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(54) Title: METHOD AND APPARATUS TO DETECT IMPEDANCE OF CONTACT BETWEEN INJECTOR VALVE MOVING PARTS

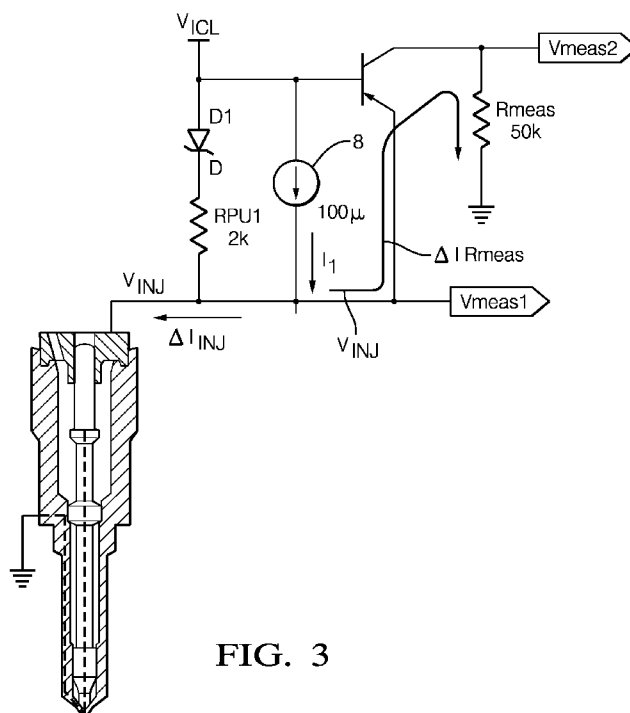


FIG. 3

(57) Abstract: A system adapted to detect the electrical continuity between components of an actuator operated fuel injector (1), where said components are adapted move relative to one another in operation, said system including a wire (7) connected to an electrical contact point on said fuel injector from a supply voltage (V_{ICL}) forming a circuit allowing current to pass through said injector (I_{inj}) to ground via said components when said components have a degree of electrical continuity, and including a constant current source (8) and transistor switch (Q1) connected in parallel such that one terminal of the current source is connected to the supply voltage V_{ICL} and a first terminal of the transistor switch, and the other terminal of said current source is connected to said electrical contact and a second terminal of the transistor switch, such that current from the constant



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current source is adapted to forma first pathway through the injector dependent on said electrical continuity and a second pathway though the switch via the from said second terminal to the third terminal of the transistor switch.

METHOD AND APPARATUS TO DETECT IMPEDANCE OF CONTACT BETWEEN INJECTOR VALVE MOVING PARTS

5

TECHNICAL FIELD

This disclosure relates to fuel injectors and has particular but not exclusive application to fuel injectors where movement of a valve needle away from a valve seat is controlled by an actuator indirectly via a hydraulic (servo) system. It has general application to controlling or detecting relative movement of moving parts in a fuel injector valve system,

BACKGROUND OF THE INVENTION

Fuel injectors generally comprise an actuator controlled valve adapted to move a valve needle away from a valve seat to dispense fuel. Thus such injectors are typically operated by energizing an actuator such as a solenoid actuator, the movement of the actuator causing the valve to open or shut. The actuator may directly control movement of the needle and pintle. However in most current modern designs of fuel injectors, due to the high pressures and forces required to open fuel injectors in very short times, the fuel injector includes a hydraulic amplification circuit (servo) where movement of the actuator allows fuel under pressure to flow to force the needle assembly to move.

In order to carefully control fuel injector operation, it is desirable to know when components which move relative to each other, are in contact or not in contact, such as when the needle tip is in contact or not with the valve seat. This allows fuel injectors to be more finely tuned in terms of operation. Particularly with indirect opening of injector needle, there is no knowledge of exact opening and closing times.

In order to overcome this problem it is known to provide injector closed loop control where means are provide which determine contact between moving parts e.g. needle and valve seat. This is usually performed by determining the electrical contact between moving parts by e.g. providing an electrical contact switch, e.g. between the injector needle and nozzle, or between other appropriate moving parts. Thus injectors may be provided with additional wiring in order to implement this. So in an example, the injector needle tip may form an electrical

contact switch. If the injector is closed, a current can flow through this switch. If the injector opens, the needle is lifting from its seat, fuel starts to flow and the electrical contact is disrupted. The expected time precision of the measured signal is in the range of 1 μ s.

5 This allows finer control and measurement and dispensing of injected fuel quantity. The value of RICL that is the measured resistance between e.g. needle and seat, may have low and high impedances, and contain information about how close the needle is to the seat.

 A problem with this is that contact surfaces are small, and there is a thin
10 separation between needle and valve (needle) body. As a result, during “nominal” contact/non –contact the impedances are not 0Ω or infinite, but have a complex, time dependent, behavior. High and varying capacitance (CICL) is also a problem. It is an object of the invention to overcome these problems

15 SUMMARY OF THE INVENTION

 In one aspect is provided a system adapted to detect the electrical continuity between components of an actuator operated fuel injector, where said components are adapted move relative to one another in operation, said system including a wire connected to an electrical contact point on said fuel injector from
20 a supply voltage (VICL) forming a circuit allowing current to pass through said injector (I_{inj}) to ground via said components when said components have a degree of electrical continuity, and including a constant current source and transistor switch (Q1) connected in parallel such that one terminal of the current source is connected to the supply voltage VICL and a first terminal of the
25 transistor switch, and the other terminal of said current source is connected to said electrical contact and a second terminal of the transistor switch, such that current from the constant current source is adapted to form a first pathway through the injector dependent on said electrical continuity and a second pathway through the switch via the from said second terminal to the third terminal of the transistor
30 switch.

 Said first terminal may be the base or gate of a bipolar or FET.

 There may be means to obtain a measure the current passing through said second pathway or through the switch.

The system may include means to measure the voltage at a point on said second pathway (V_{meas1} , V_{meas2}).

The system may include means to measure the voltage at the second or third terminals of said transistor.

5 The transistor may be a bi-polar transistor and including a measurement resistor connect to the collector terminal of said transistor and means to measure the voltage at a point between said collector terminal and measurement resistor.

The system may including means to measure the current passing through the switch from the constant current source.

10 The system may include a diode and/or resistor located between supply voltage and injector point in parallel with said constant current source.

In a further aspect is provided a method of determining the degree of electrical continuity between components of an actuator operated fuel injector, where said components are adapted move relative to one another in operation,
15 comprising using the system as above, and a) measuring the current or voltage at a point in said second pathway, and b) determining said degree of electrical continuity from the results of a).

The including determining the change in value of current or voltage at a point in said second pathway, and where step b) includes determining said degree
20 of electrical continuity from the results said changes.

The components may be a needle and needle valve seat.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is now described by way of example with
25 reference to the accompanying drawings in which:

Figure 1 shows a schematic diagram of a fuel injector which include an additional wire to detect connectivity between injector moving parts such as needle and valve seat.

Figure 2 shows a prior art circuit used in conjunction with figure 1 design
30 to detect electrical contact between moving parts

Figure 3 shows an example according to one embodiment of a circuit used to detect electrical contact.

Figure 4 shows a plot of parameters of the circuit of figure 3.

Figure 1 shows a schematic diagram of a fuel injector 1 which is adapted to provide feedback control by including means to detect contact between moving parts such as the needle tip with the valve seat.

5 DESCRIPTION OF THE PREFERRED EMBODIMENTS

The figure shows a known fuel injector 1 which is controlled by an actuator such as a solenoid actuator shown schematically by 2. An Engine Control Unit (ECU) 3 sends an activation signal (pulse) profile to the actuator, in order to actuate it via lines 4. The signal may be a Pulse Width Modulation signal.

10 The fuel injector includes a needle 5 adapted to move within a needle body (housing) 6. The needle body forms or includes a valve seat. Generally contact of the needle with the valve seat means the valve is closed. When the needle moves away from the valve seat there is no contact and fuel is dispensed.

For the aforementioned control, an additional circuit is included which includes a wire or lead 7 from the ECU. The circuit may be arranged such that current can flow through wire and through the metal injector components. The circuit may include one or more effective “switches” whereby contact of e.g. valve seat and needle allows current to flow through the circuit to ground. Where there is no contact, current cannot in theory flow. Thus by measuring the
20 resistance/impedance of these effective switches, this allows the ECU to determining the operating state of the valve and when components such as the valve seat and needle move away from contact or when they move together to form a contact. In figure 1 existing circuitry for measuring impedance and thus electrical contact may be part of the ECU and is shown generally by reference
25 numeral 10.

Figure 2 shows existing circuitry used to determine the impedance of the contact (electrical switch) between valve moving parts such as needle and seat... Such existing electronics may be located or interface inside the ECU as in figure 1 and have the functionality of the circuitry 8 of figure 1. The circuitry consists of a
30 known supply voltage VICL to which a diode D1 in series with a low impedance pull-up resistor RPU1 is connected. RPU1 is also connected to the injector needle wire 7, which as previously described is connected to injector moving parts which form one or more effective electrical switches. Thus the wire or line 7 has a

voltage designated V_{inj} . A high impedance pull-up resistor RPU2 is connected between VICL and wire 7, such that the two resistors are connected in parallel. The wire 7 is connected to voltage measurement means. essentially therefore providing analog read back of the voltage on line 7.

5 In an example the valve needle and seat form an electrical switch, and so when in contact the injector is nominally closed. Current can therefore flow through from VICL through the resistor RPU 1 and the needle tip to ground. The voltage on line 7 V_{inj} which is the measured voltage V_{meas1} thus falls to a low value or zero. If the injector is opened, the valve components (e.g. needle tip and
10 valve seat) are not in electrical contract. There is no current flow through the resistor and the needle tip to ground. The VICL thus pulls –up the voltage V_{meas1} to a higher voltage level.

So in summary there are two “pull-up” conditions. The measurement voltage V_{meas1} will be an intermediate voltage between zero and the voltage
15 VICL dependent on whether the valve is closed (electrical contact) or open (no electrical contact) as also to an extent the resistance of the injector. So the measurement V_{meas1} is a resistive division between the pull-ups and the switch resistance (R_{INJ}). The two conditions are summarized below:

20 If the switch impedance (of the switch formed by the valve parts)I is low e.g. when they are in (electrical contact) When needle : $V_{meas1} \cong \frac{R_{INJ}}{R_{PU1} + R_{ICL}}$

If the switch impedance is high (e.g. when the valve parts are not in contact) , the voltage on V_{INJ} is close to VICL (less than a diode drop):

25
$$V_{meas1} \cong \frac{R_{INJ}}{R_{PU2} + R_{ICL}}$$

There are limitations with this circuitry and method. The method and circuitry require electrical low pass filtering ($R \cdot C$) of signal due to time shift - if the value of R_{inj} is very high , the signal change when the valve changes state is
30 very low and the signal processing treatment difficult.

As mentioned the “switch” i.e. assumed electrical contact is not perfect, the impedance might be quite high, even if the switch is closed. In this case, the voltage on the switch is close to V_{ICL} and the change in impedance can be seen by a small voltage change. This voltage change is quite small, which makes signal
5 treatment on the measurement circuit difficult. The injector has significant electrical capacitance. Together with RPU2, the measurement circuit decodes a heavily filtered signal, which results in a smaller voltage drop and in a time lag.

Circuitry

10 Figure 3 shows an example according to one aspect. The figure is similar to figure 2. The circuitry consists again of a known supply voltage V_{ICL} , to connected to the injector needle wire 7, which as previously described is connected to injector moving parts which form one or more effective electrical switches. The connection is via optionally a diode D1 in series with a low
15 impedance pull-up resistor RPU1. Thus the wire or line 7 has a voltage designated V_{inj} .

Connected in parallel with the diode D1 and resistor RPU1 (between V_{ICL} and the injector wire) is (instead of the pull-up resistor RPU2 of figure 2), a current source 8 is provided which provide a current I_1 .

20 Further a switch Q1 is connected also in parallel between V_{ICL} and the line 7; the switch may comprise a transistor. The base of the transistor is connected to V_{ICL} and the other two terminals are connected respectively to ground via measurement resistor R_{meas2} and the line 7. The voltage at a point between the switch and the resistor R_{meas2} is forwarded to a measurement means
25 and it designated V_{meas2} . There may also be means to measure the voltage at a point between the current source and the transistor switch V_{meas1}

Diagnosis

In order to determine contact between the valve parts, a measure of the
30 current flowing through the injector, and thus its resistance/impedance can be determined by the circuitry of figure 3. In some instances, because of the high impedance of the injector in relation to V_{ICL} and ground, only very small currents may flow through the injector when there is appropriate contacts of parts (e.g.

needle and valve seat) so that current can flow from V_{ICL} to ground via the injector.

In one example the value of V_{meas2} is read and this is used to determine a measure of the current through the injector. In an alternative the value V_{meas1} is used instead or additionally.

At each instant I_1 is constant and $I_1 = I_{inj} + I_{R_{meas}}$ where I_{inj} is the current that goes through the injector as shown in figure 3, and $I_{R_{meas}}$ is the current that goes through the resistor R_{meas} .

Ignoring the current through D1, then the current through the injector is

$$I_{inj} \triangleq I_1 - I_{R_{meas}}$$

$$\text{and} \quad \Delta I_{inj} \triangleq - \Delta I_{R_{meas}}$$

and value V_{meas2} give a measure of $I_{R_{meas}}$.

Thus small changes in current through the valve will be seen as changes in voltage of V_{meas2} . It is to be noted that when I_{inj} fall the voltage V_{meas1} or V_{meas2} increases.

In operation the current sources tries to push current (I_1) shown in figure 3 through the switch Q1 and passes this current to the measurement circuit V_{meas2} in case the voltage on the switch goes above V_{ICL} .

Small currents going through the injector (high impedances) are immediately seen on the measurement circuit V_{meas2} because the impedance of a current source is small compared with the impedance of the injector. At each instant of time, the sum of the current in the injector and of the current in the switch is constant. The electrical capacitance of the injector does not affect the measured signal. The amplitude of the measured signal V_{meas2} is much higher i.e. responsive and does not require without heavy filtering and can easily be tweaked to suit the observed impedance changes. So compared with the prior art pull-up RPU2 is replaced with I_1 , Q1 and R_{meas} .

Figure 4 shows a plot of and (a) I_{inj} , (b) V_{meas2} , (c) V_{meas1} against time. This example is for a fuel injectors where movement of a valve needle away

from a valve seat is controlled by an actuator indirectly via a hydraulic (servo) system. In the example of a solenoid actuated valve, a plot d) of current through the solenoid/coil (I_{coil}) is also shown to give an additional time reference.

Of course the plots of a) b) and c) are applicable to for other designs of fuel injectors to detect when any injector moving parts come into contact or move away from contact to each other. In the example the connections with respect figure 1 and figure 3 determine the current flowing across the needle and seat, so I_{inj} is this current. It is to be noted that in respect to this only a portion of the activation pulse (current) profile is shown.

Time span A shows the end of the actuator "hold" phase, following a high, generally short activation phase. In the example, the injector valve is a solenoid driven actuator that will, once opened, allow fuel flow inside the injector that will, subsequently, through hydraulic amplification, result in opening the injector needle. Once the injector needle is opened, there is fuel flow. The actuator valve has already opened and usually a short time after the end of the hold phase the needle starts to lift away from its seat i.e, injector valve opens. This is an important parameter which examples of the invention allow to be accurately determined. The time delay between valve opening and needle opening is mainly influenced by fuel viscosity and pressure, it is mostly independent of the injector current waveform.

As can be seen the needle opening is at point X. Here the current through the injector i.e. between needle and valve seat rapidly falls as the valve seat and needle move away from each other. This is detected by the fact that V_{meas1} and V_{meas2} start to rise. So in other words, at point X, when the current through the injector falls in value (e.g. when valve parts move away from each other) the voltage at V_{meas1} and V_{meas2} rises distinctly. This is particularly pronounced on V_{meas2} .

At point Y the valve closes again. There will be some delay between the end of the coil current waveform (after time A) and the closing time. At point Y, the valve parts (needle and seat (nozzle body) come into (e.g. close) contact allowing current to flow through the injector; this results in a decrease in the values of V_{meas1} and V_{meas2} . The instant in time where the needle closes (and

the Vmeas2 signals returns to 0V is at that time or a after a short time (few 100us later).

It is to be noted that examples of the invention can be used for any two valve components which move relative to one another and especially which come into contact or close contact. As well as detecting when the needle is in contact with needle seat (valve body) it can be used to detect when e.g. an actuator (e.g. end) comes into contact with a valve component (e.g. a component of the servo valve system). It is applicable to both solenoid and piezo actuated injectors.

CLAIMS

1. A system adapted to detect the electrical continuity between components of an actuator operated fuel injector (1), where said components are adapted
5 move relative to one another in operation, said system including a wire (7) connected to an electrical contact point on said fuel injector from a supply voltage (V_{ICL}) forming a circuit allowing current to pass through said injector (I_{inj}) to ground via said components when said components have a degree of electrical continuity, and including a constant current source (8) and transistor
10 switch (Q1) connected in parallel such that one terminal of the current source is connected to the supply voltage V_{ICL} and a first terminal of the transistor switch, and the other terminal of said current source is connected to said electrical contact and a second terminal of the transistor switch, such that current from the constant current source is adapted to form a first pathway through the injector
15 dependent on said electrical continuity and a second pathway through the switch via said second terminal to a third terminal of the transistor switch.
2. A system as claimed in claim 1 wherein said first terminal is the base or gate of a bipolar or FET.
20
3. A system as claimed in claims 1 or 2 including means to measure the current passing through said second pathway or through the switch.
4. A system as claimed in claims 1 to 3 including means to measure the
25 voltage at a point on said second pathway (V_{meas1} , V_{meas2}).
5. A system as claimed in claims 1 to 4 including means to measure the voltage at the second or third terminals of said transistor.
- 30 6. A system as claimed in claim 2 to 5 where said transistor is a bi-polar transistor and including a measurement resistor connected to the collector terminal of said transistor and means to measure the voltage at a point between said collector terminal and measurement resistor.

7. A system as claimed in claims 1 to 6 including means to measure the current passing through the switch from the constant current source.
8. A system as claimed in claim 1 to including a diode and/or resistor
5 located between supply voltage and injector point in parallel with said constant current source.
9. A method of determining the degree of electrical continuity between components of an actuator operated fuel injector (1), where said components are
10 adapted to move relative to one another in operation, comprising using the system as claimed in claims 1 to 7, and
- a) measuring the current or voltage at a point in said second pathway, and
 - b) determining said degree of electrical continuity from the results of a).
- 15 10. A method as claimed in claim 9 including determining the change in value of current or voltage at a point in said second pathway, and where step b) includes determining said degree of electrical continuity from the results said changes.
- 20 11. A method as claimed in claims 1 to 10 wherein said components are needle and needle valve seat.

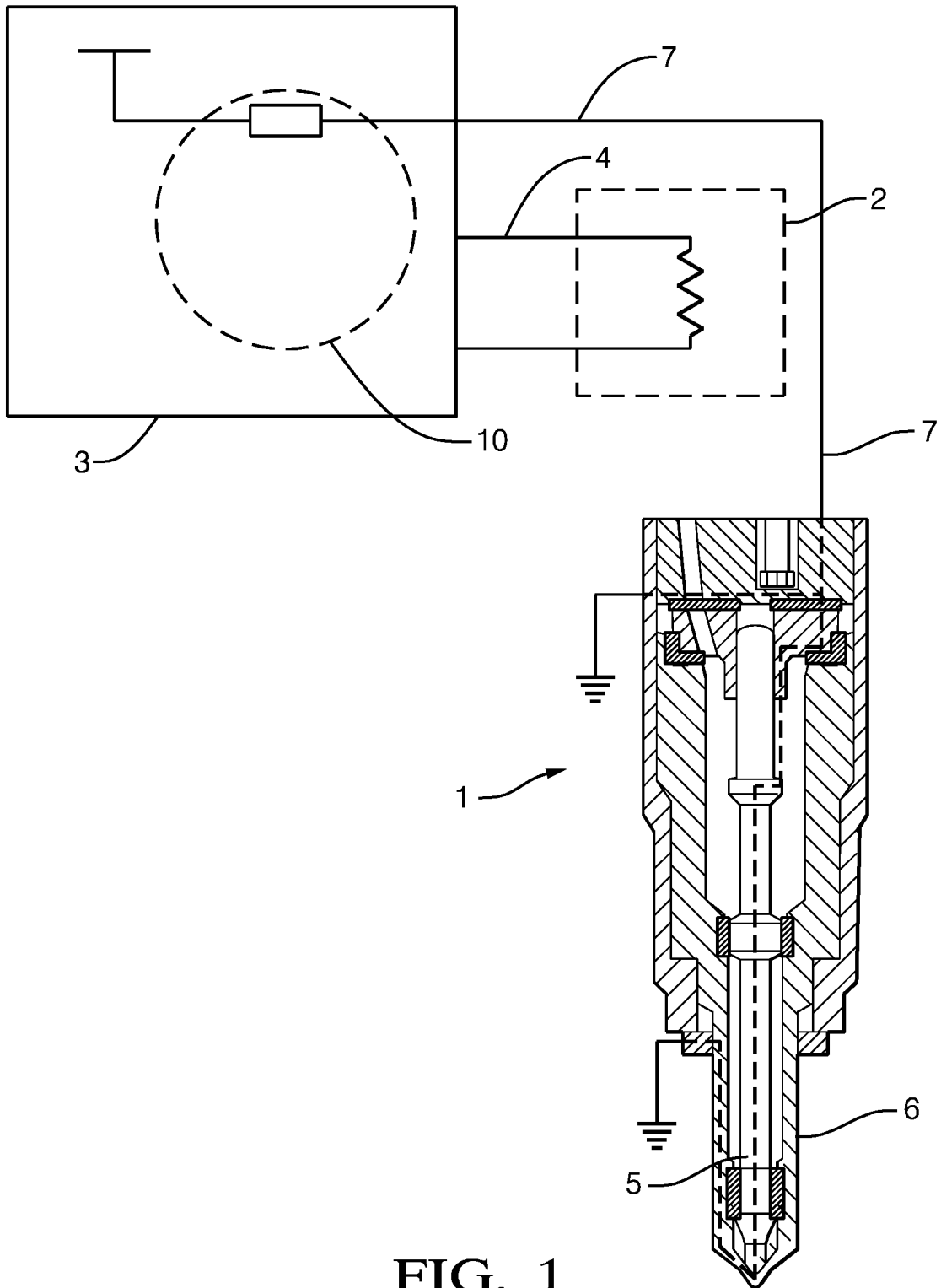


FIG. 1

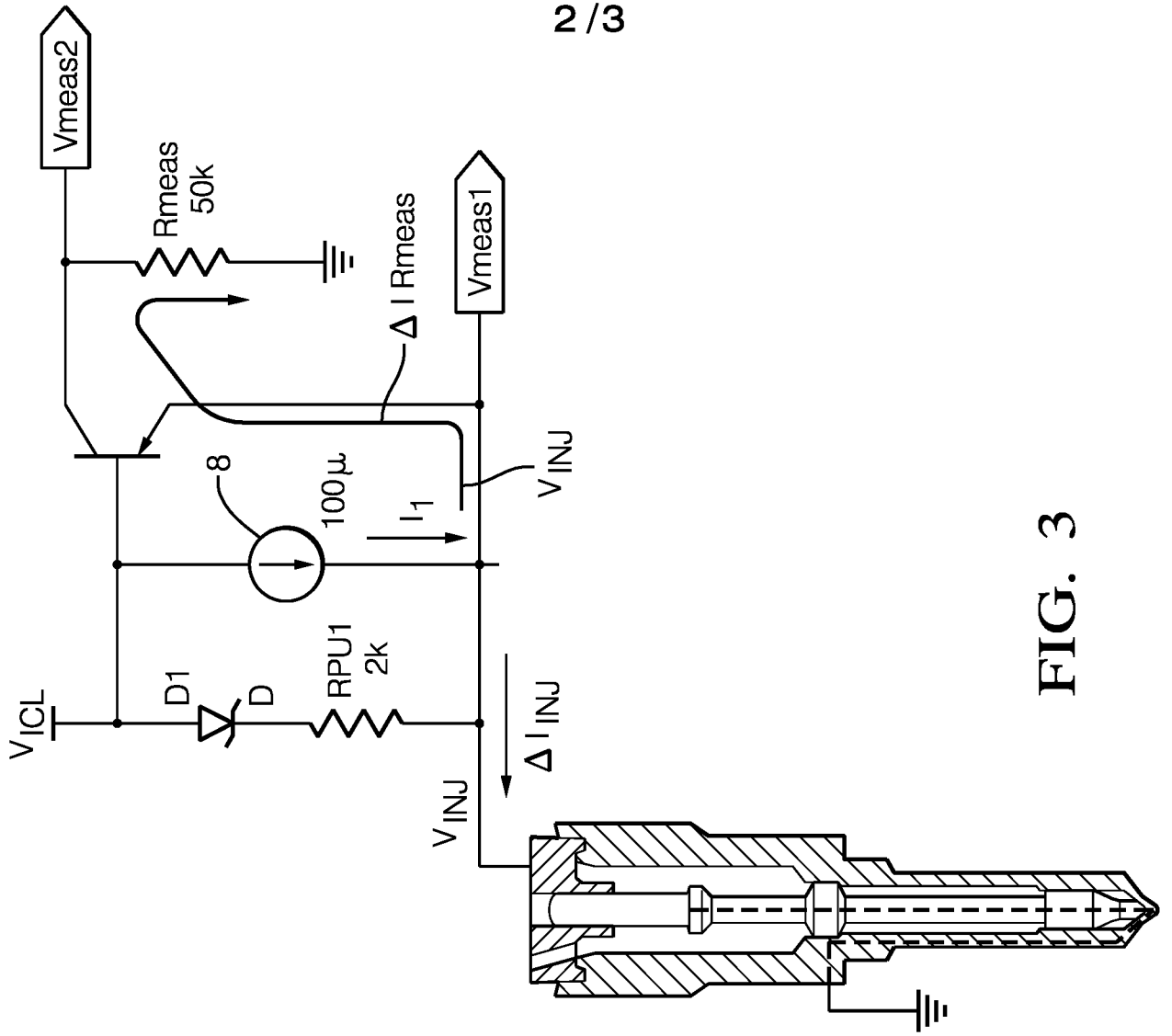


FIG. 3

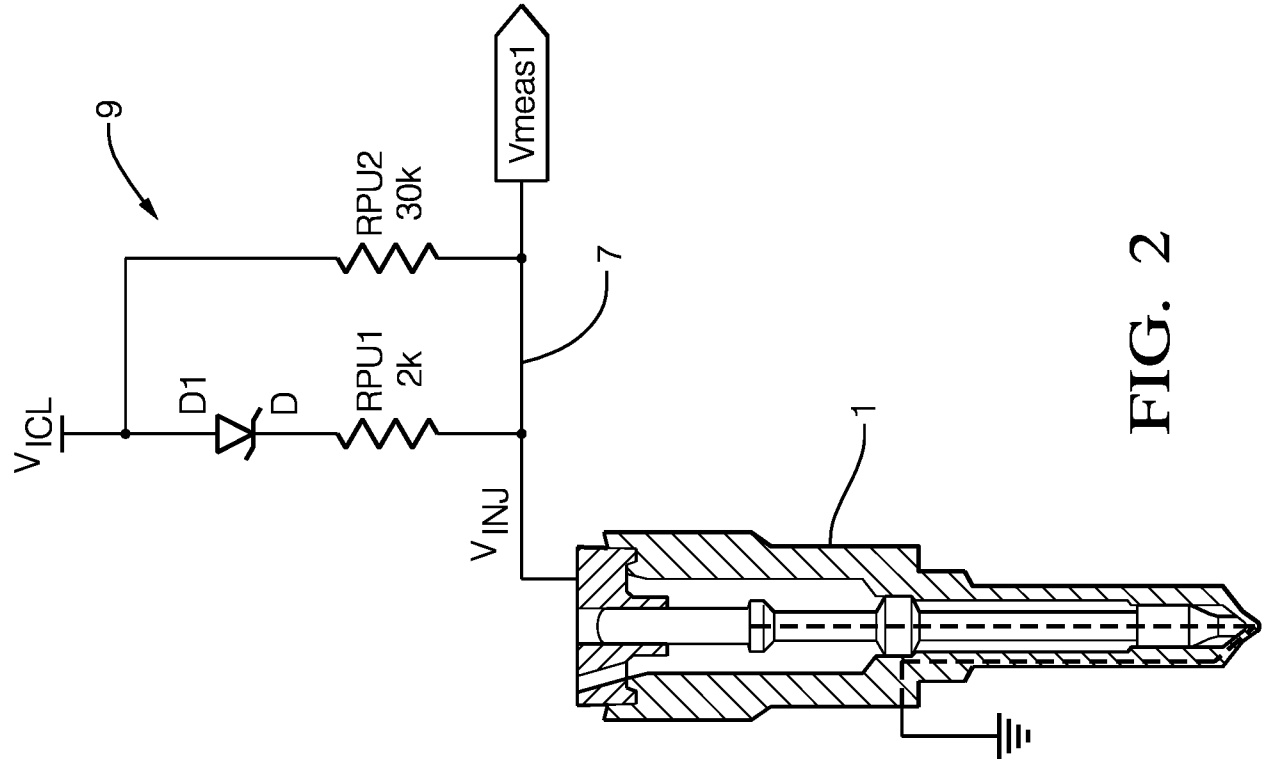


FIG. 2

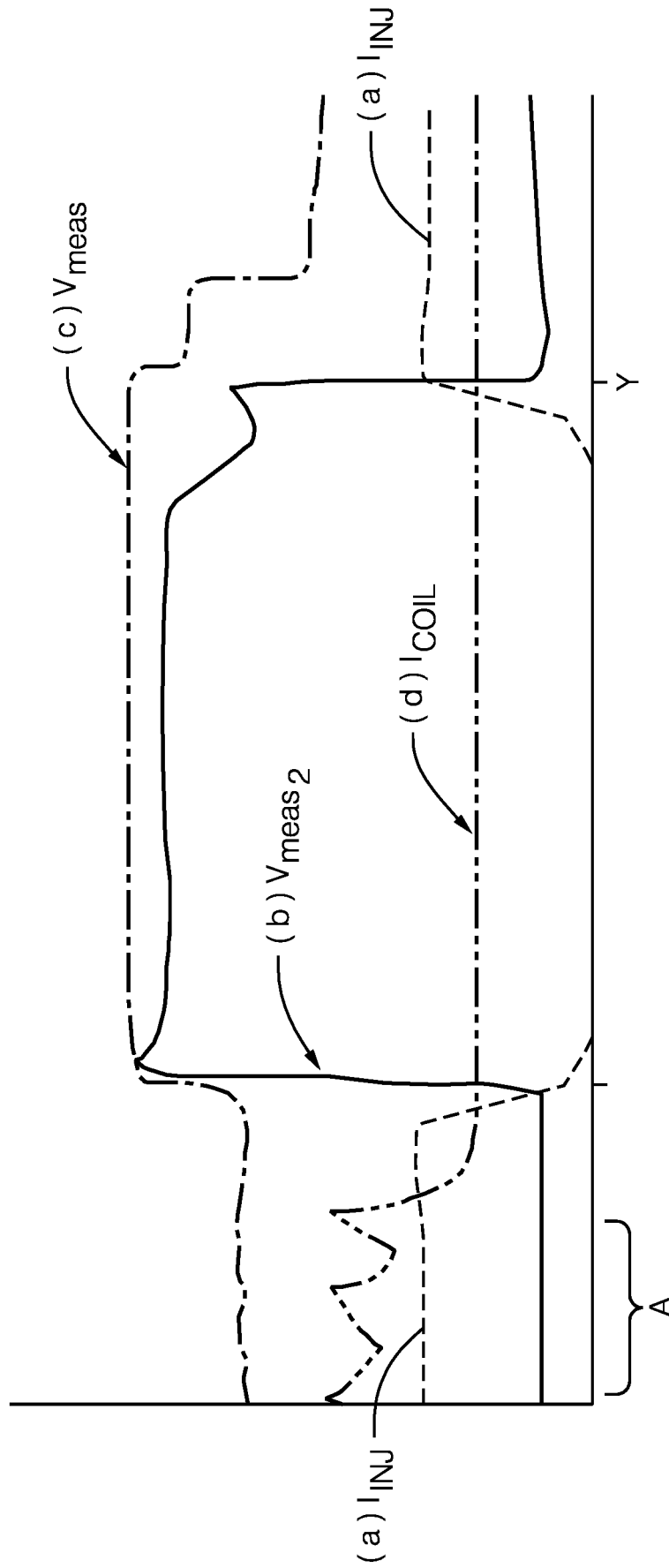


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075897

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/20 F02M65/00
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
F02D F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 8 January 2018	Date of mailing of the international search report 15/01/2018
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Ducloyer, Stéphane
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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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