March 1, 1966 G. O. HUNTZINGER ETAL 3,238,416

SEMICONDUCTOR IGNITION SYSTEM

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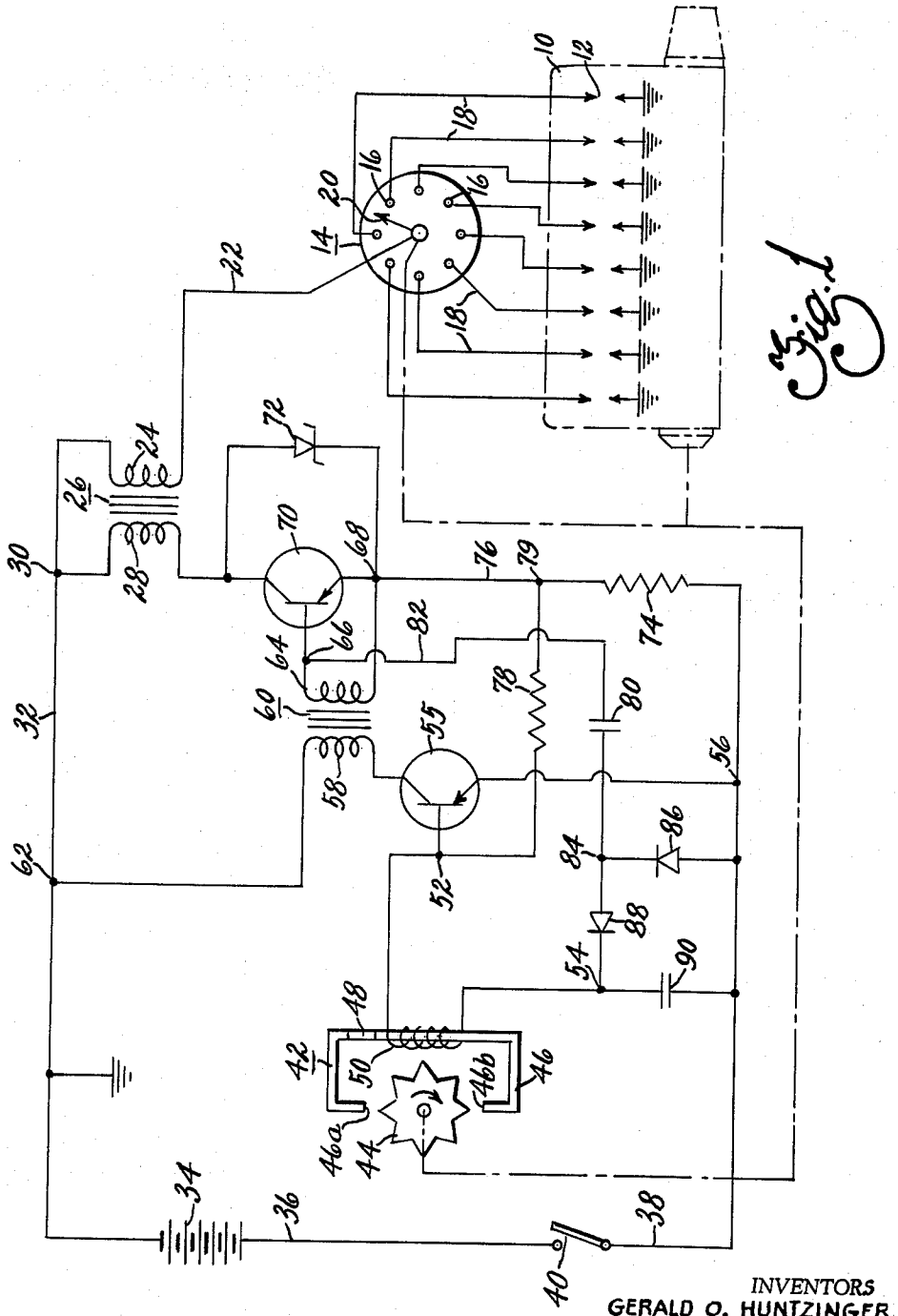


Fig. 1

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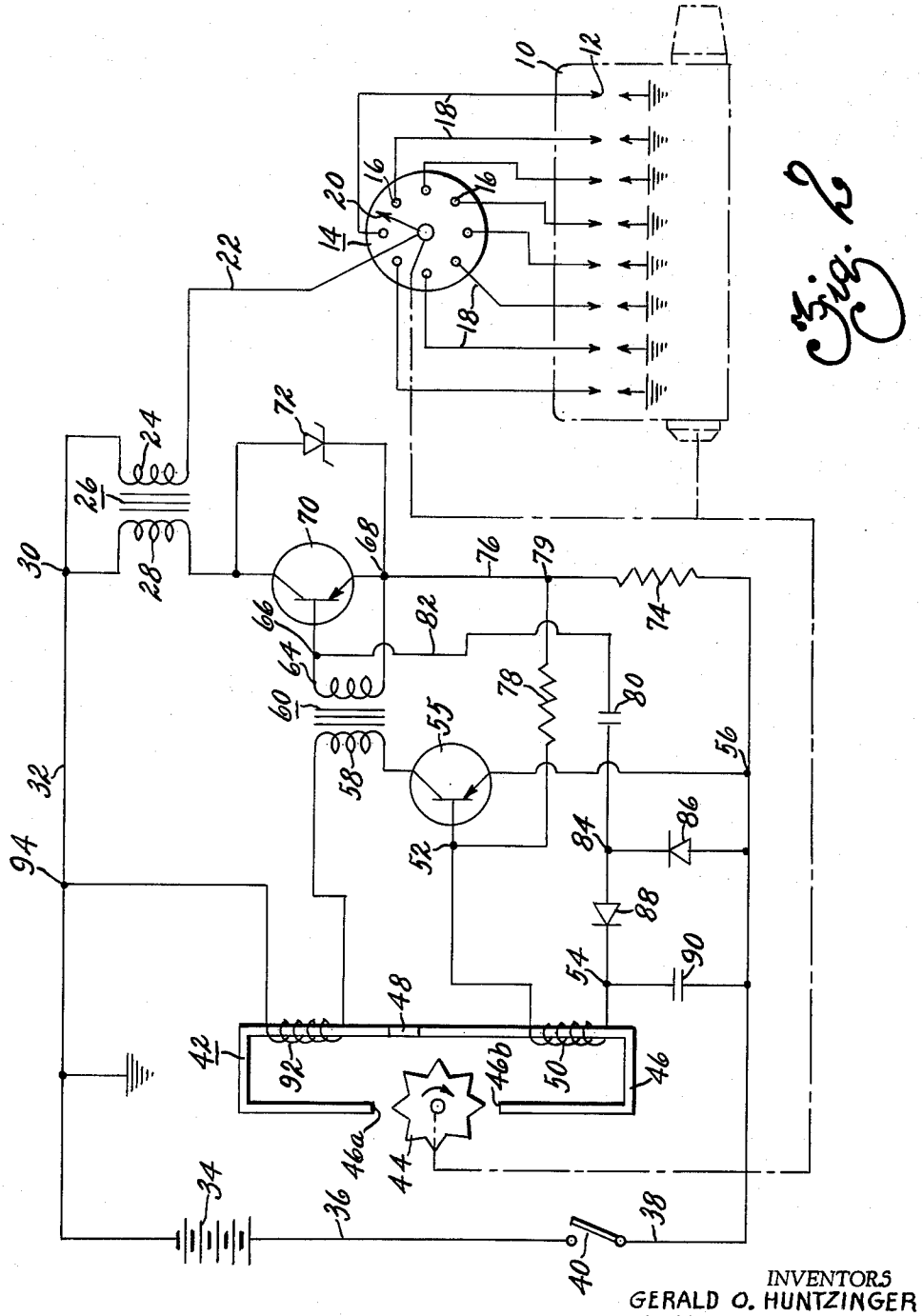


Fig. 2

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SEMICONDUCTOR IGNITION SYSTEM

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This invention relates to ignition systems for internal combustion engines and more particularly to an ignition system wherein a semiconductor such as a transistor controls the current flow through the primary winding of the ignition coil.

One of the objects of this invention is to provide a semiconductor controlled ignition system which maintains a substantially constant energy storage time in the primary winding of the ignition coil over the entire speed range of the engine. With this arrangement, the amount of power required to operate the ignition system is reduced to a minimum.

Another object of this invention is to provide an ignition system wherein a semiconductor switch means such as a transistor controls the current flow through the primary winding of an ignition coil and wherein the semiconductor switch means is controlled by a system that includes a magnetic pick-up, the system including means whereby the time that the semiconductor switch means is turned on is maintained substantially constant both at high and low speeds of the engine.

Still another object of this invention is to provide an ignition system wherein a semiconductor switch means such as a transistor controls the current flow through the primary winding of an ignition coil and wherein the conduction of the transistor is controlled by a magnetic pick-up having a coil winding in which pulses of voltage are induced in synchronism with the engine, the coil winding being connected with a capacitor which is charged in accordance with the speed of the engine and in accordance with the "on" time of the semiconductor switch means which controls current flow through the primary winding of the ignition coil. In this arrangement, the voltage which is induced in the pick-up coil must overcome the charge on the capacitor and the on time of the semiconductor switch means that controls primary winding current is therefore maintained substantially constant over a widely varying speed range of the engine.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawings wherein preferred embodiments of the present invention are clearly shown.

In the drawings:

FIGURE 1 is a schematic circuit diagram of a breakerless transistor ignition system made in accordance with this invention.

FIGURE 2 is a schematic circuit diagram of a system which is a modification of the system illustrated in FIGURE 1.

Referring now to FIGURE 1, the reference numeral **10** designates an engine having a plurality of spark plugs each of which is designated by reference numeral **12**. The spark plugs **12** are supplied with electrical energy through a current distributing mechanism which in this case takes the form of a distributor cap **14** having a plurality of fixed contacts or electrodes **16**. It is seen that the electrodes **16** are connected with the spark plugs **12** by conductors **18**. A rotor contact **20** of conventional construction is provided which is connected with a high voltage lead **22**. The rotor contact **20** is driven by the engine **10** and swings in close proximity to the fixed contacts **16** in a manner well-known to those skilled in the art.

The high voltage lead **22** which is electrically connected with the rotor contact **20** is connected to one side of a secondary winding **24** of an ignition transformer **26**. The ignition transformer **26** has a primary winding **28** one side of which is connected with a junction **30**. It is seen that one side of the secondary winding **24** is also connected with the junction **30** and that the junction **30** is connected with a grounded power supply conductor **32**.

The power supply conductor **32** is connected with the negative side of a D.C. voltage source designated by reference numeral **34**. This D.C. voltage source **34** is shown as a battery and on a motor vehicle electrical system, the battery will, of course, be charged by a generator which can supply the ignition system of this invention when the engine is operating and the output voltage of the generator is greater than battery voltage. The positive side of battery **34** is connected with conductor **36** and this conductor is connected with a conductor **38** through a manually operable ignition switch **40**. When the ignition switch **40** is closed, the power supply conductor **32** is at a negative potential whereas the conductor **38** is at a positive potential.

The ignition system of this invention uses a magnetic pick-up designated in its entirety by reference numeral **42**. This magnetic pick-up includes a rotor **44** which is driven by the engine **10** and which is formed of magnetic material. It is seen that the rotor has eight radially extending teeth which can become progressively aligned with the pole faces **46***a* and **46***b* of a magnetic core **46**. A permanent magnet **48** is provided for causing a flow of magnetic flux through the magnetic core **46** and through the rotor **44** when a pair of radially extending teeth complete the magnetic circuit between the pole faces **46***a* and **46***b*. A pick-up coil **50** is wound on the magnetic core **46** and an A.C. voltage is induced in this pick-up coil **50** which has a frequency which is a function of the speed of the engine **10**. It will be appreciated that the magnetic flux for the core **46** could be provided by an electrical field coil rather than the permanent magnet **48** if so desired.

It is pointed out that as a pair of teeth are moving into alignment with pole faces **46***a* and **46***b*, a voltage of one polarity is induced in the coil winding **50** and as the radially extending teeth then move out of alignment with the pole faces **46***a* and **46***b*, a voltage of an opposite polarity is induced in the coil winding **50**. Since there are eight radially extending teeth on the rotor **44**, there will be eight cycles of alternating voltage induced in the coil winding **50** during one revolution of the rotor **44**. It will, of course, be appreciated that the number of teeth for the rotor **44** will correspond to the number of cylinders of the engine **10** and this can be varied to suit the engine.

It is noted that the magnetic pick-up **42** and the current distributing device **14** could be made as one unit and could be made in accordance with the teaching of patent application Serial No. 126, 406, filed on June 16, 1961, and assigned to the assignee of this invention.

One side of the pick-up coil **50** is connected with junction **52** whereas the opposite side of this pick-up coil is connected with junction **54**. The junction **52** is connected with the base electrode of a three terminal semiconductor switch means which in the embodiment of the invention shown takes the form of a PNP transistor **55**. The emitter electrode of transistor **55** is connected with junction **56** on power conductor **38**. The collector electrode of transistor **55** is connected to one side of the primary winding **58** of a coupling transformer **60**. The opposite side of the primary winding **58** is connected with junction **62** on power conductor **32**. The coupling transformer **60** has a secondary winding **64** which is connected respectively with junctions **66** and **68**.

The junction 68 is connected with the emitter electrode of another three terminal semiconductor switch means which takes the form of a PNP transistor 70. The base electrode of transistor 70 is connected with junction 66 and thus is connected to one side of the secondary winding 64. The collector electrode of transistor 70 is connected to one side of the primary winding 28 of the ignition transformer 26. It is seen that a Zener diode 72 is connected across the emitter and collector electrodes of transistor 70. The junction 68 is connected to one side of a resistor 74 via a conductor 76. A resistor 78 connects the junction 52 with the junction 79 on conductor 76.

The junction 66 which is connected with the base electrode of transistor 70 is connected to one side of a capacitor 80 via the lead wire 82. The opposite side of capacitor 80 is connected with junction 84. A diode 86 connects the junction 84 with conductor 38 and another diode 88 connects the junctions 84 and 54. A capacitor 90 is connected between junction 54 and the conductor 38.

When the engine 10 is being cranked or when the engine is operating and when the ignition switch 40 is closed, the ignition system is energized. With the engine 10 operating, the rotor 44 rotates and pulses of A.C. voltage are induced in the coil winding 50 with a polarity which causes junction 54 to be positive with respect to junction 52, the transistor 55 is biased to conduct in its emitter-collector circuit. Thus, a voltage of this polarity causes the emitter of transistor 55 to be positive with respect to the base electrode thereof and therefore begins to turn on the transistor 55 in its emitter-collector circuit. With this polarity of voltage, the capacitor 90 is also partially charged by the voltage induced in the pick-up coil 50.

When transistor 55 turns on in its emitter-collector circuit, current can flow from junction 56, through the emitter-collector circuit of transistor 55, through primary winding 58 and then to junction 62. The current build up in the primary winding 58 causes a voltage to be induced therein which is proportional to the rate of build-up of current. This causes a voltage to be induced in the secondary winding 64 which is of such a polarity that junction 68 is driven positive with respect to junction 66. This applies a forward bias to the transistor 70 which tends to turn it on in its emitter-collector circuit. As transistor 70 turns on, a current also flows from junction 68, through resistor 74, through diode 86, through capacitor 80 and then back to the opposite side of the secondary winding 64 at junction 66. This causes the capacitor 80 to be charged with a polarity such that junction 84 is positive with respect to junction 66. As will become more readily apparent hereinafter, the charge on capacitor 80 is used to assist in establishing the "on" time for the transistors 55 and 70 in the next cycle.

When transistor 70 turns on in its emitter-collector circuit, current will flow through resistor 74, through the emitter-collector circuit of transistor 70 and through the primary winding 28 of the ignition transformer. At low engine speed, the pick-up coil 50 furnishes enough signal to the base of transistor 55 to turn it on but not sufficient to produce saturation and allow full steady state current to pass through winding 58. Because of the drop in resistor 74, junction 79 will be more negative than junction 56 allowing additional base current to flow from junction 52 through resistor 78, junction 79, conductor 76, emitter-collector of transistor 70, primary 28 and to battery 34. Transistor 55 is thus kept fully conducting until it receives a turn off signal from pick-up coil 50.

As the rotor 44 continues to rotate, the voltage induced in coil winding 50 eventually reverses its polarity. As this polarity reverses, the junction 52 is driven positive and the base electrode of transistor 55 therefore is driven positive with respect to its emitter. This will cause the transistor 55 eventually to turn off in its emitter-collector circuit. As transistor 55 turns off in its emitter-collector circuit, the flow of current through the primary winding 58 starts to decrease and a voltage is induced in the secondary winding 64 which causes the base of transistor 70 to be positive with respect to its emitter. This turns off the transistor 70 in its emitter-collector circuit and a large voltage is then induced in the secondary winding 24 of the ignition coil 26 when the circuit to the primary winding 28 is substantially opened by the turning off of transistor 70. The high voltage which is induced in the secondary winding 24 is applied to one of the spark plugs 12 through the high voltage conductor 22, the rotor contact 20, one of the electrodes 16 and one of the conductors 18.

The Zener diode 72 has a Zener voltage which is slightly lower than the emitter to collector break down voltage rating of transistor 70. With this arrangement, the Zener diode protects the transistor 70 from the voltage induced in the primary winding 28 of the ignition transformer when the current flow through the primary winding 28 is interrupted by a turning off of the transistor 70.

The voltage which is induced in the secondary winding 64 of the coupling transformer 60 to turn off the transistor 70 will cause the potential at junction 66 to become more positive than the potential at junction 68. This will cause a current to flow from junction 66, through lead wire 82, through capacitor 80, through diode 88, through capacitor 90, through conductor 38, through resistor 74 and then back to the opposite side of the secondary winding 64 via conductor 76 and junction 68. This causes the capacitor 90 to be charged such that the junction 54 is at a more positive potential than the conductor 38. The amount of charge which is accumulated by the capacitor 90 is dependent upon the value to which the capacitor 80 was charged during the time that the transistor 70 was turned on. The amount of charge which was accumulated by the capacitor 90 determines the "on" time of the transistor 55 for a part of the ignition cycle. It thus is seen that in order to bias the base electrode of transistor 55 negative with respect to the emitter, it is necessary to overcome the potential which has been accumulated by the capacitor 90. It thus is seen that transistor 55 will not turn on until the voltage induced in the pick up coil 50 is built up to a value required to overcome the charge on capacitor 90.

This provides a time delay for the turning on of the transistor 55 in its emitter-collector circuit. The time delay in turn on of the transistor 55 is made to be inversely proportional to engine speed so that the total "on" time of transistor 55 is maintained relatively constant over the entire engine operating speed range. The charge which is accumulated on capacitor 90 is dependent upon the sum of the charges supplied by the pick up coil 50 and the charge supplied by the secondary winding 64 of the coupling transformer 60 through capacitor 80 when transistor 70 is turned off. The voltage induced in the pick up coil 50 as the rotor 44 rotates is proportional to rotor speed. The rotor 44 is driven at engine speed or at some multiple of engine speed and the voltage induced in the pick up coil 50 is therefore proportional to engine speed. The portion of the charge accumulated in capacitor 90 which is supplied by the pick up coil 50 is directly dependent on the voltage induced in the pick up coil 50 while transistor 55 is turned on. Since this voltage increases with engine speed, the portion of the charge on capacitor 90 which is supplied by the pick-up coil 50 is directly dependent upon engine speed. It will be appreciated that the portion of the charge accumulated by capacitor 90 which is supplied by the secondary winding 64 of the coupling transformer 60 through the capacitor 80 is proportional to the "on" time of transistor 55.

In practice, the voltage induced in the pick up coil 50 builds up at a slow rate at low engine speeds and at a fast rate at high engine speeds. It therefore is seen that a given charge on capacitor 90 will cause more time delay at low engine speeds than at high engine speeds. At

low engine speeds, the "on" time of transistor **55** tends to be long, but this increases the charge on capacitor **90** supplied from the secondary winding **64** of the coupling transformer and therefore causes the "on" time to be shorter. At high speeds, the "on" time of transistor **55** tends to be short, and this causes less charge to be supplied from the secondary winding **64** of the coupling transformer so that less delay and turn on of the transistor **55** results. Proper choice of circuit components will cause the "on" time of transistor **55** at low engine speeds to be only slightly longer than at high engine speeds.

With the ignition system of this invention, the transistor **70** is turned "on" only during the time that transistor **55** is turned "on" and this means that the current flowing through the primary winding **28** of the ignition transformer will always have built-up to nearly the same value before transistor **70** is turned off. This will result in less power dissipation in the circuit at lower engine speeds than would be required if the percent "on" time was allowed to remain constant over the entire engine speed range.

Referring now particularly to FIGURE 2, an ignition system is illustrated which is identical with the system shown in FIGURE 1 with the exception that a feedback coil **92** is provided which is connected between one side of the primary winding **58** of the coupling transformer and the junction **94** on conductor **32**. The system of FIGURE 2 is in other respects identical with the system of FIGURE 1 and the same reference numerals have therefore been used in FIGURE 2 to identify equivalent parts in each of the figures.

The system of FIGURE 2 operates in the same fashion as the system of FIGURE 1 with the exception of the effect of the feedback coil **92**. Thus when the transistor **55** is turned "on," a current will flow through the feedback coil **92** as well as through the primary winding **58** of the coupling transformer **60**. As the current starts to flow in the feedback coil **92**, a voltage will be induced in this coil which will be proportional to the rate of current build up in this coil. This will cause a voltage to be induced in the pick up coil **50** which will be of such a polarity as to increase the forward bias on the transistor **55**. This will cause more drive current to flow from the pick up coil **50** through capacitor **90** and the emitter to base circuit of transistor **55**. This increase drive current will cause more current to flow through the emitter to collector junction of transistor **55**, the primary **58** of the coupling transformer **60** and the feedback coil **92**. As a result, the transistor **55** is more readily driven to its fully turned on state.

It can be seen from the foregoing, that the only difference in the operation of the systems illustrated in FIGURES 1 and 2 is that in FIGURE 2, the feedback coil **92** operates to more readily turn the transistor **55** fully on when the voltage induced in the pick-up coil **50** is of such a polarity as to switch this transistor on.

It will be appreciated that the transistor ignition systems illustrated in both FIGURES 1 and 2 are arranged such that they require a minimum amount of power to operate them. This is accomplished by providing a system wherein the transistor **70** which controls primary winding current is turned on for substantially the same time during both high speed and low speed operation of the engine.

The term "three terminal semiconductor switch means" as used in the specification and claims is intended to cover transistors and any other three terminal semiconductors such as controlled rectifiers which are capable of being used in place of transistors.

While the embodiments of the present invention as herein disclosed, constitute a preferred form, it is to be understood that other forms might be adopted.

What is claimed is as follows:

1. An ignition system for an internal combustion engine comprising, an ignition transformer having a primary winding and a secondary winding, a source of direct current power, magnetic pick-up means including a pick-up coil, said magnetic pick-up means having a part which is adapted to be driven by the engine, a first transistor having emitter, collector and base electrodes, means connecting the emitter-collector circuit of said first transistor in series with said source of direct current power and in series with said primary winding of said ignition transformer, a second transistor having emitter, collector and base electrodes, a coupling transformer having a primary winding and a secondary winding, means connecting said secondary winding of the coupling transformer across the emitter and base electrodes of said first transistor, means connecting the primary winding of said coupling transformer in series with the emitter-collector circuit of said second transistor and across said source of direct current power, means connecting one side of said pick-up coil with the base electrode of said second transistor, a capacitor connecting the opposite side of said pick-up coil with one side of said source of direct current power, and circuit means for charging said capacitor from the secondary winding of said coupling transformer.

2. An ignition system for an internal combustion engine comprising, a source of direct current power, an ignition energizing circuit, a first transistor having emitter, collector and base electrodes, means connecting the emitter-collector circuit of said first transistor in series with said ignition energizing circuit and in series with said source of direct current power, a second transistor having emitter, collector and base electrodes, means coupling the collector circuit of said second transistor with the base circuit of said first transistor, a voltage pulse generating means driven by said engine and including a coil winding, means connecting one side of said coil winding with the base electrode of said second transistor, a first capacitor connected with an opposite side of said coil winding, a second capacitor, a charging circuit for said second capacitor connected with the base electrode of said first transistor, and a charging circuit for said first capacitor including said second capacitor and connected with the base electrode of said first transistor.

3. The combination according to claim **2** wherein the means for coupling the collector circuit of the second transistor with the base circuit of the first transistor is a coupling transformer.

4. In combination, an internal combustion engine, at least one spark plug for said engine, an ignition transformer having a primary winding and a secondary winding, semiconductor switch means, a source of direct current power, means connecting the current carrying terminals of said semiconductor switch means in series with said primary winding and in series with said source of direct current power, control means connected with said semiconductor switch means for turning said semiconductor switch means on and off, said control means having a part driven by said engine, means for developing a first signal that is a function of engine speed, means for developing a second signal which is a function of the turn-on time of said semiconductor switch means, and means for delaying the turning on of said semiconductor switch means in response to said first and second signals.

5. The combination acccording to claim **4** wherein the semiconductor switch means is a transistor.

6. The combination according to claim **4** wherein the control means is a magnetic pick-up having a pick-up coil in which voltages are induced of an alternating polarity.

7. The combination according to claim **4** wherein the means for delaying the turning on of the semiconductor switch means includes a capacitor.

8. In combination, an internal combustion engine, at least one spark plug for said engine, an ignition transformer having a primary winding and a secondary winding, means connecting said secondary winding with said spark plug, semiconductor switch means, a source of

direct current, means connecting the current carrying terminals of said semiconductor switch means in series with said primary winding and in series with said source of direct current, control means connected with said semiconductor switch means for turning said semiconductor switch means on and off, said control means having a part driven by said engine, means for developing a first voltage that is a function of engine speed, means for developing a second voltage which is a function of the turn on time of said semiconductor switch means and means for delaying the turning on of said semiconductor switch means in response to said first and second voltages.

9. The electrical system according to claim **8** where the means for delaying the turning on of the semiconductor switch means includes a capacitor which is charged by said first and second voltages.

10. An ignition system for an internal combustion engine comprising, a spark plug for said engine, an ignition transformer having a primary winding and a secondary winding, means connecting said secondary winding with said spark plug, a source of direct current power, a semiconductor switch means connected between said source of direct current power and the primary winding of said ignition coil, control means driven in synchronism with said engine for causing said semiconductor switch means to be turned on and off and means for causing the on time of said semiconductor switch means to be substantially constant over the varying speed range of said engine, said last-named means including means for delaying the turning on of said semiconductor switch means in accordance with engine speed, the amount of delay increasing as engine speed decreases.

11. The combination according to claim **10** wherein the semiconductor switch means is a transistor.

12. The combination according to claim **10** wherein the control means includes a magnetic pick up having an output coil in which pulses of alternating voltage are induced in synchronism with operation of the engine.

13. An ignition system for an internal combustion engine comprising, a spark plug for said engine, an ignition transformer having a primary winding and a secondary winding, means connecting said secondary winding with said spark plug, a source of direct current, a semiconductor switch means connected between said source of direct current and said primary winding of said ignition coil, control means including means driven in synchronism with said engine for applying turn-on and turn-off signals to said semiconductor switch means whereby said semiconductor switch means is turned on and off in accordance with the signal applied to it from said control means, said turn-on and turn-off signals being developed between predetermined angles of rotation of said engine, and means for maintaining the on time of said semiconductor switch means substantially constant over the varying speed range of the engine, said last-named means including means for delaying the turning on of said semiconductor switch means as engine speed decreases, said delay being increased as engine speed decreases.

14. An ignition system for an internal combustion engine comprising, a spark plug for said engine, an ignition coil having a primary winding and a secondary winding, means connecting said secondary winding with said spark plug, a source of direct current, a semiconductor switch means connected between said source of direct current and said primary winding, a voltage pulse generating means driven in synchronism with said engine and operative to supply time spaced turn-on and turn-off pulses for controlling the conduction of said semiconductor switch means, the spacing between said turn-on and turn-off pulses being a function of the speed of rotation of said engine, and a control means coupling said pulse generating means to said semiconductor switch means for applying said turn-on and turn-off pulses to said semiconductor switch means, said control means including means for delaying the turning on of said semiconductor switch means when one of said turn-on pulses is developed, said delay being increased as engine speed decreases whereby a substantially constant on time is maintained for said semiconductor switch means over the varying speed range of said engine.

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