United States Patent [19]

Ford

[11] **3,896,776**

[45] **July 29, 1975**

[54] **IGNITION TIMING FOR INTERNAL COMBUSTION ENGINES**

[75] Inventor: **Eric Harold Ford,** London, England

[73] Assignee: **Lumenition Limited,** London, England

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[30] **Foreign Application Priority Data**

Apr. 6, 1973 United Kingdom 16680/73

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

[51] **Int. Cl.**[2] **F02P 5/04**

[58] **Field of Search** .... 123/148, 117 R, 146.5 A

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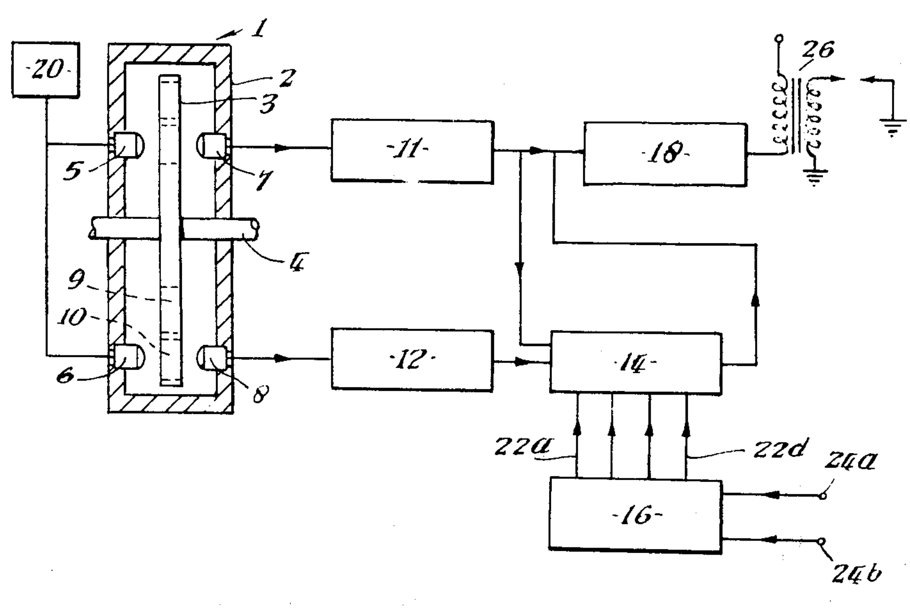
Primary Examiner—Charles J. Myhre
Assistant Examiner—Joseph Cangelosi
Attorney, Agent, or Firm—Larson, Taylor & Hinds

[57] **ABSTRACT**

An ignition system for an internal combustion engine in which not only the timing of the spark is controlled in accordance with the speed of and load on the engine, but the duration of the spark is controlled relative to the angular position of the crank-shaft such that the spark at the spark plug is extinguished at a predetermined crank-shaft angle irrespective of the crank-shaft angle at which the spark is initiated.

12 Claims, 5 Drawing Figures



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SHEET 1

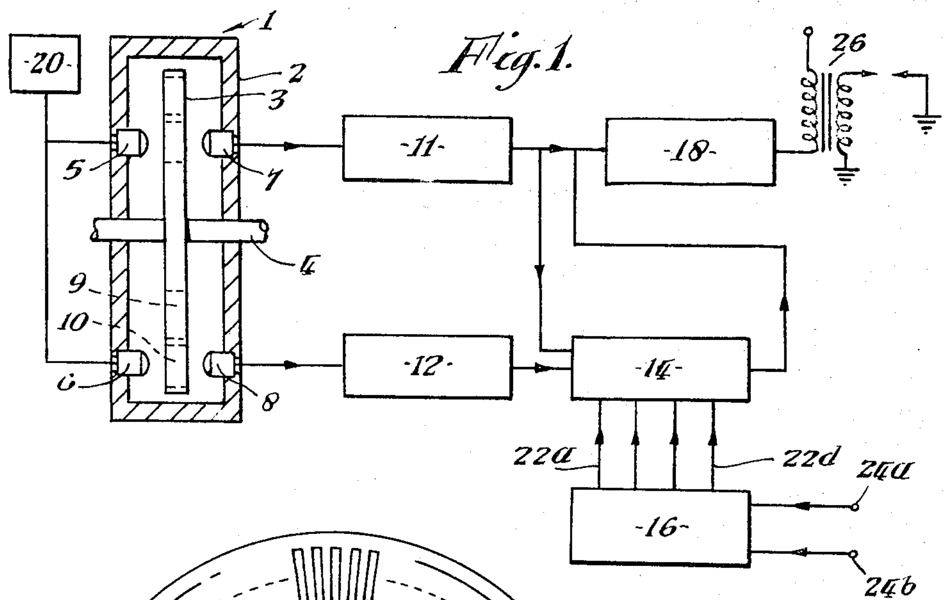

Fig. 1.

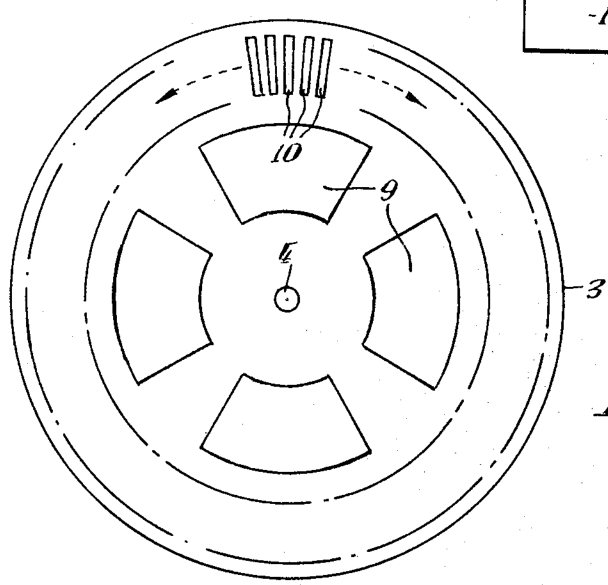

Fig. 2.

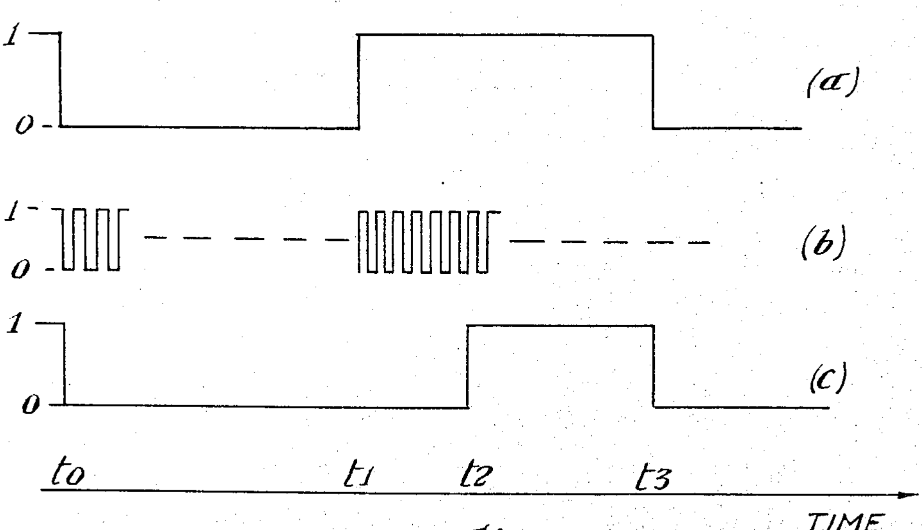

Fig. 4.

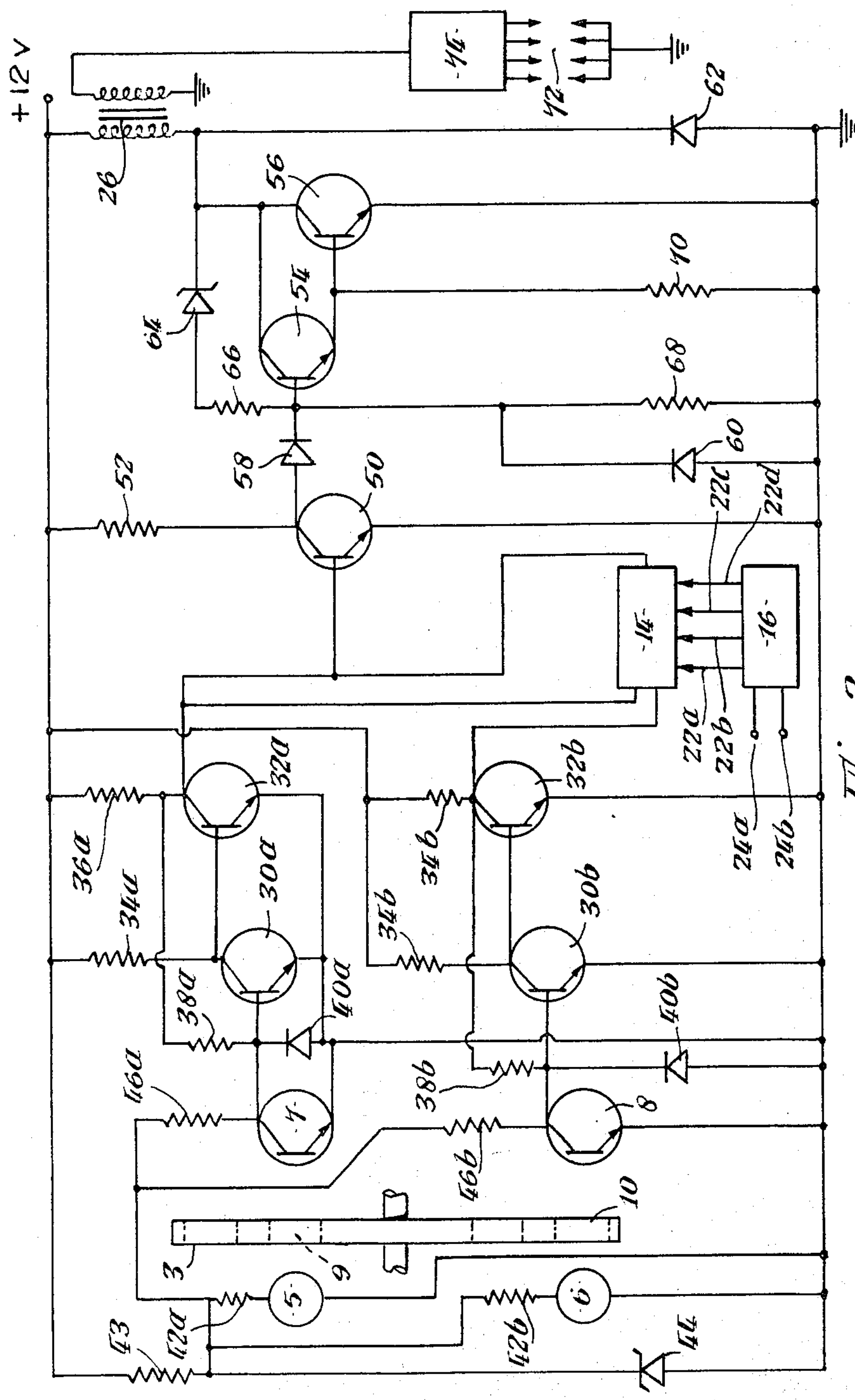
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Fig. 3.

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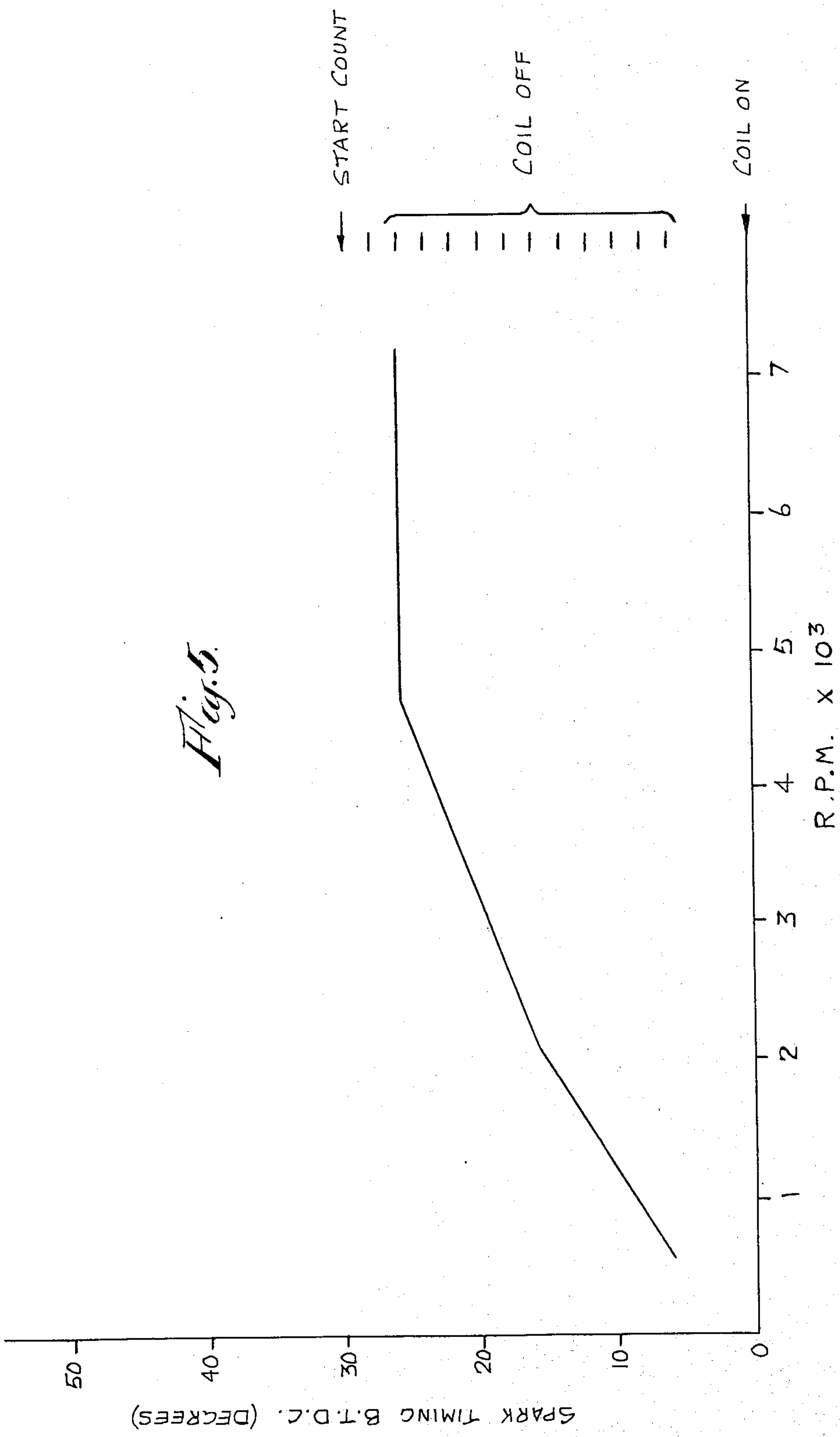
SHEET 3

Fig. 5



IGNITION TIMING FOR INTERNAL COMBUSTION ENGINES

FIELD OF THE INVENTION

The present invention relates to an ignition system for internal combustion engines and more particularly to the timing of the switching on and off of the spark.

DESCRIPTION OF THE PRIOR ART

A known type of ignition system for an internal combustion engine employs contact breaker points operated by a cam driven via suitable gearing from the engine crank-shaft. In this system the contacts are closed and thus the battery is connected across the ignition coil for a fixed number of degrees of crank-shaft rotation irrespective of engine speed. The duration of the spark, which commences when the contact breaker points are opened is a function of the electrical parameters of the system and is substantially independent of engine speed.

Another known type of ignition system for internal combustion engines employs a magnetic trigger to switch off the current to the ignition coil so initiating a spark, the current being switched on again a suitable time before another spark is required. The period of time between switch off of the ignition coil and switch on of the ignition coil is related by suitable control means to the speed of the engine such that the coil has sufficient "on" time for its magnetic field to accumulate sufficient energy to produce a spark.

A further known type of ignition system is triggered by opto-electronic means at appropriate crank-shaft positions, the triggering switching off the current to the ignition coil, the coil being reconnected to the battery a fixed period after switch off. In such a system the crank-shaft position at which a spark is initiated is precisely defined. The spark duration depends on the electrical parameters of the system, switch on of the coil being a fixed time after switch off rather than a particular number of crank-shaft degrees later. This system is effectively monostable since the spark is produced by an electronic circuit which has a stable state in which the coil is on and is triggered to the unstable state to interrupt the current in the primary winding and thus initiate the necessary secondary voltage to produce the spark, the circuit returning to the stable state a fixed time thereafter.

A known improvement upon the above monostable opto-electronically controlled system is a bistable system as disclosed in my U.S. Pat. No. 3,605,712 whereby the crank-shaft angles corresponding to switch on and switch off of the coil have a fixed angular displacement one to another.

Recent concern about the pollutant effects of the exhaust emissions of motor vehicles has led to more stringent requirements regarding their performance. It has become evident that to produce correct combustion of the fuel, and hence a clean exhaust, a correctly timed and sufficiently powerful ignition spark must be reliably provided within the combustion chamber. An essential component of the ignition system is the spark plug, and thus it is of vital importance for the production of an adequate spark that the spark plug is in good condition. If an engine is to meet exhaust pollution requirements over an extended period of time the spark plugs must be maintained in a good condition and to achieve this end without mechanical intervention requires a fuller control of spark timing and particularly angular duration than has hitherto been considered necessary for the following reasons.

Studies of the combustion process within an internal combustion engine have shown the combustion process to have two distinct stages. Firstly after the initiation of the spark there is a low pressure stage wherein the mixture is igniting and a flame is starting to spread within the combustion chamber. At some subsequent point in time a sharp discontinuity in the pressure within the cylinder is observed which marks the commencement of the second explosive stage of combustion. During the initial stage of combustion temperatures and pressures within the combustion chamber are low compared with the temperatures and pressures within the combustion chamber during the second stage of combustion.

Studies of the mechanisms of wear of spark plugs have shown that when a plug is sparking during the initial stage of combustion it suffers little wear and very little metal is transferred across the spark gap to degrade the electrodes. However, when a spark plug is sparking during the second stage of combustion, i.e. when ambient temperatures and pressures are very high, metal transfer across its electrodes is dramatically accelerated as is its wear rate.

By the commencement of the second stage of combustion the mixture in the cylinder is well alight and the presence of any spark at the spark plug is irrelevant to the following process of combustion within the cylinder. In the event that the spark plug continues to spark during the second stage of combustion the spark plug will suffer a high rate of wear as explained above. Thus to maintain the spark plug in good condition it is necessary to switch off the spark at the end of the first stage of combustion. Experiment has shown that the end of the first stage of the combustion process occurs when the piston reaches a region which lies between top dead centre (T.D.C.) of the cylinder and approximately 5° later.

A disadvantage of all the prior art ignition systems is their lack of control of the spark switch off point, thus with all the prior art ignition systems conditions can occur wherein a sparking plug is sparking during part of the second stage of combustion, leading to rapid spark plug wear.

A further disadvantage of the prior art ignition systems is that if their electrical parameters are chosen to produce a relatively short spark this spark may end (at slow engine R.P.M.) prior to the end of the initial stage of combustion during all of which a spark is preferably present in order to assist ignition.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an ignition system for an internal combustion engine which overcomes partially or wholly some or all of the above-mentioned disadvantages of the known systems.

According to the present invention there is provided an electronic ignition system for an internal combustion engine including means for initiating a spark at a crank-shaft angle whose position between two given limits is determined at any instant in accordance with the speed of and load on the engine; and means for extinguishing the spark at the spark plug at a predetermined crank-shaft angle irrespective of the crank-shaft angle at which the spark is initiated.

Preferably the ignition system includes means for generating a beam of electro-magnetic radiation; a radiation sensing device; and means positioned between the radiation generating device and the sensing device to interrupt the radiation, the interrupting means being driven in synchronism with the crank-shaft of the engine such that when the radiation is cut off at a given crank angle this determines the two given limits in which the spark is to be initiated in accordance with the speed of and load on the engine and when the radiation is once again received by the sensing device this determines the point at which the spark is extinguished.

Preferably the electronic ignition system for an internal combustion engine includes means for generating a first series of voltage pulses in synchronism with the engine revolutions to provide a series of alternate highs and lows; means for generating a second series of voltage pulses at a frequency greatly in excess of the first series; means for counting a given number of the second series of voltage pulses from a given point in relation to the first series of voltage pulses; means for producing an output of a given level from said counting means after said count has been completed; means for detecting the presence of both a signal at said given level from the first pulse generating means and the counting means in order to bring about the initiation of the spark, the extinguishing of the spark being effected when the signal from the first generating means changes to the opposite level; and means for varying the count of the counting means in accordance with the speed and/or load conditions on the engine.

Preferably the system controls the advance and retard of the ignition, the counting means starting to count from the position of maximum advance. Thus a signal at said given level from the first trigger initiates the count of the counting means, which then counts down the number it has been set to before giving a signal at said given level to cause the initiation of the spark.

The counting means is preferably a frequency divider.

Preferably the means for varying the count of the frequency divider is a computer whose digital output is modified in accordance with digital information fed into it as regards the speed and/or load conditions on the engine.

The first and second series of generated pulses may be fast switched and current amplified by a trigger circuit comprising a plurality of cascaded transistors arranged to switch in inverse relation to one another so that at any one time at least one transistor is always fully saturated whilst its immediate neighbours are hard off.

The outputs from the first trigger and the counting means preferably operate a power transistor stage with one or more pre-amplifying stages to effect the initiation of the spark by interrupting the current through the primary winding of the ignition coil.

The power transistor stage may consist of a darlington pair having a commoned collector electrode, a zener diode and series resistor being connected between the commoned collectors and the base electrode of the first transistor of the pair. The collector electrode of the last transistor of the trigger is preferably connected to the base electrode of the first transistor of the darlington pair by way of a diode and iron cored inductor connected in series, the function of the latter being to slow down the switching rate of the Darlington pair.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:

FIG. 1 is a diagram (partly in block form) of one form of spark control device for use with a spark ignition system of an internal combustion engine;

FIG. 2 is a front view of the disc shown in FIG. 1;

FIG. 3 is a detailed circuit diagram of the electronic control device shown in FIG. 1;

FIG. 4 is a set of waveforms which assist in explaining the operation of the circuit shown in FIG. 3; and

FIG. 5 is a graph which explains the operation of the spark control device at varying engine speeds.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The ignition control system according to the present invention will now be described with reference to a four cylinder internal combustion engine.

Referring to FIGS. 1 to 3, the device achieves electronic control of the advance and retard of the initiation of the spark and of the termination of the spark and includes a radiation chopper device generally designated **1**; a first fast inverse switching trigger circuit **11**; a second fast inverse switching trigger circuit **12**; a frequency divider **14**; a computer **16**; and an amplifier and power transistor stage **18**.

The radiation chopper device **1** consists of a housing **2**; a disc **3**; a shaft **4** carrying the disc **3**; infra-red radiation sources **5** and **6**; and radiation detectors **7** and **8**. The infra-red radiation sources **5** and **6** are preferably gallium arsenide lamps and the radiation detectors are preferably photo-transistors, all these elements being fixed to the housing **2**. The shaft **4** is journalled in bearings (not shown) in the housing **2** and is driven at cam shaft speed of the engine.

The chopper disc **3** comprises two series of concentric apertures **9** and **10**. There are four large apertures **9** in equi-spaced relation and a large number of small apertures or slits **10** (e.g. 68). The apertures **9** permit infra-red radiation from the lamp **5** to reach the photo-transistor **7**, and the slits **10** permit infra-red radiation from the lamp **6** to reach the photo-transistor **8**. The lamps **5** and **6** are energized through a common stabilized voltage source **20**.

The output from the respective photo-transistors **7** and **8** is fed to the inputs of respective fast inverse switching triggers **11** and **12**. The output of the second trigger **12** is fed to the frequency divider **14** which normally gives a 0 output, but which on completion of the count down set into it from the computer **16** gives a 1 output. The count set into the frequency divider **14** is controlled from the computer **16** by means of four output lines **22*a*** to **22*d***, each of which is either at a high level of voltage to represent a 1 or at a low level of voltage to represent a 0 in accordance with the binary notation. The computer **16** receives at two inputs **24*a*** and **24*b*** information in digital form concerning the speed and load on the engine, this information being obtained from any known analogue type of measuring device and then converted into digital form so that the computer can calculate the count down necessary before the frequency divider **14** will give a 1 output so as to obtain the correct advance or retard of the ignition timing. In this example, the computer has a maximum count of sixteen. The amplifier and power transistor stage **18** controls the current flow through the primary winding of the ignition coil **26.** When the outputs from the stages **11** and **14** are either 0 and 1 or 1 and 0 or 0 and 0 current flows through the primary winding of the ignition coil **26,** but when both outputs are at the high level 1, then the current through the coil is interrupted, producing the collapse of the magnetic field and the resultant high secondary voltage necessary for the spark.

Referring now to FIG. **3,** the first and second triggers **11** and **12** respectively include first transistors **30***a* and **30***b*, second transistors **32***a* and **32***b*, first collector load resistors **34***a* and **34***b*, second collector load resistors **36***a* and **36***b*, and feedback resistors **38***a* and **38***b*. The first and second transistors of each trigger are connected in cascade to switch in inverse relation to one another, so that when one is fully saturated (ON) the other is fully non-conductive (OFF). Also the output from the photo-transistors **7** and **8** is connected to the base electrodes of the respective first transistors **30***a* and **30***b* such that when the photo-transistors conduct, the first transistors switch off and vice versa. Respective diodes **40***a* and **40***b* are connected across the collector-emitter electrodes of the photo-transistors **7** and **8** to ensure clean switching of these elements.

The gallium arsenide lamps **5** and **6** are connected in series with respective resistors **42***a* and **42***b* and connected in parallel with one another across the +12 volt battery supply through a resistor **43.** A zener diode **44** is connected across the paralleled gallium arsenide lamps **5** and **6** in order to provide a stabilized voltage. The voltage across the photo-transistors **7** and **8** is also stabilized by means of the zener diode **44** the photo-transistors being connected in series with respective resistors **46***a* and **46***b*.

The output from the collector electrode of the transistor **32***a* of the first trigger **11** is applied direct to the base electrode of a transistor **50** constituting the amplifier stage of the power transistor stage **18** and also to the set/reset input of the frequency divider **14.** The output from the collector electrode of the transistor **32***b* of the second trigger **12** is applied indirectly to the base electrode of the transistor **50** through the frequency divider **14.** The transistor **50** will conduct only if the outputs from the stages **11** and **14** are at the high level representing a 1. This transistor is thus normally "off" under all the three conditions except the double high when it becomes fully saturated. A resistor **52** is provided in series with its collector electrode.

The power transistor stage **18** also includes two power transistors **54** and **56** connected as a Darlington pair; diodes **58, 60** and **62**; a zener diode **64**; resistors **66, 68** and **70.** The power transistors **54** and **56** are fully protected by means of the zener diode **64** and the diode **62.** The zener diode is arranged to conduct above a certain voltage level so that if there are any positive going transients induced in the circuit when the Darlington pair has switched off, these break down the zener diode **64** which conducts them through the resistor **66** to the base electrode of the power transistor **54.** The Darlington pair is thus caused to turn on in a controlled manner for the duration of these transients so that there is no risk of either of the components of the Darlington pair being broken down in the event of high positive going voltage surges. Negative going transients which occur when the Darlington pair is switched off are conducted to earth via the diode **62.** The purpose of the diode **58** is to prevent the voltage passed by the zener diode **64** from flowing to earth via the transistor **50.**

The secondary winding of the ignition coil is connected to the spark plugs **72***a* to **72***d* via a distributor **74** in conventional manner.

The operation of the electronic spark control device will now be described in greater detail with the aid of the three waveforms shown in FIG. **4.** As the disc **3** is rotated at crank-shaft speed of the engine, the infra-red radiation from the lamps **5** and **6** impinges on the respective photo-transistors **7** and **8** through the apertures **9** and slits **10.** Accordingly, the photo-transistor **7** produces four current pulses per revolution of the disc **3,** whilst the photo-transistor **8** produces a large number (e.g. 68) of pulses per revolution. The two triggers **11** and **12** fast switch and amplify these pulses to produce the waveforms (a) and (b) respectively. During the time $t0$ to $t1$ the photo-transistor 7 is energized by infra-red radiation and is therefore ON. The transistors 30*a* and 32*a* are respectively OFF and ON which means that the output from the first trigger is at the low level representing a 0. At $t1$, the infra-red radiation is cut off and the output of the first trigger becomes high representing a 1. This output is applied to both the frequency divider **14** and the transistor **50** of the stage **18.** The frequency divider **14** now counts the pulses from the second trigger **12** according to the number set into it from the computer **16.** The output of the frequency divider **14** is at the low level **0** from the time $t0$ up to and beyond the time $t1$ unless the computer calls for maximum advance of the ignition. Therefore when the trigger 11 produces a high level output, the power transistors are not switched because of the continued presence of a low level output from the frequency divider 14. In the example illustrated the frequency divider 14 is set to count down a total of six pulses before its output switches to the high level. Therefore at time $t2$ when the count of six has been completed, the output becomes high at the seventh pulse and the transistor 50 switches ON. This in turn switches the power transistor Darlington pair 54–56 OFF to switch off the flow of current in the primary winding of the ignition coil 26, and thus initiate the spark through the high induced secondary voltage on the collapse of the field in the primary winding of the coil. At time $t3$, the output of the first trigger reverts to the low level thus extinguishing the spark and resetting the frequency divider which also reverts to the low level, as shown by waveform (*c*), these events both happening when the photo-transistor 7 is again energized by infra-red radiation.

As and when the load and/or speed of the engine varies, the computer **16** re-calculates from the information fed to it, the new value for the count which is applied to the output thereof in digital form. The frequency divider **14** when started now counts fewer or more pulses before giving a high level output thus varying the timing of the commencement of ignition so as to achieve an advance or retard over the previous position. In the example illustrated the computer has a maximum digital output of sixteen so that the count of the frequency divider can vary from zero up to fifteen, zero being the count for maximum advance and fifteen for maximum retard.

Referring now to FIG. 5 which shows the timing of the initiation of the spark given in crank angle before top dead centre (B.T.D.C.) plotted to a base of engine R.P.M. × 10^3, each aperture **9** in the disc is arranged such that the count starts at 30° B.T.D.C. when the radiation from the lamp **5** is cut off. For engine R.P.M. over 4,600 the coil is switched off at 26° B.T.D.C. Between 2,100 and 4,600 R.P.M. the coil is switched off at an angle which varies linearly from 16° to 26° B.T.D.C. respectively, i.e. it has a slope of 500 R.P.M./2°. Between 600 and 2,100 R.P.M. the coil is switched off at an angle which varies linearly from 6° to 16° B.T.D.C., i.e. it has a slope of 300 R.P.M./2°. When the infra-red radiation from the lamp **5** impinges on the photo-transistor **7**, the trigger **11** produces a low level output which turns on the power transistors **54, 56** and the coil to extinguish the spark. Thus, the extinction of the spark is dependent upon the position of the leading edge of each aperture **9** with respect to the crankshaft. In every case the coil is switched on again at zero degrees B.T.D.C., i.e. at top dead centre.

The spark duration in terms of crank angles is thus controlled from a minimum of 6° at 600 R.P.M. up to a maximum of 26° at speeds of 4,600 R.P.M. and over.

The above described system thus provides the electronic control of the advance and retard of the initiation of the spark in an internal combustion engine and the electronic control of the point of extinction of said spark, the degree of advance or retard of the spark being dependant on the speed and/or load conditions of the engine and the point of extinction of the spark being dependant on the crank-shaft angle of the engine.

The above described electronic ignition system has the advantage over the known systems of extinguishing the spark at a predetermined crank angle, the spark being maintained until this angle is reached.

What I claim and desire to secure by Letters Patent is:

1. An electronic ignition system for an internal combustion engine including means for initiating a spark at a crank-shaft angle whose position between two given limits is determined at any instant in accordance with engine requirements and means for extinguishing the spark at the spark plug at a predetermined crank-shaft angle irrespective of the crank-shaft angle at which the spark is initiated.

2. An electronic ignition system according to claim **1**, including means for generating a beam of electromagnetic radiation; a radiation sensing device; and means positioned between the radiation generating device and the sensing device to interrupt the radiation, the interrupting means being driven in synchronism with the crank-shaft of the engine such that when the radiation is cut off at a given crank angle this determines the two given limits in which the spark is to be initiated in accordance with the engine requirements and when the radiation is once again received by the sensing device this determines the point at which the spark is extinguished.

3. An electronic ignition system according to claim **1**, including means for generating a first series of voltage pulses in synchronism with the engine revolutions to provide a series of alternate highs and lows; means for generating a second series of voltage pulses at a frequency greatly in excess of the first series; means for counting a given number of the second series of voltage pulses from a given point in relation to the first series of voltage pulses; means for producing an output of a given level from said counting means after said count has been completed; means for detecting the presence of both a signal at said given level from the first pulse generating means and the counting means in order to bring about the initiation of the spark, the extinguishing of the spark being effected when the signal from the first generating means changes to the opposite level; and means for varying the count of the counting means in accordance with engine requirements.

4. An electronic ignition system according to claim **3**, including first and second infra-red radiation sources; first and second photo-transistors associated with the respective first and second infra-red radiation sources; an opaque element having a first set of arcuate apertures therein for producing said first series of voltage pulses and a second set of arcuate apertures for producing the second series of voltage pulses, said opaque element being positioned between the radiation sources and photo-transistors, said first set of arcuate apertures being arranged such that the infra-red radiation is interrupted at a first position before top dead centre to start the count for the precise timing of the spark according to engine requirements, the infra-red radiation being established at a second position which is approximately at top dead centre in order to extinguish the spark irrespective of the position at which it was initiated.

5. An electronic ignition system according to claim **3**, including means for generating the highs of the first series of voltage pulses at 30° before top dead centre of respective cylinders of the engine; means for fixing the maximum advance of the ignition at 26° before top dead centre and the maximum retardation to 6° before top dead centre so that the spark is initiated within this range 26° – 6° before top dead centre according to the engine requirements, and means for generating the lows of the first series of voltage pulses at 0° before top dead centre of respective cylinders of the engine.

6. An electronic ignition system according to claim **3**, wherein the counting means is a frequency divider, and the means for varying the count of this divider is a computer whose digital output is modified in accordance with digital information fed into it in accordance with engine requirements.

7. An electronic ignition system according to claim **3**, including first and second trigger circuits for fast switching and current amplifying the first and second series of voltage pulses, each trigger circuit comprising a plurality of cascaded transistors arranged to switch in inverse relation to one another so that at any one time at least one transistor is always fully saturated whilst its immediate neighbours are hard off.

8. An electronic ignition system according to claim **7**, including at least one power transistor and one or more pre-amplifying stages between the power transistor and the output from the first trigger and counting means, said power transistor being in series with the primary winding of the ignition coil, whereby the spark is initiated on interruption of the current through the primary winding of the ignition coil on the power transistor becoming non-conductive.

9. An electronic ignition system according to claim **1** further comprising an ignition coil, said spark extinguishing means comprising means for switching said coil on to extinguish said spark at a first, predetermined crank angle position which is approximately at top dead center and said spark initiating means comprising means for switching off said coil to initiate said spark at a variable crank angle position in advance of said first crank angle position in accordance with the engine requirements.

10. An electronic ignition system for an internal combustion engine in which the spark is initiated between two given crank angles before top dead centre depending on the speed of and load on the engine at any given instant and in which the spark is extinguished at a predetermined crank angle in relation to top dead centre including means for generating a first series of voltage pulses in synchronism with the engine revolutions to provide a series of alternate highs and lows; first means for fast switching and current amplifying said first series of voltage pulses; means for generating a second series of voltage pulses at a frequency greatly in excess of the first series; second means for fast switching and current amplifying said second series of voltage pulses; means for counting a given number of the second series of voltage pulses from a given point in relation to the first series of voltage pulses; means for producing an output of a given level from said counting means after said count has been completed; means for detecting the presence of both a signal at said given level from the output of the first fast switching and current amplifying means and the counting means in order to bring about the initiation of the spark, the extinguishing of the spark being effected when the signal from the first generating means changes to the opposite level; and means for varying the count of the counting means in accordance with the engine requirements.

11. An electronic ignition system according to claim **10,** wherein the two limits for the initiation of the spark are 26° and 6° before top dead centre and wherein the spark is extinguished at a predetermined point in the range of from 0° to 5° after top dead centre.

12. An electronic ignition system according to claim **10,** including a darlington pair output stage in series with the primary winding of the ignition coil and one or more pre-amplifying stages between the commoned output of the first means for fast switching and current amplifying and the counting means and the input electrode of the power transistor stage.

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