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(54) **Method of providing multicharge ignition**

(57) A method for providing multicharge ignition, i.e. multiple ignition sparks across the same spark plug, to an internal combustion engine is proposed. It comprises a first charging event of an ignition coil followed by a first discharge event to produce a spark, and at least one recharging event followed by a corresponding discharge event to produce a further spark, wherein:
the interruption of the primary current following a recharging event is triggered based on the amount of energy stored in the ignition coil. However, each recharging event takes place for at least a predetermined minimum recharging period regardless of the amount of energy stored in the ignition coil.

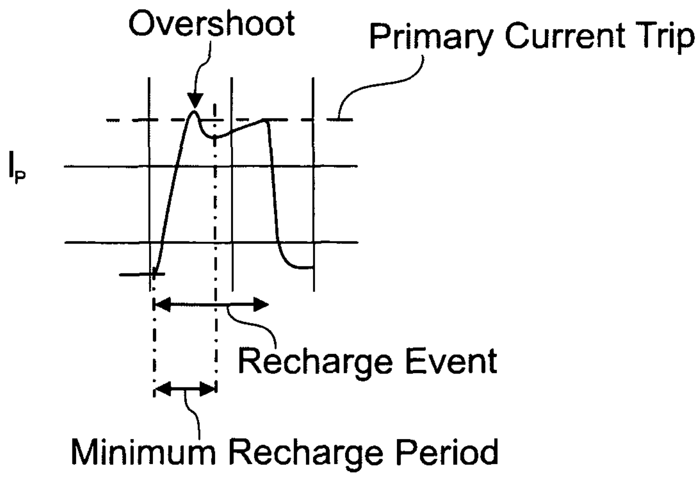


Fig. 4

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## Description

FIELD OF THE INVENTION

**[0001]** The present invention generally relates to the control of ignition in an internal combustion engine, and more particularly, to the production of repetitive sparks for ignition of the combustion mixture.

BACKGROUND OF THE INVENTION

**[0002]** So-called Multicharge ignition systems are designed to generate multiple spark events during a combustion event. Such ignition systems provide a sequence of (preferably fast) spark breakdowns to ensure ignition of a combustible air/fuel mixture introduced in a cylinder of an internal combustion engine. According to the multicharge ignition strategy, a series of sparks is provided to increase the probability of combustion of the air/fuel mixture by extending the time and total energy available for ignition.

**[0003]** Typically, an ignition coil undergoes an initial charge (i.e., initial dwell) wherein a primary current is established in a primary winding of the ignition coil. The initial dwell is immediately followed by an initial discharge of the ignition coil wherein a secondary current in a secondary winding thereof discharges through a spark plug to generate a first spark. Subsequent recharge intervals/ events (i.e., subsequent dwell periods) follow, accompanied by respective discharge intervals/events (i.e., spark events). The number of sparks produced is generally determined by a predetermined operating strategy (e.g., a fixed number of sparks, or, the greatest number of sparks that can be initiated before the end of a predetermined angle of engine rotation or a predetermined fixed time).

**[0004]** Today, so-called current-controlled multicharge systems are considered superior to time-controlled systems (where the period of time allowed for the discharge of the coil-i.e. spark event-and burn before the next recharge and the period of time allowed for the next recharge is determined solely based on time).

**[0005]** Current-controlled systems detect the energy that is taken away from the coil during a discharge event and replace this energy to an exactly defined percentage during the following recharge event before it fires again. The value (or level) of the primary current is used as a measure of the coil energy. In contrary to time-controlled systems the charge state of the current controlled ignition coils is always known. Besides, varying conditions in the combustion chamber can lead to a more or less emptied coil during sparking. Time-controlled systems cannot determine the varying coil charge state. To avoid a highly discharged coil, in current-controlled systems the secondary current can also be measured and the spark can be interrupted when the secondary current drops below a certain given threshold.

**[0006]** US 6,378,513 describes such a current-controlled multicharge ignition system, which permits to minimise or eliminate the variability in the amount of energy delivered to the combustion chamber. The ignition system includes an ignition coil having a primary winding and a secondary winding that is coupled to a spark plug in a combustion chamber of the engine. The system further includes a switch responsive to an ignition control signal for causing a primary current to flow through the primary winding circuit. A control circuit is configured to generate the ignition control signal so as to repetitively interrupt the primary current, creating pulses of secondary current to produce a plurality of sparks at the spark plug. A sensing circuit is designed to determine the level of the current in both the primary winding and the secondary winding; this allows controlling the amount of energy that is stored in said ignition coil and delivered to the combustion chamber, respectively.

**[0007]** In practice, a primary current threshold and a secondary current threshold are set. The recharge event is performed until the level of primary current sensed in the primary winding reaches the primary current threshold. The discharge is conducted until the level of secondary current sensed in the secondary winding drops down to the secondary current threshold.

**[0008]** A disadvantage of all multicharge systems is the interruption of the spark during the recharge interval of the coil. During this time the plasma may extinguish and the flame kernel can be blown out, before a new spark can be established. Thus, the providers of multicharge ignition systems try to reduce the recharge time as much as possible, for instance by using very fast charging coils that charge up to very high primary currents in the range of 20 to 30 A. Also, a supply voltage above the normal level of a car battery of about 14 V is used. Furthermore, the threshold of the secondary current can be set close to the starting value of the secondary current, so that the threshold is rapidly reached and the coil stays almost fully charged.

**[0009]** Striving for reduced recharge times always implies to reduce the burn time of the individual sparks at the same time. The shorter the burn time, the lesser the stored energy taken from the coil, whereby lesser energy needs to be replaced until the next firing.

**[0010]** It may be noted that the actual state of pressure, temperature and mixture of air and fuel in the combustion chamber determines the energy rate that is being taken from the coil. In cases where this energy rate is very low and a very short burn time has been chosen to minimize the interruption of the spark, the total energy loss per firing of the coil is only marginal. Under such circumstances the recharge time can be very short. As explained above, to determine when to stop the recharge, the primary current level is measured and compared to a primary current threshold. When this value is reached the recharging is stopped and the coil fires again.

**[0011]** Unfortunately, due to the nature of the coil being an oscillation circuit it can be observed that when reestablishing the current in the primary winding after a discharge event, the primary current is not just jumping back to the value that corresponds to the energy that remained in the coil: there is an overshoot in the primary current level while jumping back. For the above-mentioned case of very short burn times, the peak value of the primary current overshoot can be above the primary current threshold level, which indicates a fully charged coil to the ignition control circuit that consequently stops charging and opens the switch again to initiate a new discharge event. In other words, the switch, which can e.g. be a transistor or an IGBT, is opened and closed within microseconds without any chance to restore energy to the coil. This causes the switch to run through its linear range twice without any effect on the system, thereby leading to substantial switching losses. This erroneous control of the switch is not only problematic with respect to ignition control, but there is a risk of thermal overstress or even destruction of the switch.

## OBJECT OF THE INVENTION

**[0012]** Hence, there is a need for a method for providing multicharge ignition to an internal combustion engine that allows producing a fast sequence of sparks with short burn time and does not comprise the above-described shortcomings.

**[0013]** This object is achieved by a method as claimed in claim 1.

## SUMMARY OF THE INVENTION

**[0014]** According to the present invention, a method for providing multicharge ignition to an internal combustion engine comprises a first charging event of an ignition coil followed by a first discharge event to produce a spark, and at least one recharging event followed by a corresponding discharge event to produce a further spark. The recharging/discharge cycle may be repeated as often as necessary depending on the desired multicharge strategy. In the present method:

> the first charge event, respectively recharging event, comprises charging an ignition coil by establishing a primary current through a primary winding of the coil;
>
> the discharge event comprises producing a spark by interrupting the primary current to thereby generate a secondary current in a secondary winding of the coil.

**[0015]** Furthermore, the recharging event of the ignition coil includes determining a level of primary current, and the subsequent interruption of the primary current is triggered based on the amount of energy stored in the ignition coil.

**[0016]** According to an important aspect of the present invention, the recharging event takes place for at least a predetermined minimum recharging period regardless of the amount of energy stored in the ignition coil. Preferably the level of primary current in the primary winding is used as an indication of the amount of energy stored in the ignition coil.

**[0017]** In other words, the method of the present invention employs a timer feature that sets a minimum recharging period during which the coil recharging is to take place, and this regardless of the amount of energy stored in the ignition coil (as indicated e.g. by the current level in the primary winding). This minimum recharging period starts with the beginning of each recharging event, i.e. when the current is re-established in the primary winding. Once the minimum recharging period has elapsed, the current-controlled recharge of the primary coil is resumed and the charging will then be stopped once the desired amount of energy is stored in the coil.

**[0018]** The duration of the minimum recharging period is set to be greater than the time interval during which the overshoot in the primary current (typically at the beginning of the recharging event) may occur. In doing so, should an overshoot in the primary occur before the minimum recharging period has elapsed, it would not stop the recharging event.

**[0019]** Since this overshoot phenomenon is mainly due to the coil characteristics and the electronics, the minimum recharging period may be a fixed value, over the ignition cycle of a combustion chamber. It can be easily determined by testing. However, the minimum recharging period can also be designed as a variable parameter, e.g. corresponding to a given percentage of the starting current of the recharging event and/or variable with the spark order number.

**[0020]** As explained hereinabove, the minimum recharging period is applied to the recharging events of the coil, because in the customary practice of current-controlled multicharge ignition the initial (first) charging of the primary coil is set by the engine control unit that determines the start and end of this charge, as well as the primary current level (which may be higher than the threshold level for the recharging events).

**[0021]** Preferably, the discharge event is stopped depending on the amount of energy remaining in the coil. In one embodiment, the level of secondary current in the secondary winding is determined, and the discharge event is stopped when the secondary current level reaches a predetermined threshold.

**[0022]** As it is known in the art, the primary current level threshold at which the primary current is interrupted, respectively the secondary current level threshold at which the next recharge event may be initiated, can be fixed for a given combustion event, or can be made variable from combustion event to event, or even variable between recharge events within the combustion event.

**[0023]** The method according to this invention is particularly interesting for performing multicharge ignition in an engine having an ignition system equipped with so-called "slow coils" that can store more energy than "fast coils". "Slow coils" are coils that require dwell times well above 1 ms to be fully charged. It is thus possible to operate the recharge/discharge events very close to the primary current threshold level (trip) without experiencing recharging interruptions due to the overshoot phenomenon (which is ignored). The present method makes it possible to operate slow coils at fast switching rates. For example, in the case of a recharge/discharge cycle (recharge event plus discharge event) may be in the range of 100 to 200 μs, the minimum recharging period may be in the order of 5 to 30 μs.

**[0024]** The present invention also concerns an ignition system for an internal combustion engine as claimed in claim 9.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0025]** The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1: shows timing diagrams illustrating the operating principle of current-controlled multicharge ignition;

FIG. 2: shows timing diagrams illustrating the overshooting phenomenon as can be observed under certain operating conditions with prior art current-controlled multicharge ignition;

FIG. 3: is a principle diagram of a current-controlled multicharge ignition system designed to implement the present method; and

FIG. 4: is a timing diagram of the primary current illustrating the effect of the Minimum Recharging Period feature of the present method.

## DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

**[0026]** Fig.3 illustrates an ignition system 10 for an internal combustion engine (not shown) designed to operate the present multicharge ignition method. The engine is of the type having a rotating crankshaft to which are connected a plurality of pistons disposed in respective cylinders in a manner understood to those skilled in the art. Engine may be of the type having a direct ignition system for initiating combustion.

**[0027]** Before proceeding to a detailed description of ignition control system 10, a general overview of the background and control established by the present invention will be set forth. Control system 10 relates generally to an ignition system for generating repetitive spark during a combustion event of an internal combustion engine. Systems of this type are commonly known as "multicharge" systems, since an ignition coil portion must be charged and recharged multiple times to produce a corresponding number of sparks. Such systems may be characterized by the amount of energy delivered by the ignition system in a specified time frame (i.e., during the combustion event).

**[0028]** More specifically, the present method is advantageously based on the current-controlled multicharge ignition principle, as illustrated in Fig.1, which gives the primary current (Ip), secondary current (Is) and secondary voltage Us for a single combustion event in a combustion chamber to which an ignition coil is associated.

**[0029]** As shown in Fig.1, multicharge ignition involves:

a) Initially charging an ignition coil by establishing the primary current Ip through a primary winding of the coil. The coil is generally empty when this initial charging event starts.

b) In subsequent (first) discharge event (indicated $t_{burn}1$), a spark is produced by interrupting the primary current to thereby generate a secondary current in a secondary winding of the coil.

c) Next, in a recharging event, the ignition coil is recharged by establishing the primary current through the primary winding of the coil.

d) In the following discharge event ($t_{burn}2$ etc.) a further spark is then produced by interrupting the primary current to thereby generate a secondary current in a secondary winding of the coil.

**[0030]** To be precise and as is known to those skilled in the art, it may be noted that when switching off the primary current (in a discharge event) a secondary voltage is first generated at the secondary winding due to induction law. This voltage breaks down the spark plug gap (punch through) and then the secondary current starts flowing.

**[0031]** As shown in Fig.1, the recharging and discharge events are repeated several times, as necessary.

**[0032]** The recharging and discharge events are triggered on the basis of the amount of energy stored in the coil, respectively discharged from the coil. This may be done in practice by comparing the current level in the primary and secondary windings to preset thresholds. This can be clearly understood from Fig.1. The initial charge event (which is typically controlled differently from the recharging events, as explained further below) is followed by a first discharge event that starts with the interruption of the primary current Ip. This produces a first spark and a secondary current Is is generated, which discharges through the spark plug gap. The discharge event is stopped when the secondary current Is reaches a threshold known as Secondary Current Trip. Then a first recharging event is initiated by reestablishing the current in the primary winding, until the primary current Ip reaches a threshold referred to as Primary Current Trip. When the primary current Ip reaches the Primary

Current Trip, the primary current Ip is interrupted, marking the start of the corresponding (second) discharge event. A spark is produced and energy is accordingly discharged from the coil as can be seen in Fig.1. This sequence of recharging/discharge events may be repeated as often as necessary, based on the levels of the primary and secondary currents Ip and Is to initiate a discharge or recharge event, respectively.

**[0033]** As already explained, the strive for reduced recharge times always implies to reduce the burn time of the individual sparks at the same time. The shorter the burn time the less of the stored energy is taken from the coil and thus less energy is to be replaced until the next firing.

**[0034]** As shown above, conventional current-controlled multicharge systems perform the coil recharging until a predetermined constant or variable (based on predetermined algorithm) primary current level (Trip) is reached. Then the coil fires again. The Primary Current Trip can also vary from combustion event to event or even within the same multicharge cycle (i.e. within the same combustion event). For instance, the Primary Current Trip can increase from recharge to recharge period by a value or a factor or decrease in the same way, or follow any other algorithm.

**[0035]** The actual state of pressure, temperature and mixture of air and fuel in the combustion chamber determines the energy rate that is being taken from the coil. In cases where this energy rate is very low and a very short burn time has been chosen to minimize the interruption of the spark, the total energy loss per firing of the coil is only marginal. Under such circumstances the recharge time would be very short. To determine when to stop the recharge the primary current Ip is measured and compared to the primary current trip level that is given by the ignition control circuit. When this value is reached the recharging is stopped and the coil fires again. Unfortunately, the primary current Ip is not just jumping back to the value that corresponds to the energy that remained in the coil: it is overshooting while jumping back. For the described case of very short burn times, the peak value of the overshoot can be above the primary current trip level, which is suggesting a fully loaded coil to the control circuit that would consequently stop charging.

**[0036]** This overshooting phenomenon is shown in Fig. 2, which shows a part of a multicharge ignition cycle where the recharge primary current hits the Primary Current Trip threshold and switches off four times before a "proper" recharging event takes place (overshoots are indicated $O_1..O_4$). The leading edge of the "proper" recharge is showing the overshoot (however not exceeding the Trip level) that is causing this behavior.

**[0037]** The spark current (here negative) is being interrupted several times for a few microseconds before a proper recharge takes place.

**[0038]** The described phenomenon can repeat often, once the coil has being charged to the Primary Current Trip and then firing very shortly.

**[0039]** This phenomenon is putting significant thermal stress on the electric switch, typically an IGBT, that is used to open or close the primary current flow path through the primary winding. It causes the IGBT to be switched on and off within microseconds without any chance to restore energy to the coil. Consequently, the IGBT runs through its linear range twice without any effect on the system. But this linear range is the most significant contributor to the so-called switching losses. Hence, not only is the overshooting phenomenon problematic with respect to ignition control, but there is a risk of thermal destruction of the IGBT, i.e. of the ignition control system itself.

**[0040]** In order to avoid recharge problems and damaging the switch (IGBT), the present method employs a timer function that sets a minimum recharging period during which the coil recharging is to take place, and this regardless of the primary current level Ip in the primary winding. The minimum recharging period starts with the beginning of the recharge event, and as long as the minimum recharge period has not elapsed, the recharge is continued regardless of the primary current Ip level, i.e. even if Ip goes above the Primary Current Trip. The minimum recharging period is predefined so as to be greater than the time window during which the overshoot is expected to occur after the IGBT switch on.

**[0041]** The efficiency of the minimum recharge period feature of the present method is illustrated in Fig.4. The start of the minimum recharge period starts with the recharging event (i.e. at IGBT switch-on); its duration is greater than the potential overshoot in Ip. Accordingly, the overshoot does not interrupt the charging event although it exceeds the Trip level. As soon as the Minimum Recharge Period has lapsed, the current-controlled operation is resumed and the recharging event is stopped as soon as the primary current reaches the Primary Current trip.

**[0042]** In other words, this timer function permits to simply ignore the primary current trip during the overshoot time, when the IGBT is switching on again to reestablish the current in the primary winding. In cases where little energy was taken from the coil during the previous discharge event, the coil would charge slightly above the Primary Current Trip. As a consequence, the next spark would burn a bit longer since it would start at a higher primary current level. This is acceptable and even beneficial since the spark duration is increased. In the contrary, a coil discharge at high energy rates would be stopped immediately when the Secondary Current Trip has been reached. In this specific case, the recharge time is not affected by the minimum recharge timer function since the high-energy rate has been discharging the coil deep enough to avoid interference between the overshoot and the desired trip.

**[0043]** It may be noted that the present timer function setting the Minimum Recharge Period can be implemented by hardwiring, e.g. in a customized IC (ASIC) or as a software function on a microcontroller-based system. Also possible are CPLDs, customized programmable logic devices. Furthermore, this timer function can be combined with various other features that may be found in an algorithm for operating an ignition coil to provide multicharge ignition to an internal combustion engine.

**[0044]** With this explanation of the present method, and now referring to Fig.3, the ignition system 10 includes an ignition coil 16 comprising primary winding 18 and secondary winding 20, a switch 22, a spark plug 24 comprising a first electrode 26 and a second electrode 28 spaced therefrom to define a gap, primary and secondary sensing circuits comprising a resistor R1 and R2 respectively, and an ignition Control Unit 30. In addition, system 10 may include a diode D1, avoiding a so-called spark-on-make, which is a spark that occurs already during the initial charge of the coil due to the secondary voltage induced by the turns ratio of the transformer.

**[0045]** Ignition coil 16 is configured to function as a selectively controllable step-up transformer. One end, such as the high side end, of primary winding 18 is connected to a supply voltage provided by a power supply, such as a vehicle battery 32. Supply voltage may nominally be approximately 12 to 14 volts. A second end of primary winding 18 opposite the high side end is connected to switch 22. A first end of secondary winding 20, namely the high side end, is coupled to spark plug 24. A second end of secondary winding 20 opposite the high end, namely the low side end, is connected to a ground node through diode D1 and sensing resistor R2. The Diode D1 is optional and can also be placed on the high side end. Primary winding 18 and secondary winding 20 are matched in a predetermined manner known in the art. In the present embodiment, one ignition coil 16 is provided per plug 24.

**[0046]** Switch 22 is provided to selectively connect primary winding 18 to ground, in accordance with a control voltage SCS applied by control unit 30. Such a connection to ground, as is known generally in the art, will cause a primary current Ip to flow through primary winding 18. Switch 22 is illustrated in the Figure as an insulated gate bipolar transistor (IGBT) block diagram; however, it should be understood that switch 22 may comprise additional and/or alternative conventional components known to those of ordinary skill in the art to perform such switching operation.

**[0047]** Coil 16 and switch 22, together, define the means for selectively storing energy, preferably in a predetermined amount, and thereafter transferring the stored energy to spark plug 24.

**[0048]** Spark plug 24 is disposed in the engine proximate a cylinder thereof, and is configured to produce a spark across the gap between its electrodes 26, 28. The spark, as is generally understood by those of ordinary skill in the art, is provided to ignite an air and fuel mixture introduced into the cylinder. During the spark, a secondary current, designated Is, flows across the gap through plug 24 through secondary winding 20 and hence to ground by way of diode D1 and resistor R2.

**[0049]** Control circuit 30 is configured generally to perform multicharge ignition as explained above in accordance with the present method. As it is known in the art, the conditions for the first spark of the multicharge ignition cycle is conventionally given by an engine control unit, such as a powertrain control module (PCM) (not shown), in the form of a ignition control signal EST (engine spark timing). The received EST signal conventionally defines the initial charging time (e.g., duration), and the relative timing (e.g., relative to cylinder top dead center) of when the initial, first spark is to occur. Under such a configuration, the control circuit 30 is configured to drive switch 22 in accordance with the received ignition control signal EST, but is further configured to thereafter generate the drive signals to switch 22 required for subsequent recharge/discharge (spark) events of ignition coil 16. It may be noted that control circuit 30 may alternately be configured to determine the EST signal by itself.

**[0050]** Secondary current sensing circuit comprising sensing resistor R2 is illustrated as being coupled to secondary winding 20 and is configured to generate a secondary current signal, designated Vs. The secondary current signal is representative of the level of secondary current Is in secondary winding 20.

**[0051]** Similarly, the primary current sensing circuit comprises sensing resistor R1 and the level of current Ip through the primary winding is indicated by the voltage Vp across sensing resistor R1.

**[0052]** Control circuit 30, in the illustrated embodiment, is further configured to discontinue the signal SCS to switch 22. This action interrupts the primary current Ip and establishes a secondary voltage at secondary winding 20. This secondary voltage is configured to cause spark plug 24 to produce a spark across gap 30, whereby secondary current Is flows and energy is discharged from the coil. Control circuit 30 is responsive to the secondary current signal Vs to terminate secondary current discharge when the secondary current Is reaches the secondary current threshold level, i.e. Secondary Current Trip. Control circuit 30 is configured to achieve the described termination of the secondary current by generating an active ignition control signal C1 to switch 22, ostensibly in preparation of the next spark. This coincides with the beginning of a recharging event.

**[0053]** In the illustrated embodiment, control circuit 30 is either an ASIC or preferably a programmed computing device that includes a controller, which has computing capability, and processing circuit. Controller may comprise conventional components, and may include a standard processing core, input/output (I/O) circuitry, a random access memory, and a read only memory. As is well known, conventional element ROM may be provided for read only storage of program instructions, data constants and calibration values. Processing core element may be provided for reading and executing program instructions stored in ROM for carrying out the control established by the present invention, especially the recharging/discharge events and the timer function setting the Minimum Recharge Period. RAM may be usefully employed for storage of data of the type, which may be cleared when, for example, ignition power is removed.

**[0054]** In accordance with the present invention, controller includes predetermined data stored in memory, such as ROM. The predetermined data comprise, inter alia, Primary and Secondary Current Trip values as well as values of the Minimum Recharge Period, or data to determine the Minimum Recharge Period.

## Claims

**1.** A method for providing multicharge ignition to an internal combustion engine, comprising a first charging event of an ignition coil followed by a first discharge event to produce a spark, and at least one recharging event followed by a corresponding discharge event to produce a further spark, wherein:

said first charge event, respectively recharging event, comprises charging an ignition coil by establishing a primary current through a primary winding of said coil;
said discharge event comprises producing a spark by interrupting said primary current to thereby generate a secondary current in a secondary winding of the coil;

wherein the interruption of the primary current following a recharging event is triggered based on the amount of energy stored in said ignition coil;
**characterized in that** each recharging event takes place for at least a predetermined minimum recharging period regardless of the amount of energy stored in said ignition coil.

**2.** The method according to claim 1, wherein the start of said predetermined minimum recharging period coincides with the start of a recharge event.

**3.** The method according to claim 1, wherein said predetermined minimum recharging period may be fixed or variable from recharging event to event, or between combustion events.

**4.** The method according to claim 1, 2 or 3, wherein during a recharge event the level of primary current in said ignition coil is determined, and the primary current level is used as an indication of the amount of energy stored in said ignition coil.

**5.** The method according to claim 4, wherein, after lapse of said minimum recharging period, the interruption of the primary current following a recharge event is triggered when the level of primary current reaches a predetermined primary current threshold.

**6.** The method according to any one of the preceding claims, wherein the end of a discharge event depends on the amount of energy discharged from said ignition coil.

**7.** The method according to claim 6, wherein during each discharge event the level of secondary current in said ignition coil is determined, and the secondary current level is used as an indication of the amount of energy discharged from said ignition coil.

**8.** The method according to claim 6 or 7, wherein each discharge event ends when the level of secondary current reaches a predetermined secondary current threshold.

**9.** An ignition system for an internal combustion engine comprising:

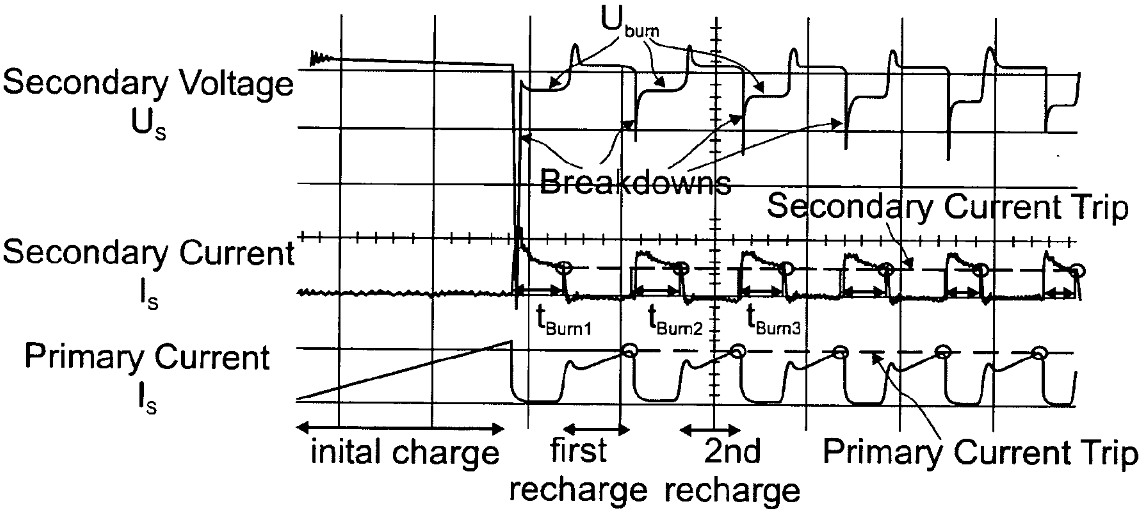
a control circuit configured to generate an ignition control signal;
an ignition coil having a primary winding and a secondary winding, said
primary winding including a first end coupled to a power supply;
a switch connected to a second end of said primary winding and configured to cause a primary current to selectively flow through said primary winding in response to said ignition control;

wherein said control circuit is configured to operate charging and recharging events of said ignition coil by generating said ignition control signal to cause primary current to flow through said primary winding, said control circuit being further configured to cause said switch to interrupt said primary current in order to establish a secondary current in said secondary winding configured to cause a spark plug coupled to said secondary winding to produce a corresponding spark;
**characterized in that** said control circuit is configured so that a recharging event takes places for at least a minimum recharge period, and so as to interrupt said primary current after lapse of said minimum recharge period based on the amount of energy stored in said ignition coil.

**10.** The ignition system according to claim 9, further comprising a sensing circuit in sensing relation with said primary winding configured to generate a primary current signal representative of the level of secondary current in said primary winding; wherein said control circuit is responsive to said primary current signal and processes the primary current signal as an indication of amount of energy stored in said ignition coil.

**11.** The ignition system according to claim 10, wherein after lapse of said minimum recharge period said primary current is interrupted when said primary current reaches a primary current threshold.

**12.** The ignition system according to claim 9, 10 or 11, further comprising sensing circuit in sensing relation with said secondary winding configured to generate a secondary current signal representative of a level of secondary current in said secondary winding; wherein said control circuit is responsive to said secondary current signal and configured to initiate a recharge event by generating said ignition control signal so as to reestablish said primary current in preparation of a further spark during a combustion event when said secondary current reaches a secondary current threshold.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U_s
Breakdowns
Secondary Current Trip
Secondary Current
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t_Burn2
t_Burn3
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inital charge
first
recharge
2nd
recharge
Primary Current Trip

Fig. 1

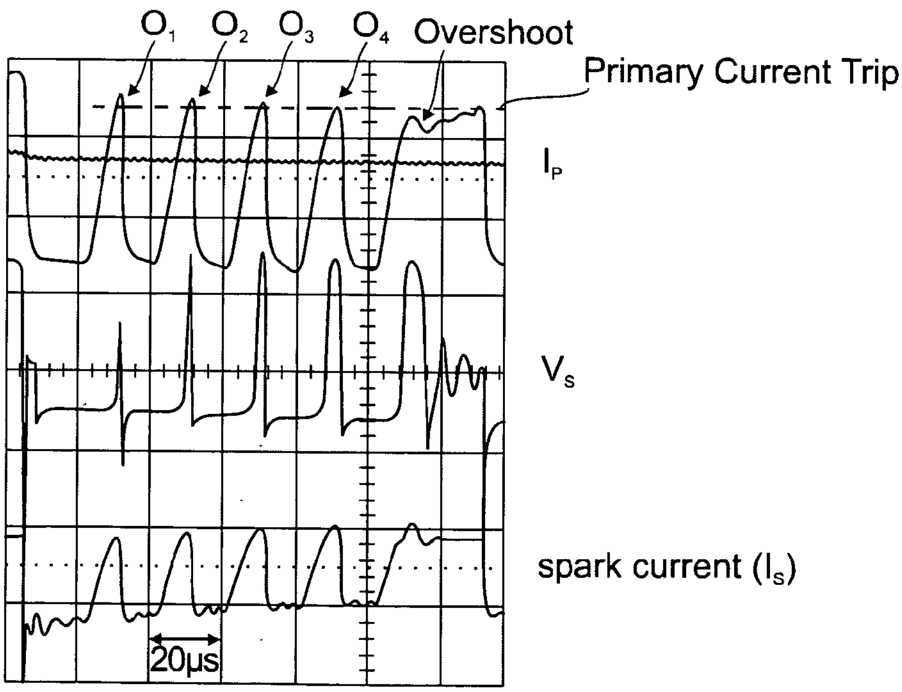
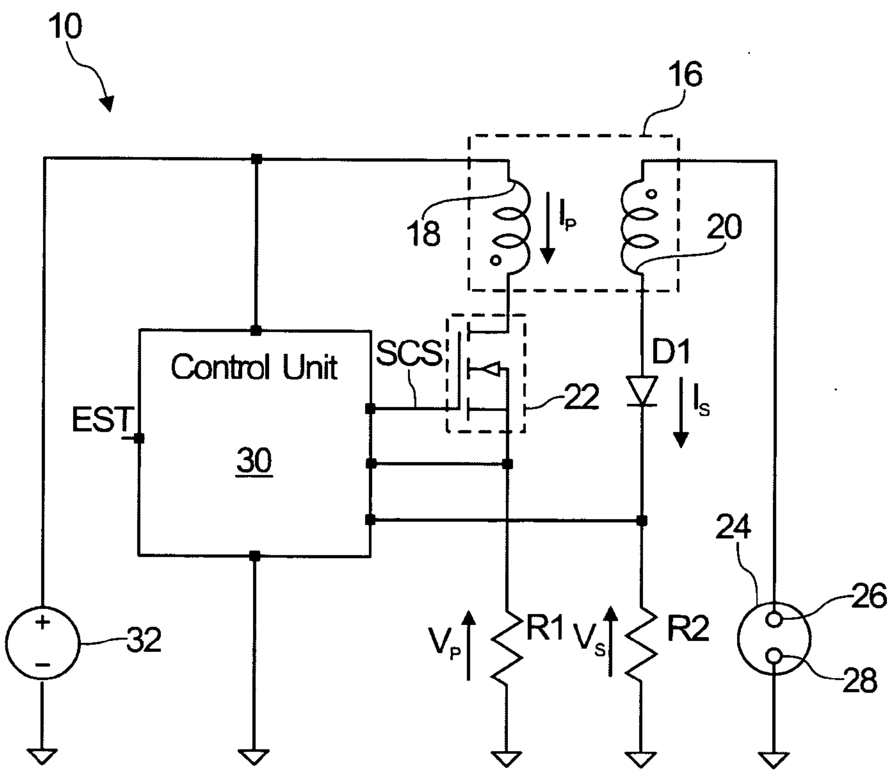

O1
O2
O3
O4
Overshoot
Primary Current Trip
I_P
V_S
spark current (I_S)
20µs

Fig. 2


10
16
18
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20
SCS
Control Unit
30
EST
D1
22
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24
26
32
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R1
$V_S$
R2
28

Fig. 3

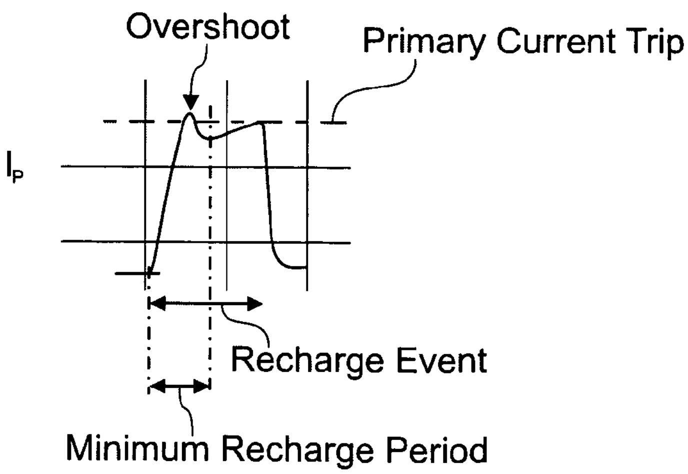
Overshoot
Primary Current Trip
$I_P$
Recharge Event
Minimum Recharge Period

Fig. 4

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# EUROPEAN SEARCH REPORT

Application Number
EP 08 15 6187

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