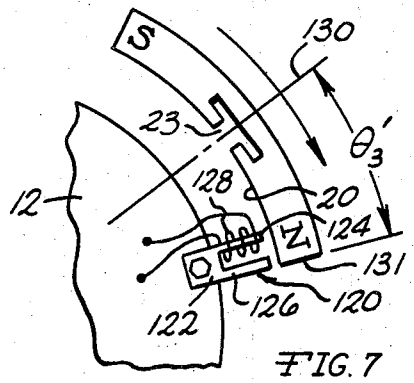


FIG. 7

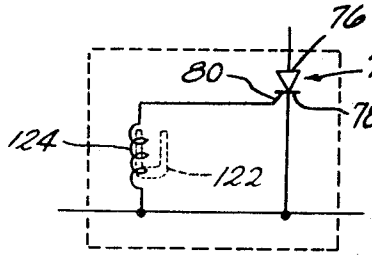


FIG. 8

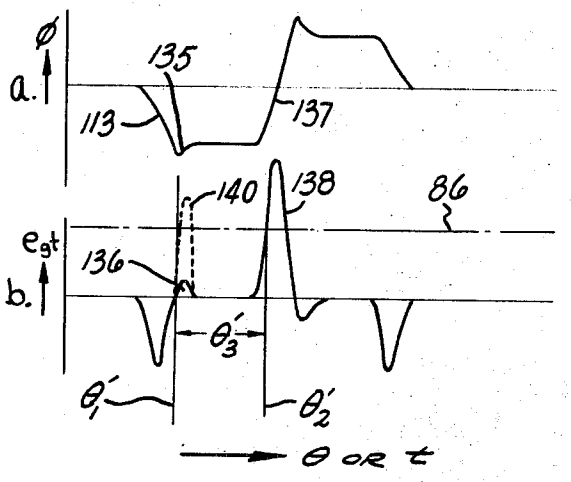


FIG. 9

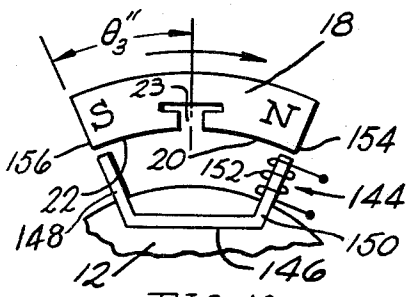


FIG. 10

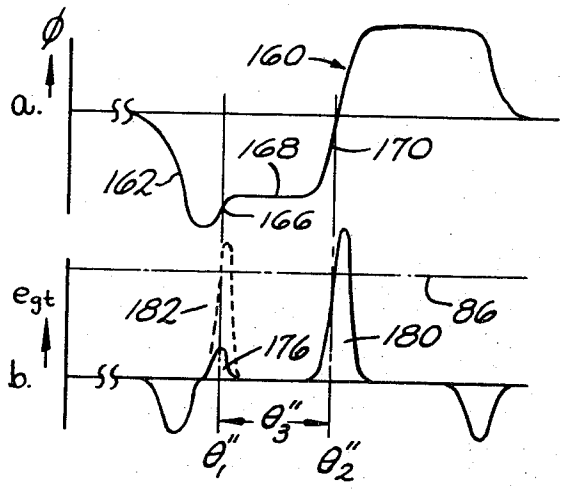


FIG. 11

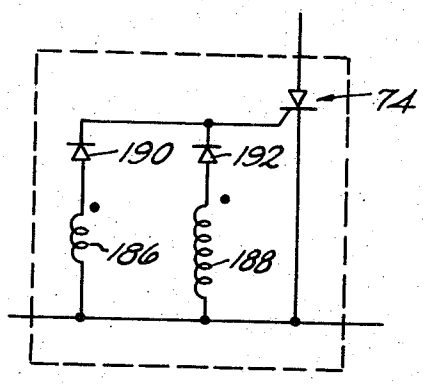


FIG. 12

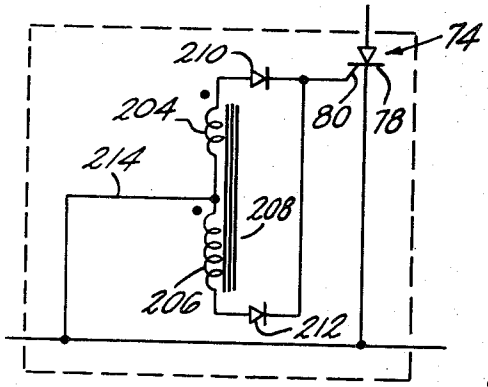


FIG. 13

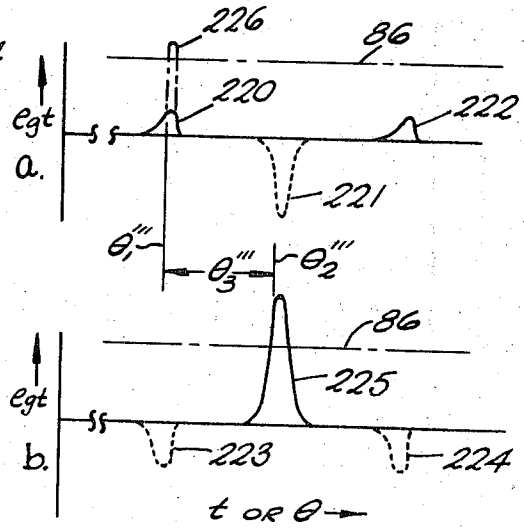


FIG. 14

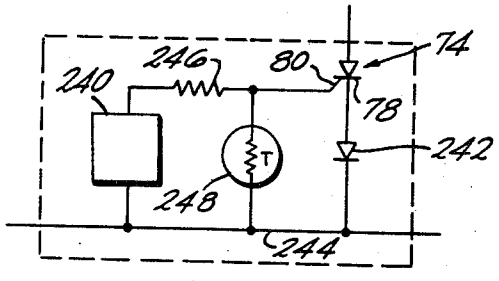


FIG. 15

IGNITION CIRCUIT WITH AUTOMATIC SPARK ADVANCE

This is a division of application Ser. No. 882,355, filed Dec. 15, 1969, now U.S. Pat. No. 3,661,132, issued May 9, 1972, which in turn is a continuation of application Ser. No. 684,052, filed Nov. 17, 1967 (now abandoned).

It is well known that the combustible charge in an internal combustion engine is normally ignited at or near top dead center during the compression stroke of the piston. Engine performance can be improved if the ignition timing varies with engine speed. Ignition may be timed at substantially top dead center during starting with the timing being advanced as the speed of the engine increases. With breaker point ignition systems, ignition timing may be advanced using mechanical means that are responsive to engine speed. Such ignition systems have numerous disadvantages associated primarily with wear of the breaker points and other parts that in time cause unwanted variation in the ignition advance.

Relatively high manufacturing costs as well as service and maintenance problems have generally precluded the use of such ignition systems having automatic timing advance on single-cylinder engines that are mass produced at the lowest possible cost. It is essential that the cost of an ignition system for single-cylinder engines be held to a minimum due to vigorous competition in the small engine field. Hence it is common practice in the samll engine field to select a fixed ignition timing representing a compromise between the optimum timing at starting and at running speeds. Easy starting has been a problem with small engines, particularly with engines having manual starting. However, as long as engine timing is fixed at a compromise for starting and for running, there is a limit to which the ease in starting may be improved. Hence, it is highly desirable to provide a timing advance between starting and running speeds at a low cost. Automatic timing advance at a low cost would be particularly desirable when incorporated in solid state ignitions such as disclosed in my copending application entitled "Ignition System," Ser. No. 654,860, filed July 20, 1967, now Pat. No. 3,490,426.

The objects of the present invention are to provide ignition systems having automatic timing advance that are compatible with solid state ignition circuits that eliminate moving parts and hence eliminate well-known disadvantages from wear in prior ignition systems having having automatic timing advance; that are simple in construction, relatively low in cost and reliable by comparison with prior ignition systems having automatic timing advance; that provide an effective shift in engine timing from an optimum timing for starting to an effective timing at running speeds; and that are particularly suited to ignition systems for single-cylinder engines that are mass produced at the lowest posible cost.

Other objects, features and advantages of the present invention will be apparent in connection with the following description, the appended claims and the accompanying drawings in which:

FIG. **1** is a view diagrammatically illustrating a magneto having a main charging coil and a pair of trigger coils having different turns;

FIG. **2** is a circuit diagram of a solid state, capacitor-discharge ignition circuit used with the magneto shown in FIG. **1**;

FIG. **3** is a diagram illustrating waveforms of voltages generated in the trigger coils of FIGS. **1** and **2**;

FIG. **4** is a fragmentary view of a magneto showing another embodiment of the present invention wherein two trigger coils are arranged with different air gaps;

FIG. **5** is a circuit diagram illustrating the modification in the circuit of FIG. **2** for the dual coil arrangement of FIG. **4**;

FIG. **6** illustrates a still further modification for the circuits of FIGS. **2** and **5** to isolate the trigger coils from each other;

FIG. **7** is a fragmentary view of a magneto showing yet another embodiment wherein a single trigger coil is arranged on a narrow U-shaped core to develop consecutive triggering pulses;

FIG. **8** is a circuit diagram illustrating modification of the circuit of FIG. **2** for the single trigger coil and U-shaped core of FIG. **7**;

FIG. **9** is a diagram illustrating waveforms for voltates generated in the modification of FIGS. **7** and **8**;

FIG. **10** is a fragmentary view of a magneto showing a still further embodiment wherein a single trigger coil is arranged on a wide U-shaped core;

FIG. **11** is a diagram illustrating waveforms of voltages generated in the single coil modification of FIG. **10**;

FIG. **12** illustrates a still further modification of the present invention;

FIG. **13** illustrates a modification of the present invention wherein two coils are wound on the same core and connected in push-pull;

FIG. **14** is a diagram illustrating the waveforms of the voltages generated in modification of FIG. **13**; and

FIG. **15** is a circuit diagram illustrating one temperature compensation circuit.

Referring more particularly to FIGS. **1–3**, there is illustrated a magneto designated generally at **10** and comprising a stator **12** and a rotor **14** which is drivingly connected to the crankshaft of a single-cylinder engine (not shown) so as to rotate in a clockwise direction as viewed in FIG. **1** in synchronism with the engine. A permanent magnet **18** embedded in rotor **14** has a north pole face **20** and a south pole face **22** that extend circumferentially along the inner periphery of rotor **14.** Faces **20, 22** have a magnetic gap **23** therebetween. The stator **12** is fastened on the engine by suitable means and is stationary relative to rotor **14.** Mounted on stator **12** is a main charging coil assembly **26** which includes a charging coil **28** wound on the center leg **32** of an E-shaped core **34.** This arrangement provides a rapid flux reversal through the center leg **32** generating a relatively high voltage in the coil **28.** Two trigger coil assemblies, **40, 41** are also mounted on stator **12** in spaced relation to each other and to the main coil assembly **26.**

The trigger coil assembly **40** generally comprises a coil **42** wound on a core **44** which is mounted at its radially inner end on a plate **46** adjustably fastened on the stator **12.** Core **44** projects radially outwardly of stator **12** with the radially outer end spaced from rotor **14** to form an air gap **48** with magnet **18.** Trigger coil assembly **41** comprises atrigger coil **43** wound on a core **45** which is mounted at its inner end on a plate **47** also adjustably fastened on stator **12.** Core **45** has an air gap

50 with magnet 18. As illustrated in FIGS. 1 and 2, coil 42 has fewer turns then coil 43 and the air gaps 48, 50 are substantially equal. The angular displacement between axis 50 of the charging coil 28 and the axis 52 of the trigger coil 42 is designated θ_1 whereas the corresponding angular displacement of the axis 53 of the coil 43 is designated θ_2 and the angular displacement between the axes 52, 53 is designated θ_3. θ_1 and θ_2 may also be considered as representing crankshaft angles and also time. In general the crankshaft angle, θ_1, of the trigger coil assembly 40 is selected to provide an advanced ignition timing when the engine is running. The crankshaft angle, θ_2, of the trigger coil assembly 41 is selected to provide a retarded ignition timing when the engine is cranked during starting.

Referring more particularly to the circuit in FIG. 2, a Zener diode 58 is connected directly across the charging coil 28 to regulate the maximum positive voltage generated in coil 28 when the upper terminal as viewed in FIG. 2 is positive. Also connected across the charging coil 28 is a series circuit comprising a silicon diode 60, a capacitor 62 and the primary winding 64 of an ignition transformer 66. The secondary winding 68 of transformer 66 is directly connected across a spark plug 72. Connected directly across the serially connected capacitor 62 and winding 64 is a silicon controlled rectifier 74 having an anode 76, a cathode 78 and a gate 80. The trigger coils 42, 43 are connected in parallel with each other and across the gate 80 and cathode 78 to provide triggering signals to the gate to initiate conduction of rectifier 74 as the coils 42, 43 are swept by a magnet 18. The coils 42, 43 are wound on the cores 44, 45, respectively, and are connected to the gate 80 so as to have the same relative polarity as indicated by the dots in FIG. 2.

The operation of the ignition described hereinabove can best be understood in connection with the waveforms illustrated in FIG. 3 wherein crankshaft angles, θ, are plotted along the abscissa axis and voltage is plotted along the ordinate axis. The abscissa axis can also be considered as generally representing time at different scales for different engine speeds. It will be understood that the waveforms in FIG. 3 are for purposes of explanation and are not necessarily intended to be to scale. When the engine is turned at a relatively low cranking speed during starting, as magnet 18 sweeps past the charging coil 28, the alternating voltage generated in coil 28 is rectified by diode 60 to charge capacitor 62 to the polarity indicated in FIG. 2. As magnet 18 continues rotation in a clockwise direction past trigger coil assembly 40, an alternating triggering signal 84 (FIG. 3) is generated in coil 42 and applied to gate 80. The signal 84 comprises three pulses 87, 87', 87'' of alternating polarity. Coil 42 is connected to gate 80 so that the first pulse 87 is negative, the second pulse 87' is positive and the third pulse 87'' is negative. In the preferred embodiment, only the positive pulse 87' is used. Pulse 87' is generated when gap 23 passes core 44. Rectifier 74 has a critical gate voltage designated at the voltage level 86 in FIG. 3. The number of turns in coil 42 is selected so that at cranking speeds pulse 87' has an amplitude substantially below level 86 and hence does not fire rectifier 74. As magnet 18 continues to rotate past the trigger coil assembly 41, an alternating voltage 88 is generated in the second trigger coil 43. The signal 88 also includes a first negative pulse 89, a second positive pulse 89' and a third negative pulse 89''. The number of turns in coil 43 is selected so that at cranking speeds, pulse 89' exceeds level 86 to initiate discharge of capacitor 62 through rectifier 74. The duration of pulse 89' is sufficient to allow capacitor 62 to completely discharge in a damped oscillatory manner through rectifier 74 on one discharge half-cycle and through diodes 58, 60 on the opposite discharge half-cycle.

By way of example, coil 43 may have ten times the number of turns in coil 42 to assure sufficient amplitude difference between pulses 87', 89' at cranking speeds so that the pulse 87' will not fire rectifier 74 but pulse 89' will. A ratio of at least greater than five to one between the peak amplitudes of the pulses 89', 87' is preferred to obtain sufficient amplitude separation. The location, θ_2, of trigger coil 43 is correlated to the engine cycle so that the retarded ignition pulse 89' fires rectifier 74 at the desired crankshaft angle to facilitate easy starting, for example, at or near top dead center in the compression stroke.

As soon as the engine starts the voltage generated in coil 42 increases substantially. Hence at running speeds the first positive pulse 91' in the gate voltage from coil 42, corresponding to pulse 87', exceeds the threshold level 86 at the crankshaft angle θ_1 to fire rectifier 74 and initiate discharge of capacitor 62. The location, θ_1, of coil 43 is selected so that the advanced ignition timing pulse 91' exceeds level 86 at the desired crankshaft angle for running speeds, for example, an angle of 22° before top dead center. Although the amplitude of the retarded pulse corresponding to pulse 89' is also increased substantially at running speeds, the retarded pulse is ineffective since capacitor 62 is substantially fully discharged in response to pulse 91'. By way of example, on engines in the 2.5–7 horsepower range a typical cranking speed is in the range of 300–400 RPM with minimum cranking speeds of 100–150 RPM and a typical idle speed is above 1,500 RPM. The circuit is designated to provide a timing shift in a speed range of 800–1,000 RPM. The timing shift provides easy starting and acceptable engine performance.

Although pulses 87' and 89' are used in the preferred embodiment, it will be apparent that other pulse pairs may also be used. For example, by reversing the coil leads the first pulses corresponding to pulses 87, 89 will be positive and have the desired time separation for a timing shift of about 20°.

Referring to the embodiment of FIGS. 4 and 5, the trigger coil assemblies 40, 41 are replaced by corresponding trigger coil assemblies 100, 101. Except for the triggering circuit for rectifier 74 enclosed in dashed lines in FIGS. 2 and 5, the ignition circuit for the dual coil arrangement illustrated in FIGS. 4 and 5 is the same as that shown in FIG. 2. The trigger coil assembly 100 includes a trigger coil 102 wound on a core 104 which is mounted at its inner end on a plate 106 adjustably fastened on stator 12. Core 104 has an air gap 108 with magnet 18 (FIG. 1). The trigger coil assembly 101 comprises a trigger coil 103 wound on a core 105 which is mounted at its radially inner end on a plate 107 adjustably fastened on stator 12. Core 105 has an air gap 111 with magnet 18. Coils 102, 103 have the same number of turns but the air gap 108 is substantially greater than the air gap 11. With the difference in air gaps at any given speed of rotor 14, the signal generated in coil 103 will have a substantially higher amplitude than the signal generated in coil 102.

More particularly the air gaps **108, 111** are selected so that the triggering signal generated in coil **102** has the same relationship to the triggering signal generated in coil **103** as signal **84** (FIG. 3) generated in the coil **42** (FIGS. **1** and **2**) has to the signal **88** generated in coil **43.** Coils **102, 103** are connected in parallel with each other and directly across the gate **80** and the cathode **78.** Coils **102, 103** have the same relative polarity as indicated by the dots in FIG. **5** and are connected to gate **80** so that the second pulse in each coil generated when gap **23** passes the respective cores will be positive as with pulses **87'**, **89'** for coils **42, 43** (FIGS. **1–3**). Hence the operation of the modification of FIGS. **4** and **5** will be apparent from the description in connection with FIGS. **1–3.**

Referring to FIG. **6,** a modification for the circuit of FIG. **2** is illustrated wherein a silicon diode **114** is connected in series with coil **42** across coil **43.** Diode **114** is poled in the direction shown to decouple coil **42** from coil **43** during the positive pulse **89'**. To simplify the description, the various pulses are illustrated in FIG. **3** as relatively sharp pulses occurring at different times. However the pulses may be of longer duration with some of the pulses coincident with, or at least overlapping, other of the pulses depending on the configuration of magnet **18** together with the parameters and the separation of coil assemblies **40, 41.** For example, if the negative pulse **87''** overlaps the positive pulse **89'** the gate voltage may be reduced to such an extent that the retard pulse **89'** may not fire rectifier **74** at low cranking speeds. Additionally, with coil **42** connected directly across coil **43,** coil **42** will load coil **43** impairing the effect of the retard pulse **89'**, particularly where, as in FIGS. **1** and **2,** coil **42** has fewer turns than coil **43.** However diode **114** minimizes these problems where required.

FIGS. **7–9** illustrate a further modification for providing consecutive timing pulses whose phase and amplitude relationship at low cranking speed and at higher running speed provide automatic timing advance. The coils **40, 41** (FIGS. **1–3**) are replaced with a single trigger coil assembly **120** which comprises a U-shaped core **122** mounted at its radially inner end on stator **12.** Core **122** has legs **124, 126** spaced closely together A single coil **128** is wound on leg **124** which is considered as a leading leg in that it is the first of the legs **124, 126** encountered by the leading edge **131** of the north pole face **20** during rotation of rotor **14.** The angular separation between the core legs **124, 126** and the cicumferential length of the leading pole face **20,** that is, the angular separation between the leading and trailing edges of the pole face **20** are correlated to the engine timing cycle to obtain the required timing shift. More particularly, the leading edge **131** of the pole face **20** and the center line **130** of the gap **23** (in effect, the trailing edge of face **20**) have an angular displacement θ'_3 equal to the desired timing shift, corresponding to the angle θ_3 (FIGS. **1** and **3**). Coil **124** is connected directly across gate **80** and cathode **78** of rectifier **74** as illustrated in FIG. **8.** The ignition circuit for the narrow U-shaped core arrangement of FIG. **7** is identical to that disclosed and described in connection with the circuit of FIG. **2,** except for the trigger circuit enclosed in dotted lines (FIGS. **2** and **8**), i.e., the connection of the trigger coil **128** to the rectifier **74.**

The manner in which the advance and retard pulses are developed using the U-shaped core illustrated in FIGS. **7** and **8** will be more apparent in connection with the waveforms illustrated in FIG. **9.** FIG. **9***a* is the plot of flux, ϕ, versus crankshaft angle, θ, or the equivalent time, t, and similarly FIG. **9***b* is a plot of the voltage, V, versus crankshaft angles, θ, or the corresponding time, t. As magnet **18** approaches the trigger coil assembly **120** the first flux change is in a direction which is assumed to be negative going as illustrated by the waveform portion **113** (FIG. **9***a*). When the leading edge **131** of pole **20** reaches the trailing core leg **126,** some of the flux from leg **124** is shunted to the leg **126** causing a flux reversal and providing a positive going flux at coil **124** designated at **135** in FIG. **9***a*. As magnet **18** sweeps past the trigger coil assembly **120,** the flux in leg **124** remains substantially constant until the gap **123** reaches the trigger coil assembly **120** causing a rapid flux change in a positive going direction designated at **137** (FIG. **9***b*). The remaining portion of the flux waveform is not utilized in the embodiment being described. Referring to the voltage waveform illustrated in FIG. **9***b*, the first positive going flux change **135** generates a low amplitude positive timing pulse **136** in coil **124** and the more rapid positive going flux change **137** generates a larger amplitude positive timing pulse **138** in the coil **124.** The magnitude of the advanced timing pulse **136** generated at low cranking speeds is substantially below the critical threshold level **86** (FIGS. **3** and **9***b*). The gating pulse **138** is substantially greater than the critical level **86** and passes through level **86** at the desired crankshaft angle θ'_2 to facilitate easy starting, that is at or just about top dead center. When the engine starts the rate of change of the first positive going flux reversal, corresponding to the flux reversal designated at **135,** increases substantially generating an advanced timing pulse **140** which exceeds the threshold level **86** at the desired advanced timing position θ'_1 in FIG. **9***b*. Thus discharge of capacitor **62** is initiated at the desired crankshaft angle, θ'_1, in response to pulse **140** when the engine is operating at running speeds.

In the embodiment illustrated in FIG. **10,** the trigger coil assembly **144** generally comprises a U-shaped core **146** mounted on stator **12.** The core **146** has radially disposed legs **148, 150** whose circumferential displacement to each other is wide by comparison to the spacing between legs **124, 126** in FIG. **7.** A single coil **152** is wound on the trailing core leg **150.** The angular displacement between legs **148, 150** is selected relative to the circumferential length of the pole shoes **20, 22** to obtain the flux waveform **160** (FIG. **11***a*) which generates consecutive timing pulses having the required phase and amplitude relationships at cranking speed and at running speed. The connection (not shown) of the trigger coil **152** to the gate **80** is the same as that shown in FIG. **8** for the coil **124.**

More particularly, the angular displacement between legs **148, 150** is equal to or less than the angular separation between the leading edge **154** of pole face **20** and the trailing edge **156** of pole face **22** but greater than the length of pole face **20.** For the clockwise rotation of magnet **18** illustrated in FIG. **10,** as magnet **18** approaches the leg **148** and moves to the position relative to core **146** illustrated in FIG. **10,** the flux linking coil **152** increases in a negative direction as illustrated by the first negative going portion **162** of waveform **160.** As magnet **18** continues past the position illustrated in FIG. **10** and the trailing edge **156** of the south pole **22** breaks from leg **148,** the flux in coil **152** reverses to a

positive going flux at **166.** As the north pole **20** sweeps past the leg **150** the flux in coil **152** remains relatively constant at **168** until the air gap **23** reaches the leg **150** at which point there is a rapid flux change **170** in a positive going direction. The flux then remains substantially constant and finally drops off to zero as the south pole **20** clears leg **150.**

The corresponding voltages generated in coil **152** are shown in FIG. **11***b*. At cranking speeds the first positive going flux change at **166** is relatively slow and generates a corresponding advance ignition pulse **176** whose amplitude is substantially below the critical threshold level **86.** However at cranking speeds the relatively rapid flux change **170** generates a retarded ignition timing pulse **180** whose amplitude exceeds the critical threshold value **86** at the desired crankshaft angle, θ''_2, to facilitate easy starting. After the engine starts the rate of change of flux in coil **152** when the leg **148** clears the trailing edge **156** of the south pole **122** increases substantially. This causes a corresponding large increase in the amplitude of the advanced ignition timing pulse as illustrated by the pulse **182** (FIG. **11**). Pulse **182** exceeds the level **86** at the crankshaft angle θ''_1 to provide the desired ignition timing advance at running speeds. Hence during cranking the retarded ignition timing pulse **180** is effective to generate a spark in plug **72.** When the engine is running the advanced ignition timing pulse **182** is effective to generate the spark at plug **72.**

FIG. **12** illustrates another modification in a triggering coil circuit wherein each of the coils **186, 188** are connected in series with a respective isolating diode **190, 192** across the gate-cathode of rectifier **74.** Coils **186, 188** have a different nfmber of turns as illustrated in FIG. **12.** Diode isolation would also be useful with trigger coils having different air gaps as described hereinabove in connection with the embodiment of FIGS. **4** and **5.** Diode **190** corresponds to diode **114** (FIG. **6**) whereas diode **192** isolates coil **186** from negative pulses generated in coil **188** and from loading by coil **188.** The operation of the circuit illustrated in FIG. **12** is similar to the operation of the circuit illustrated in FIG. **6.** For example, referring to FIGS. **3** and **12** diode **192** would block the first negative pulse **89** in coil **188** so that pulse **89** does not interfere with the advanced timing pulse **87'** generated in coil **186.** The isolation provided by the diodes **190, 192** may be required to provide effective separation between the triggering pulses generated in the two coils **186, 188** depending on the particular configuration of magnet **18** and the design of coils **102, 103.**

FIG. **13** illustrates still another embodiment for generating two spaced triggering pulses having the desired phase and amplitude relationships at cranking speed and at running speed. Two trigger coils **204, 206** are wound on a common core **208** which is mounted on the stator **12** so as to be swept by magnet **18** during each revolution of rotor **14.** Coil **204** has fewer turns than coil **206.** Coils **204, 206** are each connected in series with a respective isolating diode **210, 212** across gate **80** and cathode **78** through a common connection **214.** A single coil having a tap at the connection **214** is also contemplated. As indicated by the dots in FIG. **13,** coils **204, 206** are oppositely poled in push-pull to gate **80.**

At cranking speed magnet **18** will generate in coil **204** the waveform illustrated in FIG. **14**a. The first positive pulse **220** generated when the leading pole **20** reaches coil **204** has a peak amplitude substantially below the critical voltage level **86.** The second pulse **221** which is negative is generated by the rapid flux reversal as gap **23** sweeps coil **204.** However, pulse **221** is blocked from gate **80** by diode **210.** The second positive pulse **222** is generated as the trailing edge of the trailing pole **22** breaks from coil **204.** Pulse **222** is not used in the embodiment being described. However since coil **206** is oppositely phased relative to coil **204,** magnet **18** generates in coil **206** a voltage having a waveform shown in FIG. **14**b wherein the first pulse **223** and the last pulse **224** are negative. The second pulse **225** is positive and has an amplitude that exceeds the voltage level **86** at the crankshaft angle θ'''_2. Hence at cranking speeds the advanced ignition timing pulse **225** fires rectifier **74** at the desired crankshaft angle that facilitates easy starting. After the engine starts the magnitude of the voltages generated in coil **204** increases substantially so that at running speeds the first positive pulse **226** (FIG. **14***a*) generated in coil **204** exceeds the level **86** at the desired crankshaft angle θ'''_1. As with the embodiments described in connection with FIGS. **7** and **10,** the amount of the timing shift θ'''_3 is determined in part by the configuration of magnet **18.** More particularly for the embodiment of FIG. **13,** the shift depends on the length of the leading pole **20.** It will also be apparent that although the desired amplitude relationship between pulse **220** and pulse **225** is obtained by having fewer turns in coil **204** than in coil **206,** the amplitude difference is in part due to the configuration of magnet **18** and the gap **23.**

It has been found particularly desirable to provide temperature compensation in ignition circuits having automatic advance of the type described hereinabove to assure that the ignition timing occurs at the proper crankshaft angle regardless of temperature. FIG. **6** illustrates one circuit that is useful with the various trigger coil arrangements to compensate for variations in the critical threshold level **86** with temperature. In the circuit of FIG. **15** the trigger coils are illustrated in block form at **240,** i.e., either coils having a different number of turns (FIGS. **1–3**), coils having different air gaps (FIGS. **4** and **5**), a single coil on a narrow U-shaped core (FIGS. **7–9**), a single coil on a wide U-shaped core (FIGS. **10** and **11**), or push-pull coils on a single core (FIGS. **13** and **14**). A silicon diode **242** is connected in series with cathode **78** to the common return lead **244.** Connected across the trigger circuit **240** is a voltage divider comprising a resistor **246** and a thermistor **248.** Thermistor **248** has a negative temperature coefficient so that its resistance decreases with increasing temperature. Gate **80** is connected to the divider between resistor **246** and thermistor **248.** With increasing temperatures anode-cathode leakage current through rectifier **74** develops a small voltage drop across diode **242** so that the gate-cathode junction becomes reversed biased. With increasing temperature, the gate voltage developed across the thermistor drops off. Temperature compensation using either thermistor **248** or diode **242,** alone, is also contemplated. The circuit also minimizes spurious triggering by ripple voltages generated by stray flux, particularly at high running speeds and at high temperature

It will be understood that the ignition system having automatic ignition timing advance has been described hereinabove for purposes of illustration and is not in-

tended to indicate limits of the present invention, the scope of which is defined in the following claims.

I claim:

1. In an ignition system for igniting a combustible charge in an internal combustion engine having at least one cylinder, one spark device for said cylinder and a source of electrical energy and further having circuit means adapted to transfer electrical energy from said source to said spark device at substantially a first crankshaft angle in a timing cycle of said engine when said engine is cranked at low speeds during starting and at substantially a second predetermined crankshaft angle in said timing cycle when said engine is operating at running speeds, said energy transferring circuit means comprising electronic switch means responsive to electrical triggering signals of predetermined polarity and having a predetermined value to switch from a first state to a second state and thereby cause electrical energy to be transferred to said spark device, and trigger circuit means comprising first coil means, second coil means, permanent magnet means and flux circuit means and responsive to relative movement between said flux circuit means and said first and second coil means to generate said triggering signals, said first coil means generating triggering signals having first pulsations of said predetermined polarity and an amplitude that is above said predetermined amplitude at both said cranking speeds and said running speeds to switch said switch means at a first crankshaft angle at said cranking speed, said second coil means generating triggering signals having second pulsations of said predetermined polarity and an amplitude that is less than said predetermined amplitude at said cranking speeds and above said predetermined amplitude at said running speeds to switch said switch means at said second crankshaft angle at said running speeds, that improvement comprising first coupling circuit means coupling said first coil means to said switch means so that triggering signals of both said predetermined polarity and of an opposite polarity are applied to said switch means from said first coil means at both cranking and running speeds, second coupling circuit means coupling said second coil means to said switch means so that only triggering signals of said predetermined polarity are applied to said switch means from said second coil means at both cranking and running speeds, the impedance of said second coupling means and said second coil means being such that if said first pulsations from said first coil means were shunted through said second coupling means and said second coil means at said cranking speeds the amplitude of said first pulsations might fall below said predetermined amplitude, and wherein said second coupling means includes means for isolating said first coil means from said second coil means with respect to triggering signals of said predetermined polarity generated in said first coil means so that said second coil means does not load said first coil means at said cranking speeds.

2. The improvement set forth in claim **1** wherein said switch means has a pair of input terminals for receiving said triggering signals from said first and said second coil means and wherein said first coupling circuit means comprises a pair of electrical conductors connecting said first coil means directly across said input terminals.

3. The improvement set forth in claim **2** wherein said second coil means is connected in series with a diode and said serially connected diode and second coil means are connected in parallel with said first coil means across said input terminals, said diode being poled so as to isolate said first coil means from said second coil means with respect to said first pulsations.

4. The improvement set forth in claim **1** wherein a first diode is connected in series with said second coil means and said serially connected diode and second coil means are connected in parallel with said first coil means across an input of said switch means, said diode being poled so as to isolate said first coil means from said second coil means with respect to said first pulsations.

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