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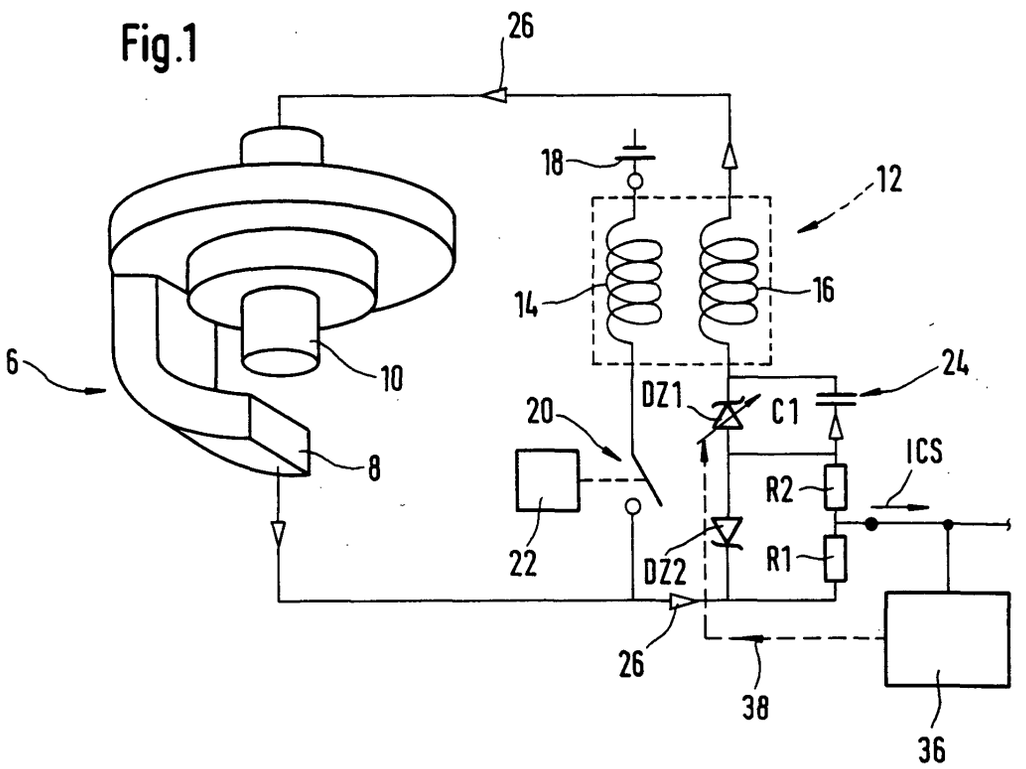
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(54) Device for ion current sensing

(57) A device for ion current sensing in a combustion chamber of an internal combustion engine comprises a first electrode and a second electrode, said first and second electrode being arranged inside said combustion chamber of said engine, and a sensing circuit. According to the invention, the sensing circuit comprises controllable means for adjusting the sensitivity of the sensing circuit.

Fig.1



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Description

Introduction

[0001] The present invention relates to a device for ion current sensing in an internal combustion engine.

State of the Art

[0002] In recent years, more effective emission control has been demanded in internal combustion engines for the protection of the environment. A more effective emission control can be achieved through an improved burning control system. Such a burning control system requires the detection of conditions of the burning of an air-fuel mixture in a combustion chamber of an engine. Many physical parameters, such as the pressure in the combustion chamber, the light generated by the burning of the air-fuel mixture, the ion current in the combustion chamber, and others can be detected as an indication of conditions of the burning of the air-fuel mixture. It is thought that particularly the ion current detection is very useful.

[0003] Ions are generated during the combustion of the air-fuel mixture, the ion concentration directly depending on the burning conditions inside the combustion chamber. Accordingly, the detection of the ion concentration in the combustion chamber means a direct observation of a chemical reaction caused during the burning of an air-fuel mixture.

[0004] In order to measure the concentration of the ions present in the combustion chamber an ion-sensing device, e.g. an ion-sensing electrode, is located inside the combustion chamber. Said ion-sensing device can be independently arranged inside the combustion chamber or integrated in an ignition device, e.g. a glow plug device or a sparking plug device. In a spark-ignition engine the gas mixture in the combustion chamber is ignited by a spark produced in the electrode gap of a spark plug. After extinction of the spark, the two electrodes of the spark plug can be advantageously used as ion density measurement probe.

[0005] A combustion condition detector using the spark plug as ion density probe is e.g. described in US-A-5,675,072.

[0006] During an ion sensing function, said ion-sensing device is supplied with a bias voltage so that the two electrodes of the spark plug form opposite electrodes for capturing the generated ions. An ion current is generated by the migrating ions, the value of which can be easily measured. The information on the ion current can then be used to control the burning conditions inside said combustion chamber.

[0007] Ion sensing circuits for operating the ion sensing electrodes comprise a bias voltage unit and a current sensing unit. Currently these ion sensing circuits are dimensioned such that, even under full load conditions of the engine, i.e. when the ion current signal is maximum, saturation of the ion current signal is prevented. In other words, the sensitivity of the sensing circuit is adjusted so that saturation is prevented. It follows, that under normal combustion conditions, the measured ion current signal is far below the saturation level and the resolution of the measured signal is not optimal.

[0008] This causes major problems especially in direct injection gasoline (DIG) engines. DIG engines generally operate with a number of combustion modes other than the homogeneous stoichiometric/rich mode used by traditional multiple port fuel injection (MPFI) engines. These additional modes will include stratified lean and homogeneous lean modes. It has been shown that when operating with highly diluted or lean air-fuel mixtures, the level of ionization detected in the combustion chamber tends to diminish. Especially in these cases an effective ion current measurement is no longer possible with prior art ion current sensing devices.

Object of the invention

[0009] The object of the present invention is to provide a device for ion current sensing, which allows a more effective ion current measurement over a range of operating modes.

General description of the invention

[0010] This object is achieved by a device for ion current sensing in a combustion chamber of an internal combustion engine, comprising a first electrode and a second electrode, said first and second electrode being arranged inside said combustion chamber of said engine, and a sensing circuit, wherein the sensing circuit comprises controllable means for adjusting the sensitivity of the sensing circuit.

[0011] With the ion sensing device of the present invention, the sensitivity of the sensing circuit can be adjusted if the measured signal gets too weak for effective analysis. If the engine operates in a lean combustion mode, the sensitivity of the sensing circuit may be increased, and the amplitude of the measured signal increases.

[0012] The means for adjusting the sensitivity of the sensing circuit are preferably responsive to an engine operating mode of said internal combustion engine. Since the ion concentration in the combustion chamber and accordingly the ion current to be sensed are largely dependent from the different combustion modes of a DIG engine, said means for adjusting the sensitivity of the sensing circuit can e.g. be responsive to a combustion mode. In this case, a specific sensitivity of the sensing circuit could be associated with each specific combustion mode and the respective adjustment will be made each time the engine switches to the specific combustion mode. A similar setting is possible where means for adjusting the sensitivity of the sensing circuit can e. g. be responsive to an engine load condition of said in-

ternal combustion engine.

[0013] In a more preferred embodiment, the device comprises means for determining a specific characteristic of said ion current signal, e.g. an amplitude of said ion current signal, and said means for adjusting the sensitivity of the sensing circuit are responsive to said specific characteristic of said ion current signal. The sensitivity of the circuit may for instance be adapted in such a way, that the resulting amplitude of the measured signal lies within a specific range. In other words, a control algorithm could operate in closed-loop mode by monitoring the amplitude of the measured ion current signal, and adjusting the sensitivity dynamically to an appropriate.

[0014] In this embodiment, the sensitivity of the sensing circuit can be dynamically adjusted to the actual conditions inside the combustion chamber. The sensitivity of the sensing circuit for ion current measurement can be maximized at all operating conditions. Independent of the combustion mode or the load condition of the engine, the measured ion current signal will have a magnitude which is suitable for effective analysis. In contrast to the known ion sensing devices, the device according to the present invention allows an effective ion current based engine control under virtually any load condition.

[0015] The analyze of a suitable ion current signal allows the determination of a plurality of combustion parameters, such as the detection of air/fuel ratio or peak pressure inside the combustion chamber, the detection of knocking or misfire, etc. Under low load conditions, the ion current signal measured in art engines with prior art ion sensing devices is too weak for suitable analysis. It follows that in these engines, dedicated sensors are required inn order to be able to determine the above described parameters under any condition. Since the device of the present invention allows an effective analyze of the signal independently from the combustion mode or load condition, these parameters can be determined at any time from the measured ion current signal. It follows that separate sensors for detecting these parameters are no longer required, resulting in reduced costs for the overall sensing equipment.

[0016] The device of the present invention may furthermore reduce the development time of the sensing device. In fact, with prior art sensing devices considerable time is spent in adjusting the fixed sensitivity in order to avoid saturation of the ion current signal but nevertheless to maximize the sensitivity of the sensing circuit. Since the sensing circuit of the present invention is adaptive, this development time can be considerably reduced. Furthermore, the amount of ions captured by the electrodes depends on the geometry of the electrodes. Accordingly the amplitude of the measured signal under specific conditions is dependent of the spark plug type. Replacing the spark plug by one of a different type can accordingly degrade the setting of the prior art devices. Since the sensitivity of the sensing circuit automatically adjusts to the actual condition inside the combustion chamber, replacement of the spark plug does not affect the quality of the measured ion current signal in a device according to the present invention.

[0017] Ion sensing circuits for operating the ion sensing electrodes comprise a bias voltage unit and a current sensing unit. It follows that the sensitivity of the sensing circuit can be adjusted in two different ways.

[0018] In a first embodiment said means for adjusting the sensitivity comprise means for adjusting the bias voltage generated by said bias voltage generating unit. In this embodiment, the bias voltage applied to the ion sensing electrodes can e.g. be increased during lean of highly diluted operation, where the level of the measured ion current is much reduced. It has been observed that increasing the bias voltage across the spark gap tends to increase the level of the measured ion current.

[0019] The bias voltage generating unit may e.g. comprise a capacitor and a Zener diode element connected in parallel, wherein said capacitor (C1) is charged during a spark event to a breakdown voltage of said Zener diode element. The means for adjusting the sensitivity may then comprise means for adjusting the breakdown voltage of said Zener diode element.

[0020] In a possible embodiment, said Zener diode element comprises two terminals for connecting said Zener diode element into said sensing circuit, at least two Zener diodes, said Zener diodes having different breakdown voltages, and a controllable switching element for selectively connecting one of said Zener diodes between the two terminals of said Zener diode element. The switching operation of the controllable switching element can be controlled by logical control signals generated by an ion current analyzing circuit. If the amplitude of the ion current signal decreases due to combustion mode changes, the analyzing circuit triggers the switching element to switch to a Zener diode having a higher breakdown voltage.

[0021] In a second embodiment, said means for adjusting the sensitivity comprise means for adjusting a gain of said ion current sensing unit. The ion current sensing unit advantageously comprises a resistor element for converting the ion current into a voltage signal. The means for adjusting the sensitivity then comprises means for adjusting the resistance of said resistor element.

[0022] A possible embodiment of said resistor element comprises two terminals for connecting said resistor element into said sensing circuit, at least two resistors, said resistors having different resistance values, and a controllable switching element for selectively connecting one of said resistors between the two terminals of said resistor element. The switching operation of the controllable switching element can be controlled by logical control signals generated by an ion current analyzing circuit. If the amplitude of the ion current signal decreases due to combustion mode changes, the analyzing circuit triggers the switching element to switch to a resistor having a higher resistance value.

[0023] Alternatively said resistor element comprises two terminals for connecting said resistor element into said sensing circuit, a first resistor being connected between said terminals of said resistor element, at least one second resistor and a controllable switching element for switching said second resistor in parallel to said first resistor. In this variant, the switching element is opened when the measured ion current is high, whereas in lean conditions, the resistors are switched in parallel.

[0024] In yet another embodiment, said resistor element comprises a controllable potentiometer. This controllable potentiometer can e.g. be a programmable IC having a variable resistance.

Detailed description with respect to the figures

[0025] The present invention will be more apparent from the following description of a not limiting embodiment with reference to the attached drawings, wherein

Fig.1: is a simplified representation of a first embodiment of an ion-sense system for an internal combustion engine;
Fig.2: shows a possible embodiment for a switchable Zener diode element;
Fig.3: is a simplified representation of a second embodiment of an ion-sense system for an internal combustion engine
Fig.4: shows a possible embodiment for a switchable resistor element.

[0026] Fig. 1 is a simplified representation of a first embodiment of an ion-sense system for an internal combustion engine. A spark plug 6, which is screwed in the combustion chamber of a cylinder of the engine (not shown), is represented by its electrodes 8, 10. Reference number 12 globally identifies an ignition coil 12 associated with the spark plug 6. This ignition coil 12 consists of a primary coil 14, with relatively few windings, a secondary coil 16, with a large number of windings, and a common magnetic core for both coils 14, 16. The primary coil 14 is connected to a battery 18 and to an electronic current breaker 20, which is operatively connected to an ignition controller 22. The high electromotive force which is required for producing a spark between the electrodes 8, 10 of the spark plug 6 is induced in the secondary coil 16 by a sudden change in the magnetic flux in the common magnetic core of the ignition coil 12 when the charging current through the primary coil 14 is interrupted by the electronic current breaker 20 under the control of the ignition controller 22.

[0027] In the ignition system shown in Fig. 1, the spark plug 6 is used as an ion density detector in the combustion chamber. An ion current sensing circuitry 24 is mounted in series with the secondary coil 16 and comprises mainly a bias voltage generating unit and a current to voltage converting unit. The bias voltage generating unit comprises a capacitor C1. This capacitor C1 is charged during the spark event to a bias voltage that is limited by a Zener diode element DZ1. After the spark event, this bias voltage generates an electric field between the electrodes 8, 10. This electric field acts on ionized gas molecules in the cylinder, so that an ion flow establishes between the electrons 8, 10. As a result of this ion flow, a current 26 establishes in the ignition circuit. This current is a direct image of the ion density in the combustion chamber. It is monitored as a voltage drop across resistor R1 and called the "ion current signal" (in the Figures the ion current signal is called "ICS" or "ion sense"). A second Zener diode DZ2 is used to clip a large negative current peak during the spark event from the measuring resistor R1.

[0028] It will be appreciate, that the bias voltage generated by the bias voltage unit is depending on the Zener voltage of DZ1. The Zener diode element DZ1 is represented as having an adjustable breakdown voltage (indicated by the arrow in the graphical symbol of DZ1). A possible embodiment of such an adjustable Zener diode element is schematically shown in Fig. 2. This Zener diode element comprises three Zener diodes D1, D2, D3 having different breakdown voltages, e.g. $V_{D1}>V_{D2}>V_{D3}$. The three Zener diodes D1, D2, D3 are connected on one side to a first terminal 28 of the Zener diode element DZ1. A controllable switching element 32 is connected to the second terminal 30 of the Zener diode element DZ1. Switching element 32 has three switching positions, whereby in each switching position one of the Zener diodes D1, D2, D3 is connected between the terminals 28 and 30.

[0029] The switching element 32 can be controlled by a logical signal applied to the control input 34. The logical signal can e.g. be generated by an ion current signal analyzing circuit 36 based upon an amplitude of the measured signal. In lean operation, where the level of the measured ion current is much reduced, the analyzing circuit 34 may e.g. generate a logical signal 38, which causes the switching element 32 to switch to diode D1 having the highest breakdown voltage. If the measured ion current signal increases, signal 38 may cause the switching element 32 to switch to diode D2 or D3, thus decreasing the bias voltage applied across the electrodes 8 and 10.

[0030] It will be appreciated, that depending on the range of the scaleable values for DZ1, the values of the associated sensing components DZ2 and C1 may have to be adaptable accordingly.

[0031] A second embodiment of an ion-sense system for an internal combustion engine is schematically represented in Fig. 3. In this embodiment Zener diode element comprises a simple Zener diode DZ1. In contrast to the embodiment of Fig. 1, the measuring resistor is replaced by a variable resistor element R1. Since resistor element R1 determines the gain of the current to voltage converter, an increase of the resistance of R1 causes the ion current signal to decrease and vice versa.

[0032] Resistor element R1 of Fig. 3 is represented

as a controllable potentiometer which can be controlled by a logical signal generated by the signal analyzing circuit 36. The controllable potentiometer can e.g. be a programmable IC having a variable resistance. An alternative embodiment of an adjustable resistor element R1 is schematically represented in Fig. 4. This resistor element R1 comprises three resistors R10, R12, R14 having different resistance values, e.g. R10>R12>R14. The three resistors R10, R12, R14 are connected on one side to a first terminal 36 of the resistor element R1. A controllable switching element 40 is connected to the second terminal 38 of the resistor element R1. Switching element 40 has three switching positions, whereby in each switching position one of the resistors R10, R12, R14 is connected between the terminals 36 and 38.

[0033] The switching element 40 can be controlled by a logical signal applied to the control input 42. In lean operation, where the level of the measured ion current is much reduced, the analyzing circuit 34 may e.g. generate a logical signal 38, which causes the switching element 40 to switch to resistor R1 having the highest resistance. If the measured ion current signal increases, signal 38 may cause the switching element 40 to switch to resistor R2 or R3, thus decreasing the voltage signal at the terminals of resistor element R1.

Claims

1. Device for ion current sensing in a combustion chamber of an internal combustion engine, comprising a first electrode and a second electrode, said first and second electrode being arranged inside said combustion chamber of said engine, and a sensing circuit, **characterized in that** the sensing circuit comprises controllable means for adjusting the sensitivity of the sensing circuit.

2. Device according to claim 1, **characterized in that** said means for adjusting the sensitivity of the sensing circuit are responsive to an engine operating mode of said internal combustion engine.

3. Device according to claim 2, **characterized in that** said means for adjusting the sensitivity of the sensing circuit are responsive to a combustion mode and/or an engine load condition of said internal combustion engine.

4. Device according to claim 1, comprising means for determining a specific characteristic of said ion current signal, **characterized in that** said means for adjusting the sensitivity of the sensing circuit are responsive to said specific characteristic of said ion current signal.

5. Device according to claim 4, wherein said specific characteristic of said ion current signal is an amplitude of said ion current signal.

6. Device according to any one of claims 1 to 5, wherein said sensing circuit comprises a bias voltage generating unit, **characterized in that** said means for adjusting the sensitivity comprise means for adjusting the bias voltage generated by said bias voltage generating unit.

7. Device according to claim 6, wherein said bias voltage generating unit comprises a capacitor and a Zener diode element connected in parallel, said capacitor (C1) being charged during a spark event to a breakdown voltage of said Zener diode element (DZ1), **characterized in that** said means for adjusting the sensitivity comprise means for adjusting the breakdown voltage of said Zener diode element (DZ1).

8. Device according to 7, wherein said Zener diode element comprises two terminals for connecting said Zener diode element into said sensing circuit, at least two Zener diodes, said Zener diodes having different breakdown voltages, and a controllable switching element for selectively connecting one of said Zener diodes between the two terminals of said Zener diode element.

9. Device according to any one of claims 1 to 8, wherein said sensing circuit comprises an ion current sensing unit, **characterized in that** said means for adjusting the sensitivity comprise means for adjusting a gain of said ion current sensing unit.

10. Device according to claim 9, wherein said an ion current sensing unit comprises a resistor element for converting the ion current into a voltage signal, **characterized in that** said means for adjusting the sensitivity comprises means for adjusting the resistance of said resistor element.

11. Device according to claim 10, wherein said resistor element comprises two terminals for connecting said resistor element into said sensing circuit, at least two resistors, said resistors having different resistance values, and a controllable switching element for selectively connecting one of said resistors between the two terminals of said resistor element.

12. Device according to claims 10, wherein said resistor element comprises two terminals for connecting said resistor element into said sensing circuit, a first resistor being connected between said terminals of said resistor element, at least one second resistor and a controllable switching element for switching said second resistor in parallel to said first resistor.

13. Device according to claim 10, wherein said resistor

element comprises a controllable potentiometer.

Fig.1

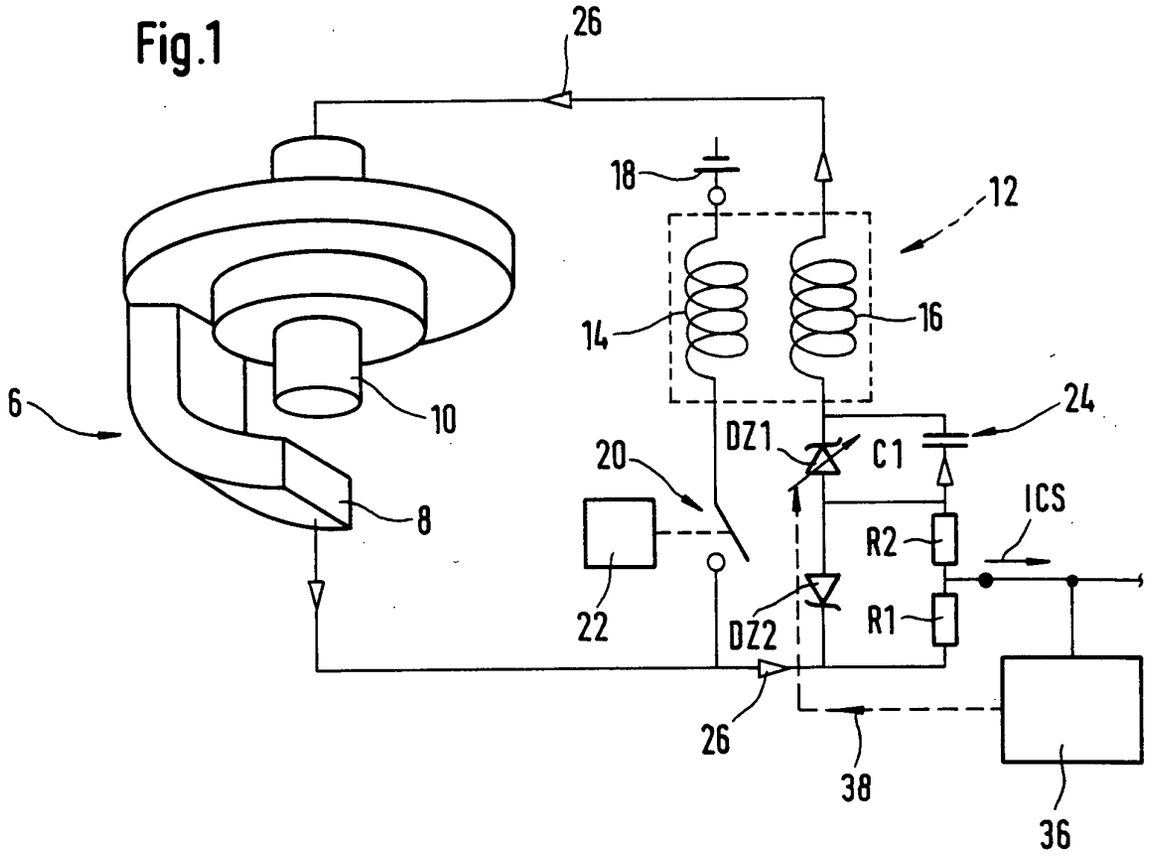

26
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12
14
16
6
10
24
DZ1
C1
20
ICS
8
R2
22
R1
DZ2
26
38
36

Fig.2

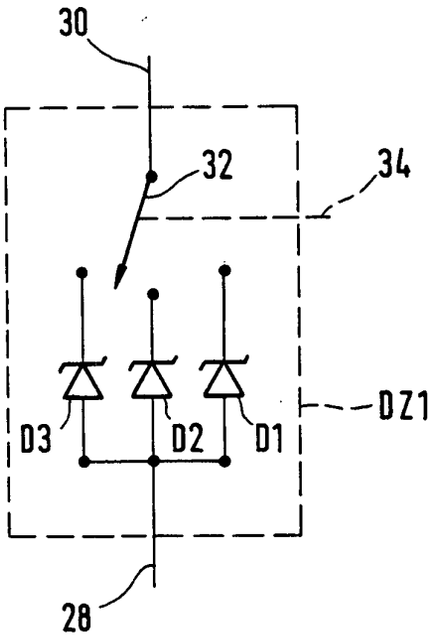

30
32
34
D3
D2
D1
DZ1
28

Fig.3

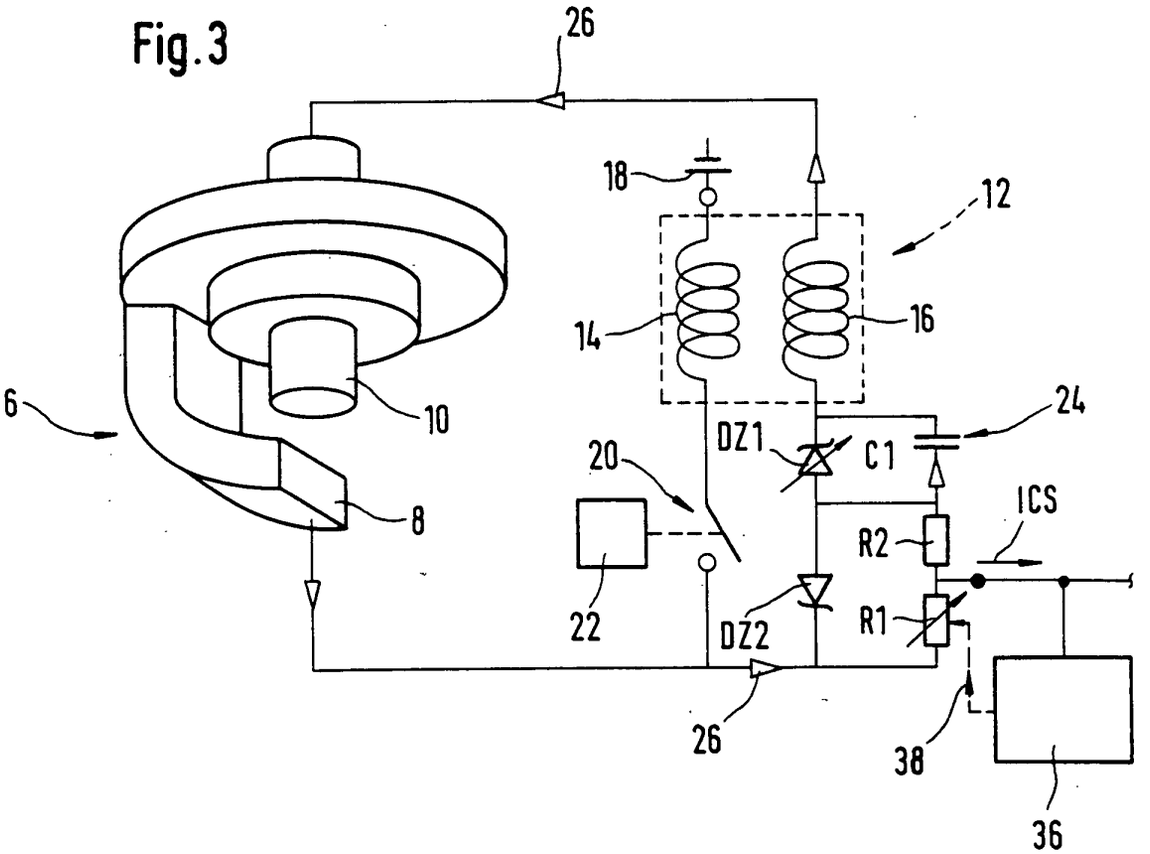
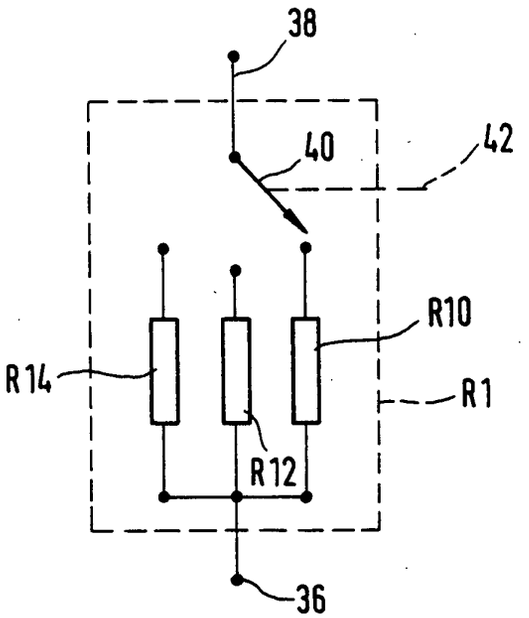

26
18
12
14
16
6
10
24
DZ1
C1
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ICS
8
R2
22
DZ2
R1
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38
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Fig.4


38
40
42
R10
R14
R1
R12
36

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EUROPEAN SEARCH REPORT

Application Number
EP 02 00 1302

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 May 2002	Libeaut, L

CATEGORY OF CITED DOCUMENTS

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