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(54) **Method for the control and diagnosis regarding the operation a fuel injector**

(57) In a fuel injector including an actuator operated valve, said valve being located within a valve body, a method comprising determining the condition where, or the point when, there is or is not electrical continuity between two injector components adapted to move relative to one another during operation. two components are i) one end of an actuator and ii) a control valve or valve needle. The method may determine when the gap between the two said components is reduced to zero and/or when there is electrical continuity between the end of the actuator and the valve/needle or proximal portion of the valve/needle. It may comprise the step of determining the point of contact between the end of the actuator and the valve/needle.

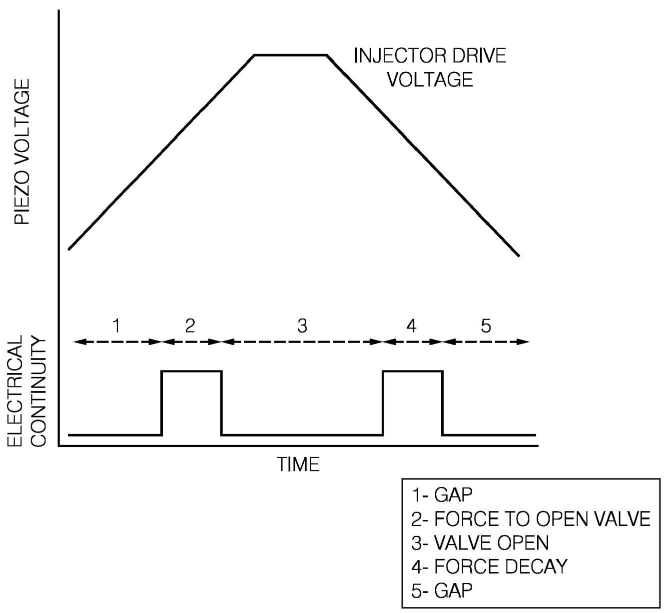

FIG. 9

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Description

Technical Field

[0001] The invention relates to fuel injectors for delivering fuel into a combustion chamber such as a cylinder of an internal combustion engine. It relates in particular, but not exclusively, to fuel injectors including piezoelectric actuators used to control movement of a needle in an injector valve.

Background of the Invention

[0002] The use of piezoelectric actuators is known as an alternative to solenoids for controlling injections in a fuel injector. Typically, a stack of piezoelectric elements can be arranged to control fuel pressure within an injector fuel chamber so as to consequentially control the movement of an injector needle away from a valve seat so as to inject fuel. In operation the distal portion of the piezo stack abuts/contacts the proximal (upper end) portion of an injector needle (typically via intermediate components), and actuation of the piezoelectric stack/actuator pushes against the needle to force the needle downward so as to displace the needle away from its seat to dispense fuel. In alternative designs fuel may be dispensed on retraction of the needle due to retraction of the piezoelectric stack. In all cases, the needle needs to be in contact with the end of the stack (albeit sometimes via intermediary components) during fuel injection process.

[0003] Components of the injector have different thermal expansion/contraction characteristics. Often there are also variations in manufacturing or measurement tolerances, clamping/clamp nut load tolerances, and there is also valve seat wear. For these reasons injector designs provide for a gap between the end of the stack. /actuator (including any associated components) and the needle(respective needle components), which is required for a fully discharged piezo stack to overcome such variations in thermal expansion/contraction, aging, wear in the valve seat, valve , head, shims and piston wear and well as to cope with variation in clamping. However the necessity of providing a gap makes certain aspects of the control of fuel delivery difficult and many fuel injector systems require consequential gap compensation strategies to be performed dynamically to minimise delivery drift, minimise injector to injector scatter allow accurate closed loop closure feedback. It is particularly advantageous to be able to estimate the gap and/or when it is closed so that closed loop detection of needle closure can be performed, as it is desirable for the gap to be reduced to zero beforehand.

[0004] It is an object of the invention to provide a method to measure the gap and to determine when the gap is reduced to zero.

Statement of the Invention

[0005] In one aspect of the invention is provided a, in a fuel injector including an actuator operated valve, said valve being located within a valve body, a method comprising determining the condition where, or the point when, there is or is not electrical continuity between two injector components adapted to move relative to one another during operation.

[0006] The two said components may be one end of an actuator and a control valve or valve needle.

[0007] The method may determine when the gap between the two said components is reduced to zero.

[0008] The valve may be actuated by a piezoelectric actuator.

[0009] The method may include determining when there is electrical continuity between the end of the actuator and the valve/needle or proximal portion of the valve/needle.

[0010] The method may comprise the step of determining the point of contact between the end of the actuator and the valve/needle.

[0011] At said point of contact, the valve/needle may be in electrical contact with said valve body, and said valve body is at ground potential.

[0012] The method may include providing an electrical path or lead at having a contact at the extremity of the actuator, such that when said gap is reduced to zero, said contact makes electrical contact with the valve/needle.

[0013] The electrical path/lead may comprise wiring connected or connectable to a terminal of the piezo-electric stack/actuator or an engine ECU.

[0014] The said electrical path/wire may be connected to the negative terminal of the piezoelectric stack/actuator

[0015] The method may include electrical insulating said electrical path/ wire from the valve body or ground potential.

[0016] In a further aspect is provided a method of estimating a gap between the end of the piezo electric stack/actuator and the valve/needle comprising varying the voltage applied to a piezoelectric stack and using any of the above methods to determine the point at which the gap is zero.

[0017] The method may include determining the point at which the valve/needle moves away from contact with the valve body by determining electrical continuity therebetween.

[0018] The fuel injector may include an actuator adapted to contact a valve/needle member, said valve/needle member or actuator being biased in a closed state by a deformable member located on a collar of said valve body, insulating said deformable member from said valve/valve collar body The method may determine the operational phase/state of a fuel injector.

[0019] In a further aspect is provided a method of compensating for variation in injector characteristics including utilising the above methods and controlling the operation of said injector as a consequence.

[0020] In a second aspect is provided a fuel injector including an actuator operated control valve/valve needle, said valve/needle being located within a valve body, comprising means to determine the condition where, or the point when, there is or is not electrical continuity between two injector components adapted to move relative to one another during operation.

[0021] The valve may be actuated by a piezoelectric actuator.

[0022] The fuel injector may include means to determine when there is electrical continuity between the end of the actuator and the valve/needle or proximal portion of the valve/needle .

[0023] The fuel injector may include means to determine the point of contact between the end of the actuator and the valve/needle.

[0024] At said point of contact the valve is in electrical contact with said valve body, and said valve body may be at ground potential.

[0025] The fuel injector may have an electrical path or lead at having a contact at the extremity of the actuator, such that when said gap is reduced to zero, said contact makes electrical contact with the valve.

[0026] Said electrical path/lead may comprises wiring connected or connectable to a terminal of the piezo-electric stack/actuator or an engine ECU.

[0027] The electrical path/lead may be connected to said terminal via a resistor.

[0028] Said electrical path/wire is connected to the negative terminal of the piezoelectric stack/actuator

[0029] The fuel injector may include electrical insulating of said electrical path/ wire from the valve body or ground potential.

[0030] The fuel injector may include means to determine the point at which the valve/needle moves away from contact with the valve body by determining electrical continuity therebetween.

[0031] The fuel injector may includes an actuator adapted to contact a valve/needle member, said valve/needle member or actuator being biased in a closed state by a deformable member located on a collar of said valve body, insulating said deformable member from said valve/valve collar body

Brief Description of Drawings

[0032]

Figures 1 a, b, c and d show sectional views of a fuel injector which includes a piezoelectric stack/actuator;

Figures 2a and b show a known design of fuel injector;

Figure 3 shows the sequence of events on actuation of the piezoelectric stack with respect to interaction between the end of the piezo-stack/actuator and the needle;

Figure 4a and b illustrate one example of the invention;

Figure 5 illustrates another example according to the invention;

Figures 6a to d shows various example of the invention;

Figure 7a to c show driver circuit arrangements that may be used with examples of the invention;

Figure 8 illustrates a further embodiment of the invention for a fuel injector which includes spring means in co-operation with the needle;

Figure 9 shows electrical continuity between injector components for various phases of operation.

[0033] Figures 1 a, b, c and d show sectional views of a fuel injector 1 which includes a piezoelectric stack 2 located within a housing 4 along a generally common central axis. The stack operates to move in slidable fashion, an injection needle 3 so as to move the tip of the needle to/away from a valve seat so as to dispense fuel into a combustion space. Figure b shows in enlarged view the end portion of the stack which includes stack components 2a,2b which in operation contact with the top end of the needle so as to actuate the needle on extension/retraction of the stack. Figure c shows a further expanded view showing the location of the gap between the end of the needle and the end component 2b of the stack arrangement, and figure 1d shows the situation with no gap.

[0034] Figure 2a also shows a known design of fuel injector. Figure 2b shows in more detail the spring installation portion. Figure 2c shows the equivalent portion of the fuel injector to figures 1a and c. Such a piezo-injector is intended to be designed without a lash adjuster between the actuator and the valve.

[0035] Thus as mentioned, in the unenergised state a gap is required between the actuator (stack) and the valve to ensure that the valve remains shut at different thermal conditions. The size of the gap can vary with temperature, piezo aging, valve/actuator wear, clamping force etc. For this design, one option is to operate the injector control valve without any lash compensation or adjustment device, in direct contact between actuator and valve. In this configuration, due to thermal and ageing effects, there is a small gap between the actuator and the valve, when the actuator is not activated or energized. This gap is varying strongly, in function of the temperature, and other effects, like wear, piezoelectric ageing etc.

[0036] Figure 3 shows the sequence of event on actuation of the piezoelectric stack. The gap is reduced as the end of the stack/stack components contact the top face of the needle. It should be understood that alternatively the top portion of the needle may be connected to other components, the most distal (uppermost) contacting the stack components in operation. In the last of the sub-figures 2c, the needle is pushed downwardly from the downward force from the stack.

[0037] The presence of this gap influences strongly the performance of the injector, as it introduces some variation in the valve movement, for a given actuator movement. It is important, for good consistency in the injector performance, to control and compensate this gap. In addition many injectors are intended to have closed loop control. It is important that the actuator and valve must be in contact for measurement of force change on the valve to enable closed loop control. Therefore, it is necessary to have a means of measuring or estimating the magnitude of this gap, or the point at which the gap is zero, during operation on the injectors , and allow a vehicle ECU to compensate this gap via a correction on the injector drive signal.

[0038] Some techniques include using hydraulic lash adjustors/amplifiers) are using strategies based on detection of stress/force change on the actuator when there is contact between the actuator and the valve, measured by detection of a change in the actuator capacitance. Other methods are based on detection of pressure decay in the rail, when the actuator manages to slightly open/leak the control valve, indicating that the gap is closed.

Detailed Description of Examples

[0039] In one aspect is provided a method for compensating for the gap by being able to detect when the actuator contacts the top of the valve using electrical continuity between the two components.

[0040] In an example , the vehicle ECU is adapted to detect the point at which there is electrical continuity between the actuator assembly and the valve (vehicle ground), hence when the actuator is in contact with the valve. This provides an effect simple and highly precise way of determining if there is a gap present or at which point the gap is reduced to zero, simply by determining is there is electrically continuity between the two elements.

[0041] Injector valves, and needles, are generally electrically connected to the vehicle earth through the injector body due to the fact it is steel and in contact with the steel valve body.

[0042] In order to provide the means for detecting the gap/the point at which the gap is closed, in one example, the piezo actuator/stack assembly is electrically insulated from the other injector components, by providing an insulation sleeve 5 as shown in figure 4. Figure 4 a and b shows portions of a fuel injector showing the piezo stack/actuator according to one example. Insulation is provided to insulate the piezo stack/actuator from the rest of the injector. The negative electrode 6(terminal) of the injector can be used as the lead to determine electrical continuity and there is provided a wire 7 from the negative terminal which runs to the distal end (tip) of the peizo actuator, and insulated from the rest of the valve/injector body. Thus in one example appropriate signal can be sent to the negative electrode and it can be determined if there is contact with the zero earth potential of the needle when the gap therebetween is zero such that there is electrical continuity.

[0043] Figure 5 shows an alternative embodiment where the actuator assembly may be provided with an additional (3rd) wire 8 connected from the ECU or the negative electrode of the piezo-stack. This 3rd wire may be connected/connectable to an engine ECU. The ECU by appropriate voltage regulation to this third wire can then ascertain any electrical continuity.

[0044] During a period when no injections are scheduled the voltage on the piezo-stack can be ramped up or down, i.e. a varying voltage applied to the stack to determine the point at which the actuator loses/makes contact with the valve and hence determine the size of the gap. Compensation for the size of the gap could then be applied to the injector drive signal.

[0045] Aspects of the invention may be applicable to servo injector where the valve needle is not directly operated by the actuator. The actuator operates a control valve which moves the valve needle using a hydraulic circuit. The gap may be between the actuator and control valve.

[0046] Figure 6a shows an example of the invention showing a schematic representation of the actuator portion 10 which includes a coating.

[0047] Figure 6b shows a schematic representation of a further example showing the actuator portion 10 with an insulation layer 12. In addition an insulating washer may be provided at the top portion and/or bottom.

[0048] Figure 6c shows an alternative example showing the actuator portion showing an additional sensor wire 15. The figure also shows the gap between the actuator and the valve as effectively represented as a switch.

[0049] Figure 6d shows another alternative without the extra sensor wire but which uses the existing Piezo actuator terminals with actuator portion 10 with resistor 14.

[0050] Figure 7a shows a standard drive circuit for a series of piezo-actuated injectors. A driver circuit 22 supplies electrical voltage to the Piezo actuators 23, arranged in parallel. A particular Piezo actuator is switched vie injector select switch 24. A discharge resistor 25 is located in parallel with each Piezo actuator. The low side injector select is the standard way to drive the injectors.

[0051] Figure 7b shows a modified shows a representation of the drive circuit which can be used according to one example where an extra wire is not used but the existing actuator/piezo terminals are used. The injector select switches have been located on the high side circuit. The switches represent contact between the actuator and valve.

[0052] Figure 7c illustrate a further alternative drive circuit according to one example and is also for embodiments which do not use the extra wire. , The circuit is similar to the figure 7a circuit but' the includes an extra resistor Radjust for each Piezo actuator. This may again require high side injector select switch (normally on low side) or separate injector drivers to isolate each switch to only discharge its own actuator.

[0053] In a further refined embodiment, it is also possible to determine the point at which the valve starts to move/move away from the injector housing. After the gap between the top of the valve (needle) and actuator stack is closed, there is electrical continuity therebetween. Further force from the actuator is required before the valve moves downwards. Typically such continuing force compresses a leaf spring during which the valve is moved downwards and this point can be determined according to this refined aspect. Figure 8 shows portion X of the valve and movement of this portion downwards results in this portion of the valve moving away from injector housing (collar region Y). Thus at this point the needle will no longer be in contact with the valve body. Preferably in order to implement this an electrically insulating washer or similar is provided between the valve body and the leaf spring.

[0054] This provides additional information on when the valve actually opens/closes and would enable the charge required to overcome the force on the valve to be measured. The typical output for the electrical continuity during an injection for the figure 6 embodiment can be seen in figure 9 along with the piezo voltage/ injector voltage (although in reality the injection may occur with no gap as that could be compensated for away from the injection as previously mentioned). As can be seen the time axis includes 5 phases, i) gap, ii) force to open valve, iii) valve opening, (these relate to valve opening) and iv) force decay and v) gap (the latter two relate to valve closing). Electrical continuity is shown for these phases; when the valve is forced open and on forced decay there is electrical continuity In one aspect, compensation could therefore be made for any evolution of the force required to open the valve and also any evolution of the force closing the valve.

Claims

1. In a fuel injector including an actuator operated valve, said valve being located within a valve body, a method comprising determining the condition where, or the point when, there is or is not electrical continuity between two injector components adapted to move relative to one another during operation characterized wherein said two components are i) one end of an actuator and ii) a control valve or valve needle.

2. A method as claimed in claim 1 which determines when the gap between the two said components is reduced to zero.

3. A method as claimed in claims 1 or 2 wherein said valve is actuated by a piezoelectric actuator.

4. A method as claimed in claims 1 to 3 wherein at said point of contact, the valve/needle is in electrical contact with said valve body, and said valve body is at ground potential.

5. A method as claimed in claims 1 to 4 including providing an electrical path or lead at having a contact at the extremity of the actuator, such that when said gap is reduced to zero, said contact makes electrical contact with the valve/needle.

6. A method as claimed in claims 1 to 5 wherein said electrical path/lead comprises wiring connected or connectable to a terminal of the piezo-electric stack/actuator or an engine ECU.

7. A method as claimed in claim 1 to 6 where said electrical path/wire is connected to the negative terminal of the piezoelectric stack/actuator

8. A method as claimed in claim 1 to 7 including electrical insulating of said electrical path/ wire from the valve body or ground potential.

9. A method of estimating a gap between the end of the piezo electric stack/actuator and the valve/needle comprising varying the voltage applied to a piezoelectric stack and using any of the above method claims to determine the point at which the gap is zero.

10. A method as claimed in any previous claim including determining the point at which the valve/needle moves away from contact with the valve body by determining electrical continuity therebetween.

11. A method as claimed in any previous claim wherein said fuel injector includes an actuator adapted to contact a valve/needle member, said valve/needle member or actuator being biased in a closed state by a deformable member located on a collar of said valve body, insulating said deformable member from said valve/valve collar body

12. A fuel injector including an actuator operated control valve/valve needle, said valve/needle being located within a valve body, comprising means to determine the condition where, or the point when, there is electrical continuity between the end of the actuator and the valve/needle or proximal portion of the valve/needle.

13. A method as claimed in claim 11 wherein said deformable member is a leaf spring.

14. A fuel injector as claimed in claim 13 including providing an electrical path or lead at having a contact at the extremity of the actuator, such that when said gap is reduced to zero, said contact makes electrical contact with the valve.

15. A fuel injector as claimed in claims 13 or 14 wherein said electrical path/lead comprises wiring connected or connectable to a terminal of the piezo-electric stack/actuator or an engine ECU.

16. A fuel injector as claimed in claims 13 to 15 the electrical path/lead is connected to said terminal via a resistor.

17. A fuel injector as claimed in claim 13 to 17 where said electrical path/wire is connected to the negative terminal of the piezoelectric stack/actuator

18. A fuel injector as claimed in claim 13 to 17 including electrical insulation of said electrical path/ wire from the valve body or ground potential.

19. A fuel injector as claimed in a claims 13 to 18 including means to determine the point at which the valve/needle moves away from contact with the valve body by determining electrical continuity therebetween.

20. A fuel injector as claimed in claim 13 to 19 wherein said fuel injector includes an actuator adapted to contact a valve/needle member, said valve/needle member or actuator being biased in a closed state by a deformable member located on a collar of said valve body, insulating said deformable member from said valve/valve collar body

21. A fuel injector as claimed in claim 20 wherein said deformable member is a leaf spring.

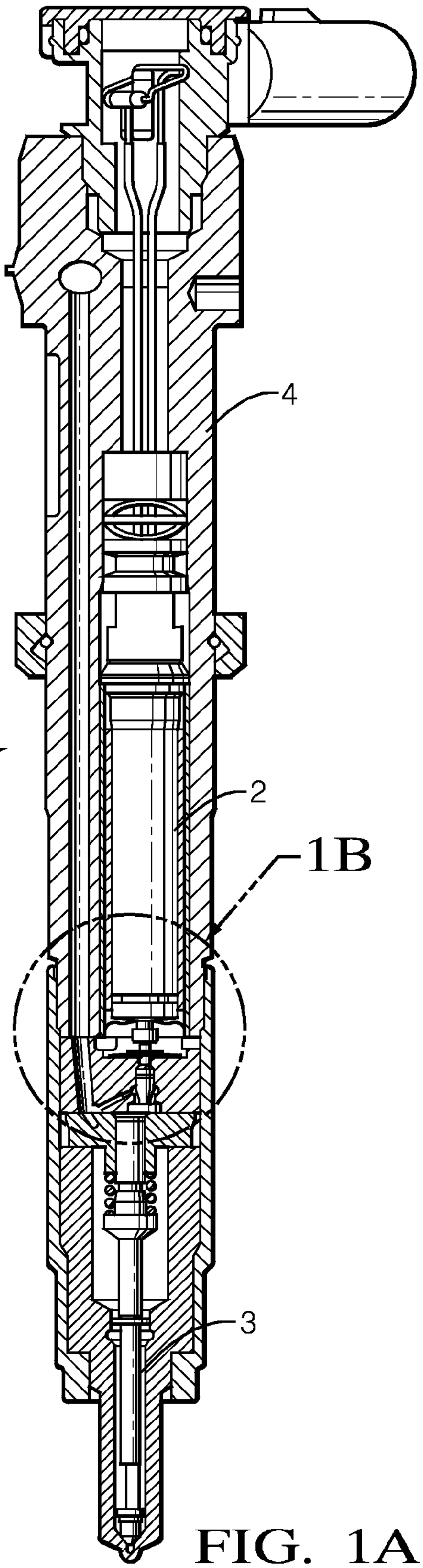


FIG. 1A

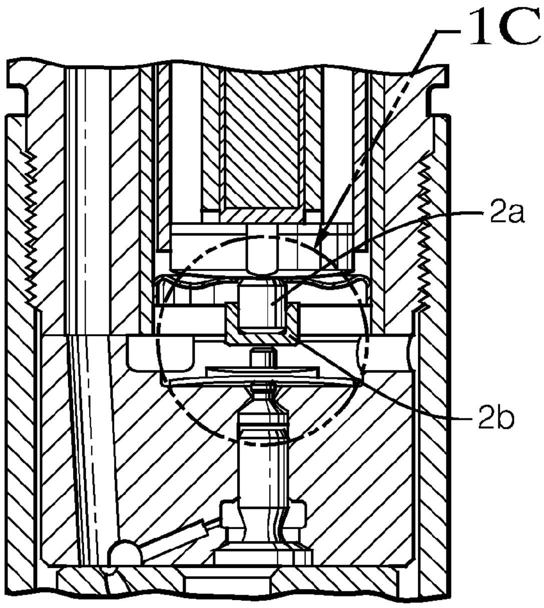


FIG. 1B

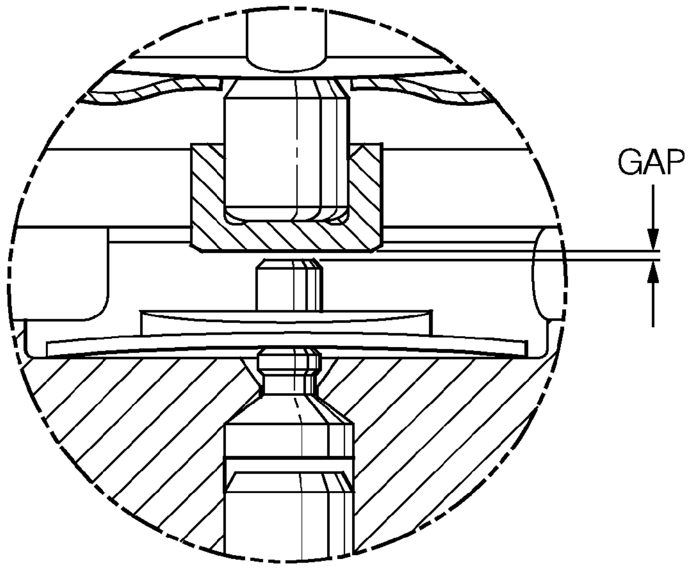

GAP

FIG. 1C

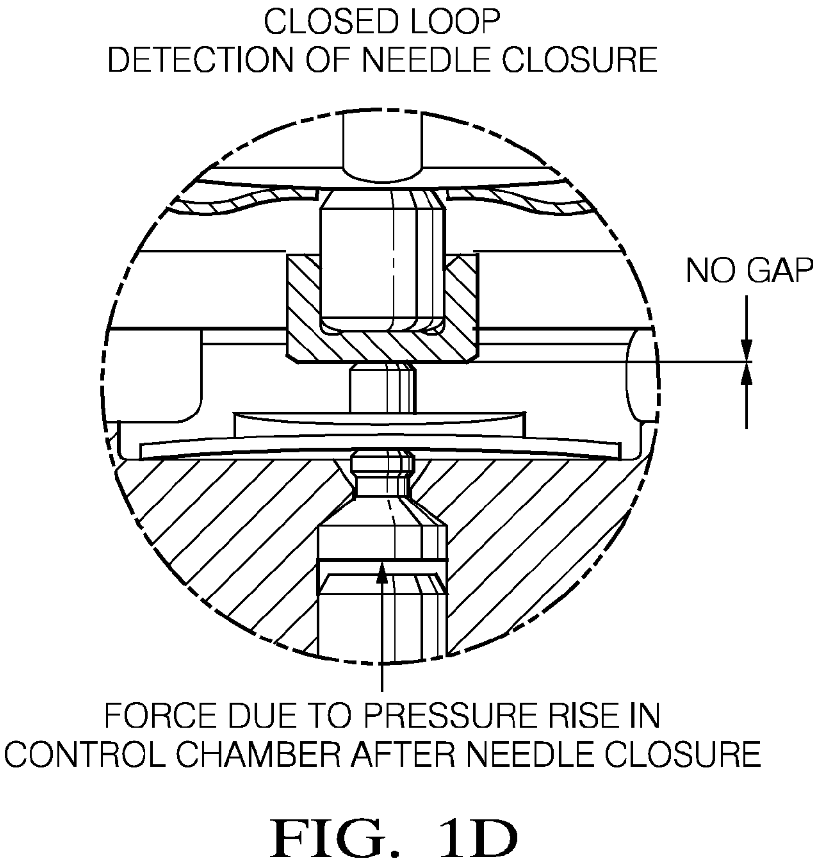

CLOSED LOOP
DETECTION OF NEEDLE CLOSURE
NO GAP
FORCE DUE TO PRESSURE RISE IN
CONTROL CHAMBER AFTER NEEDLE CLOSURE

FIG. 1D

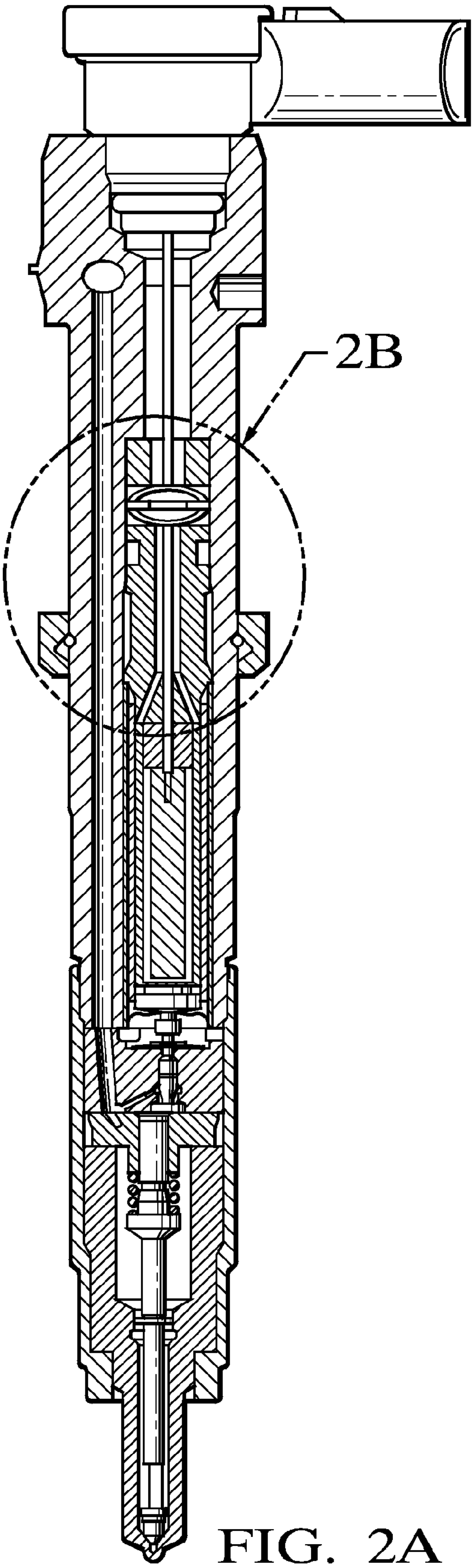


FIG. 2A

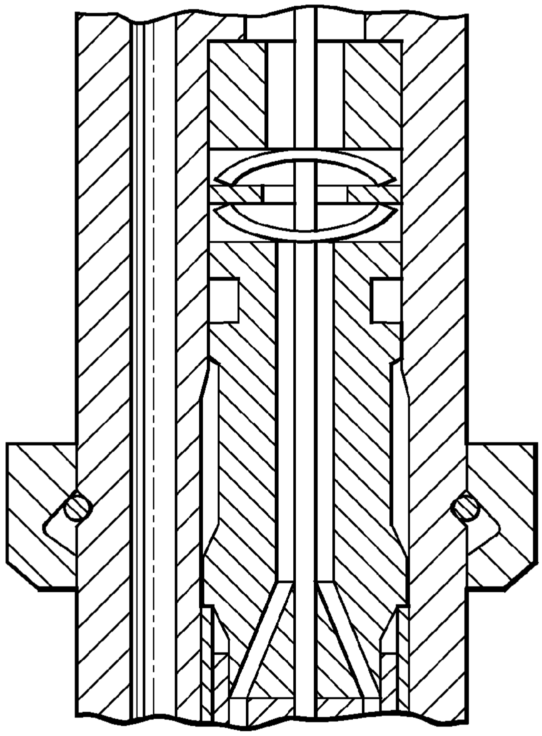


FIG. 2B

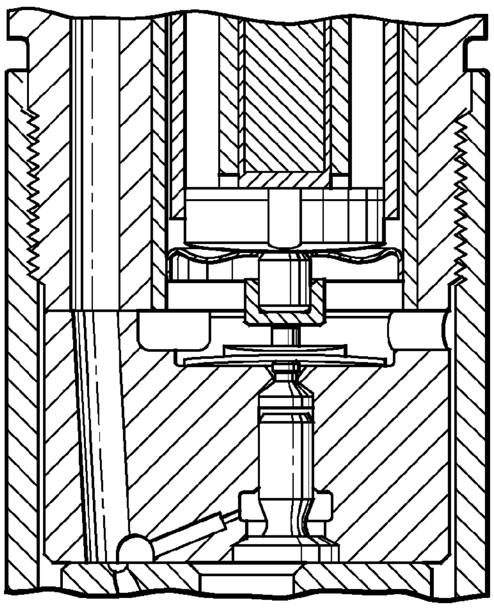


FIG. 2C

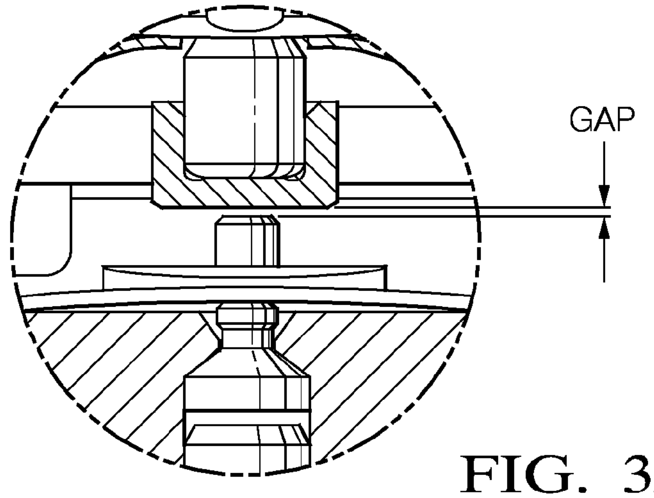


FIG. 3A

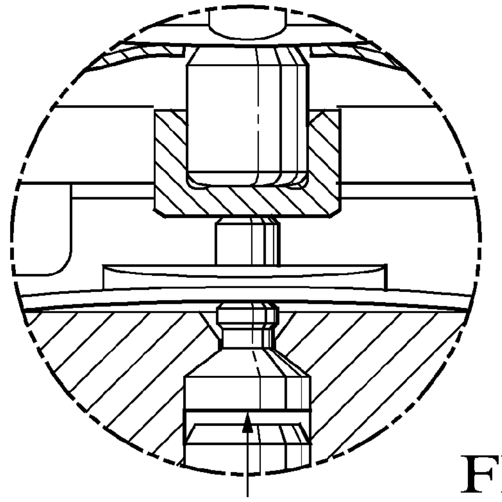


FIG. 3B

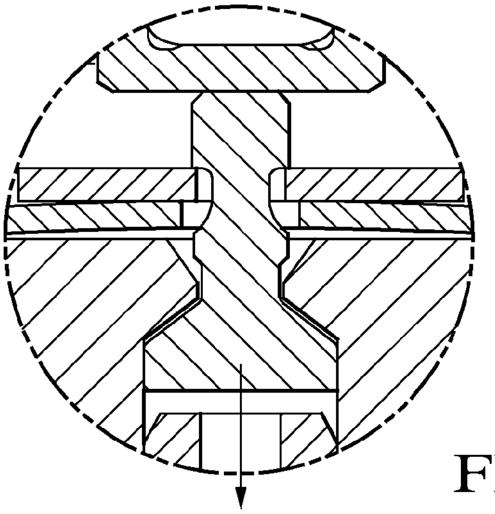


FIG. 3C

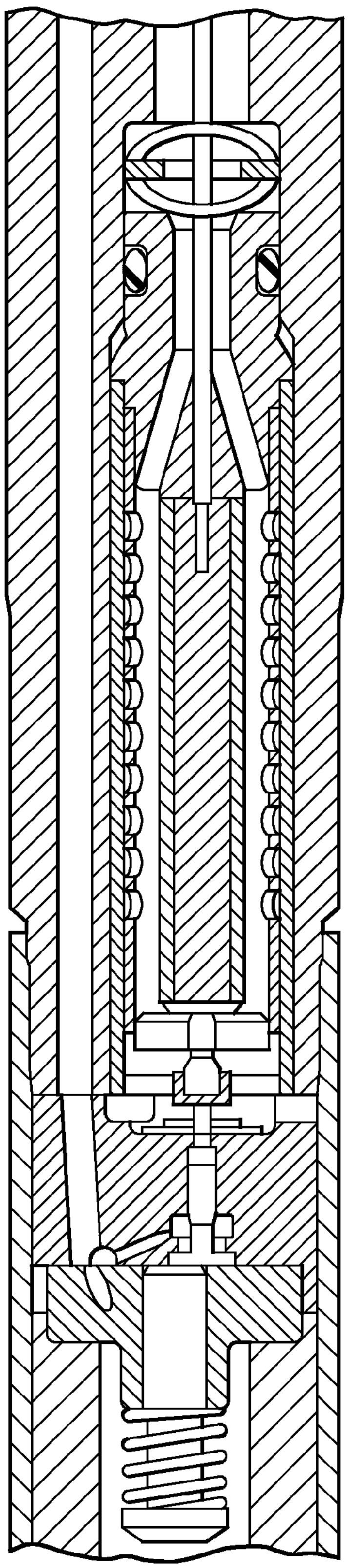


FIG. 4A

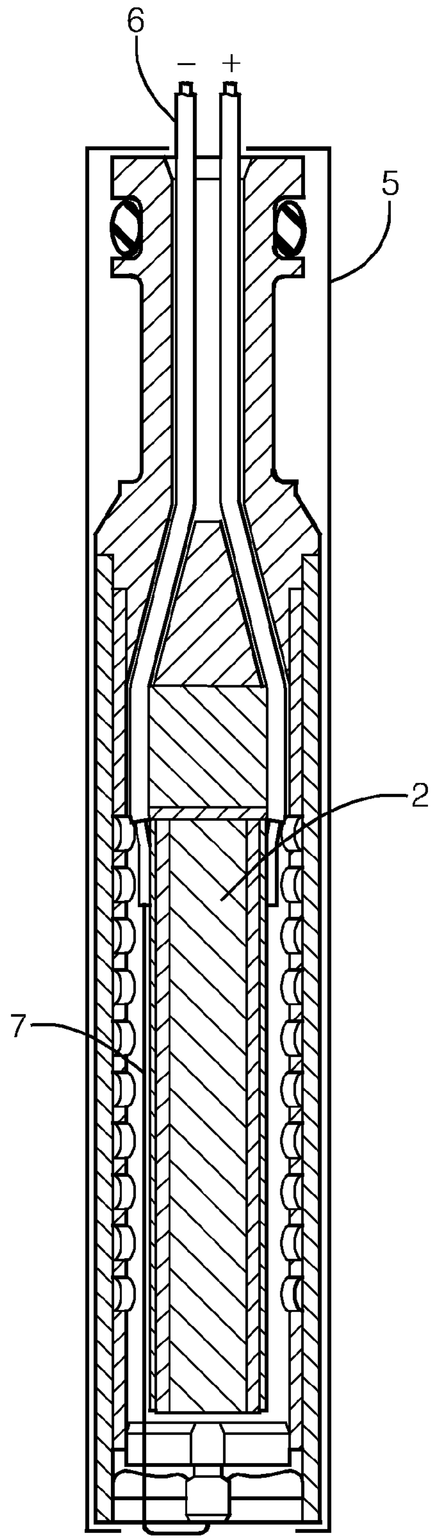


FIG. 4B

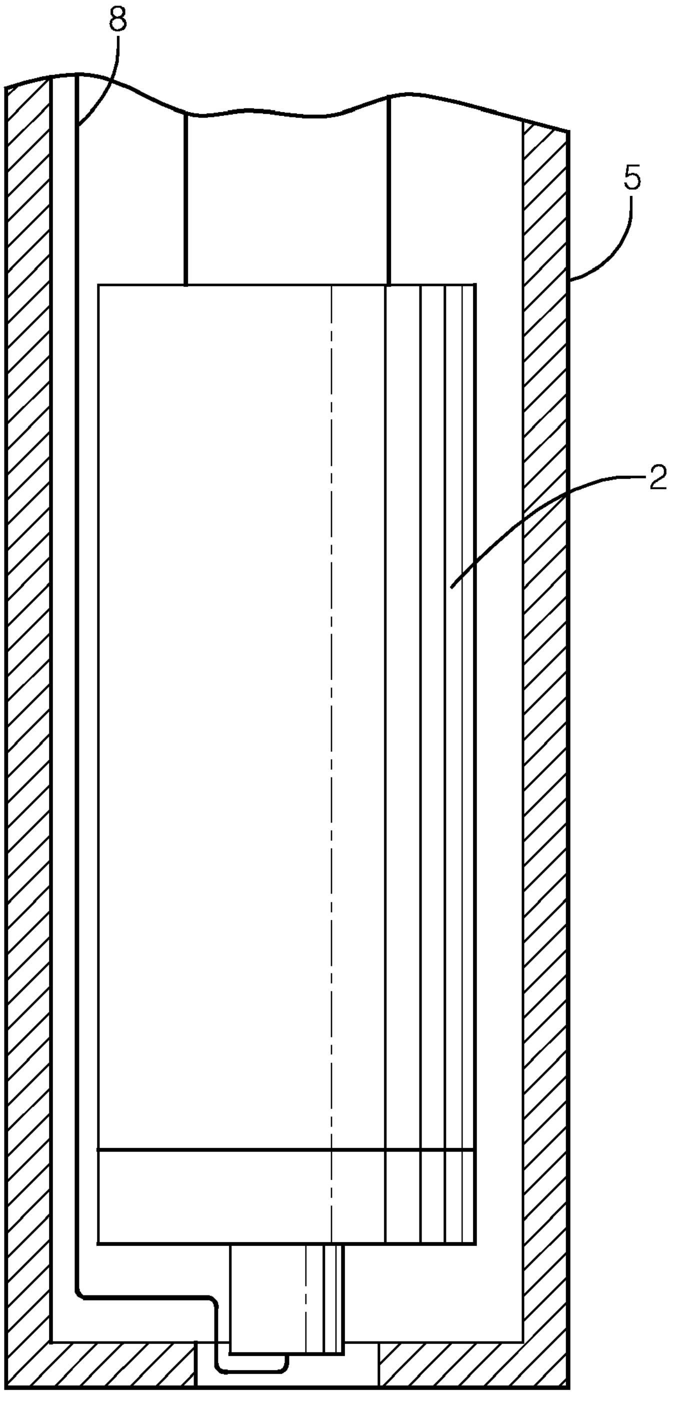


FIG. 5

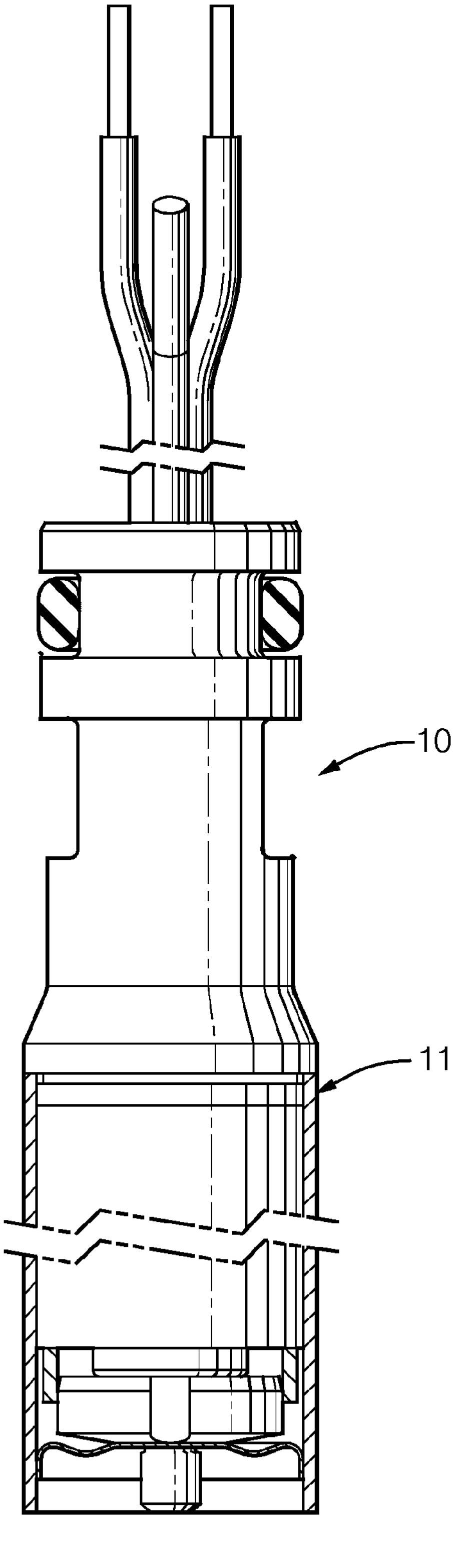


FIG. 6A

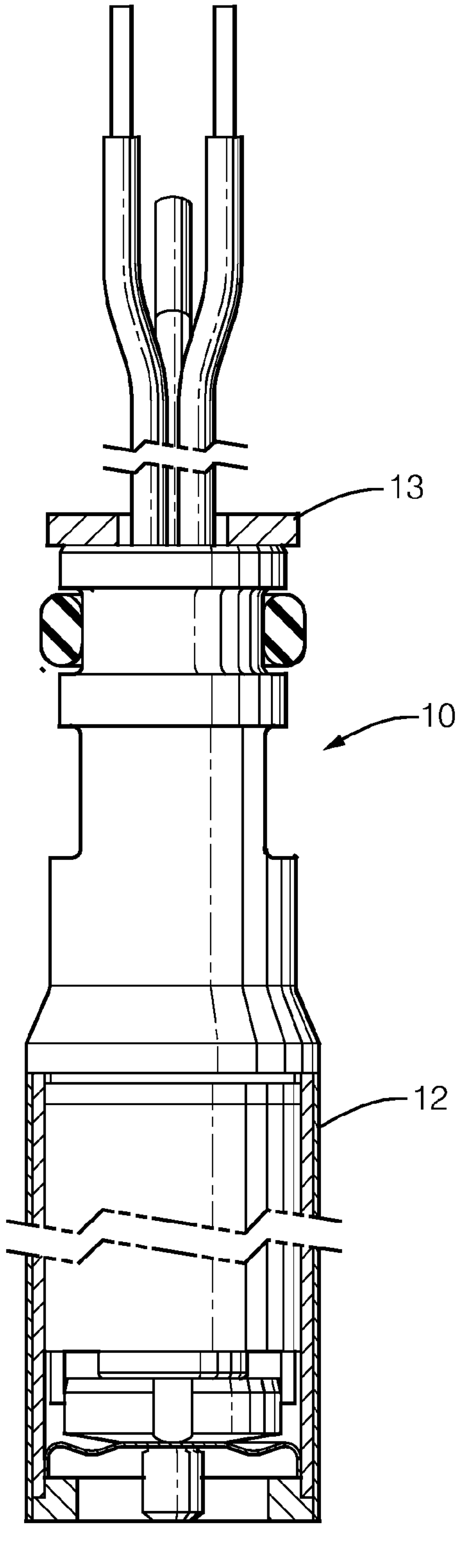


FIG. 6B

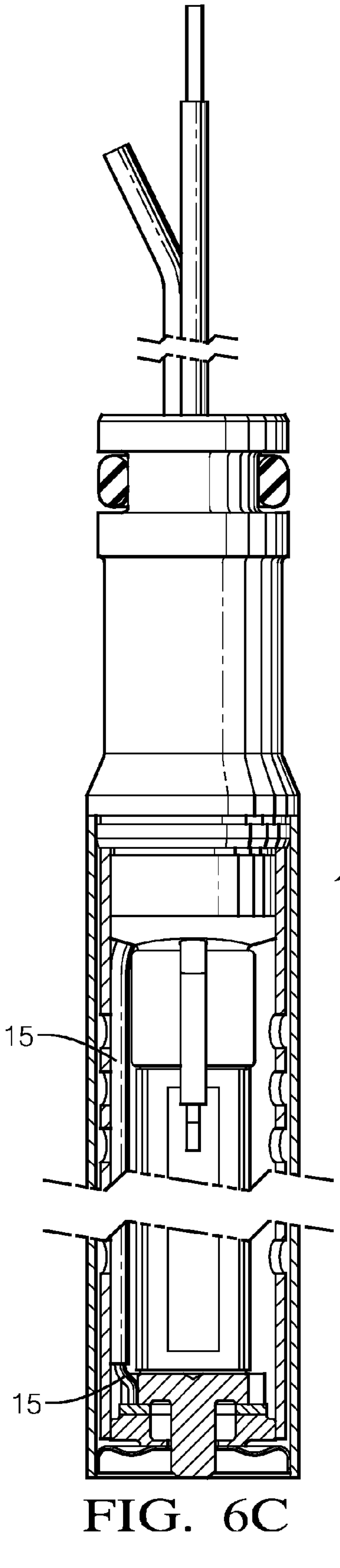


FIG. 6C

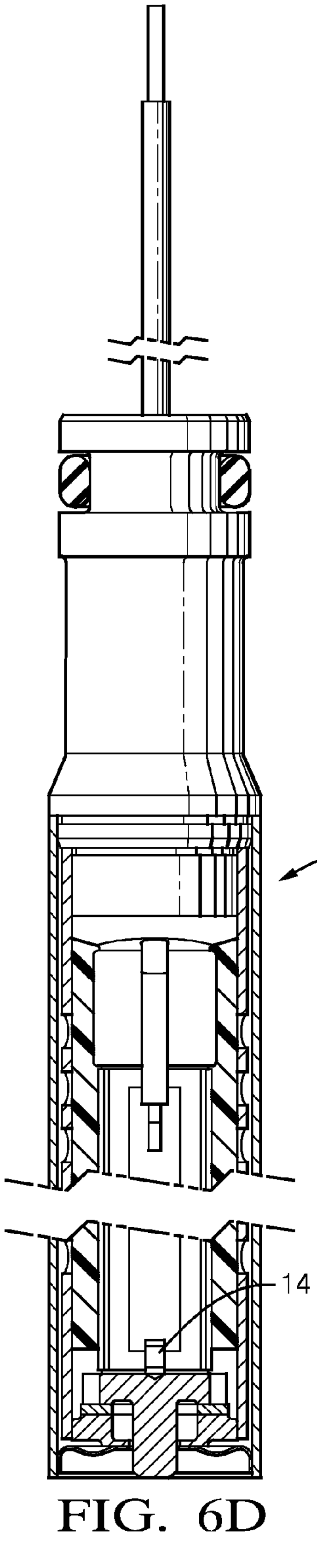


FIG. 6D

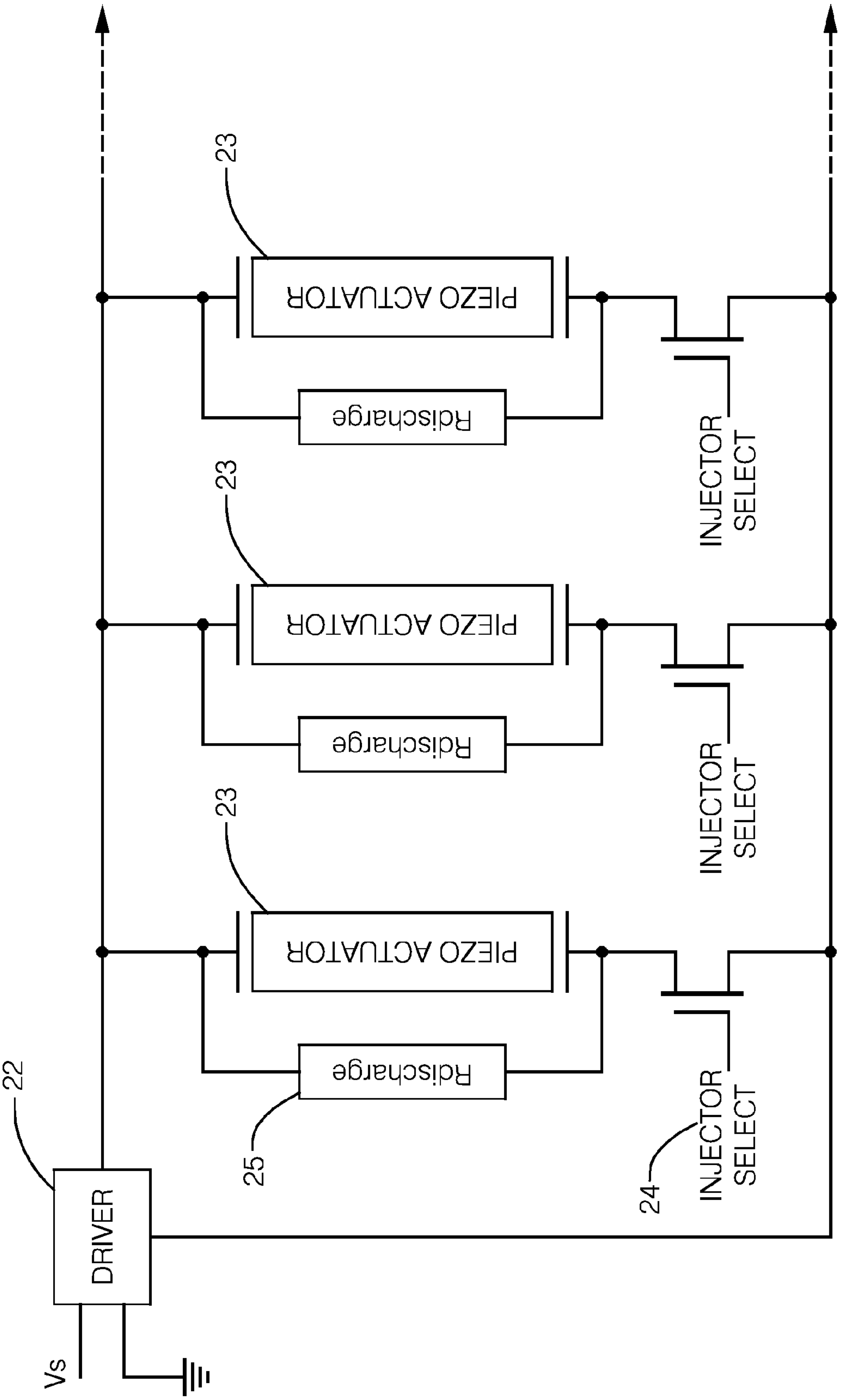
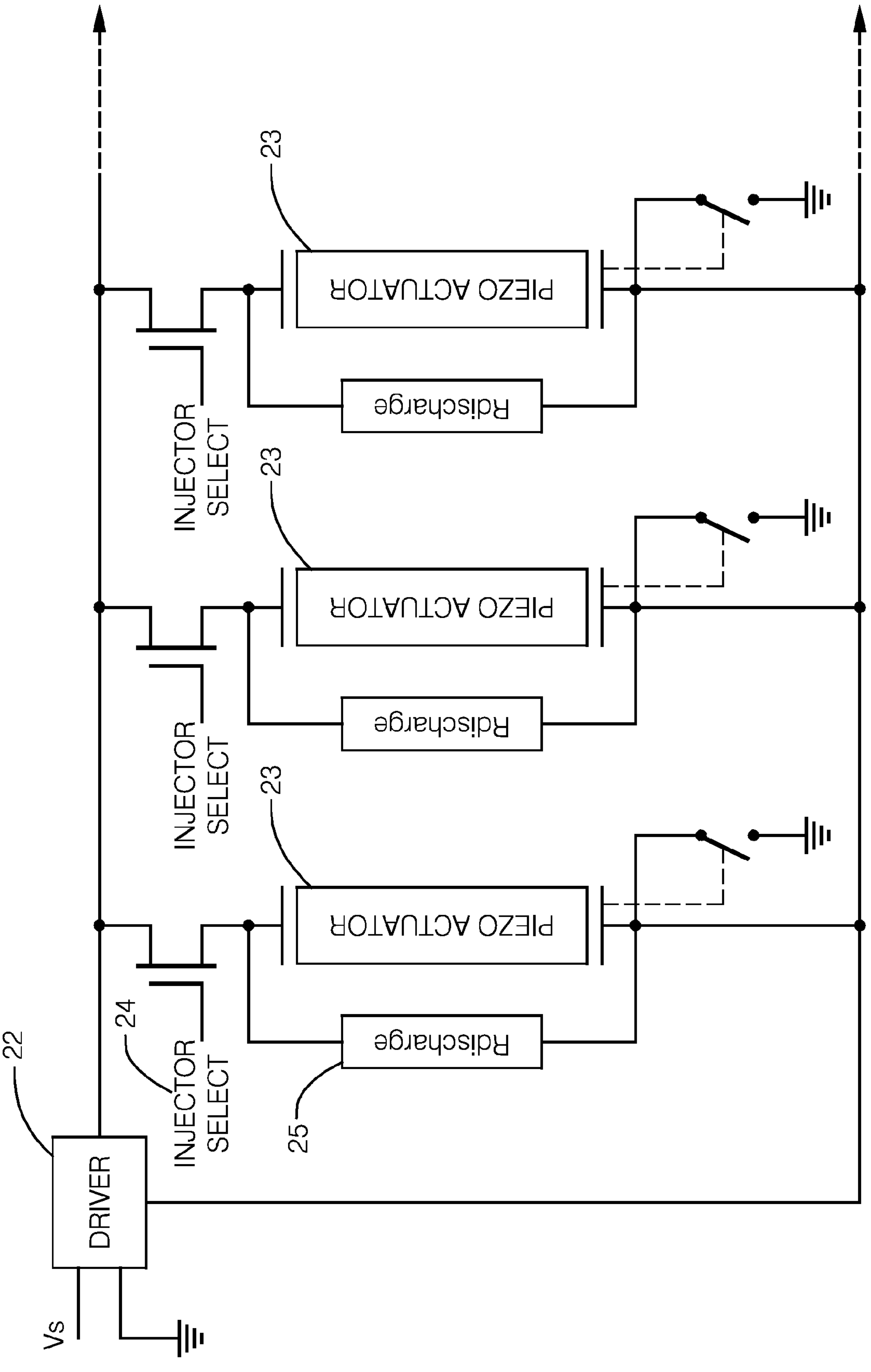

22
DRIVER
Vs
23
PIEZO ACTUATOR
Rdischarge
25
INJECTOR SELECT
24

FIG. 7A



DRIVER
Vs
22
24
25
23
23
23
INJECTOR SELECT
INJECTOR SELECT
INJECTOR SELECT
PIEZO ACTUATOR
PIEZO ACTUATOR
PIEZO ACTUATOR
Rdischarge
Rdischarge
Rdischarge

FIG. 7B

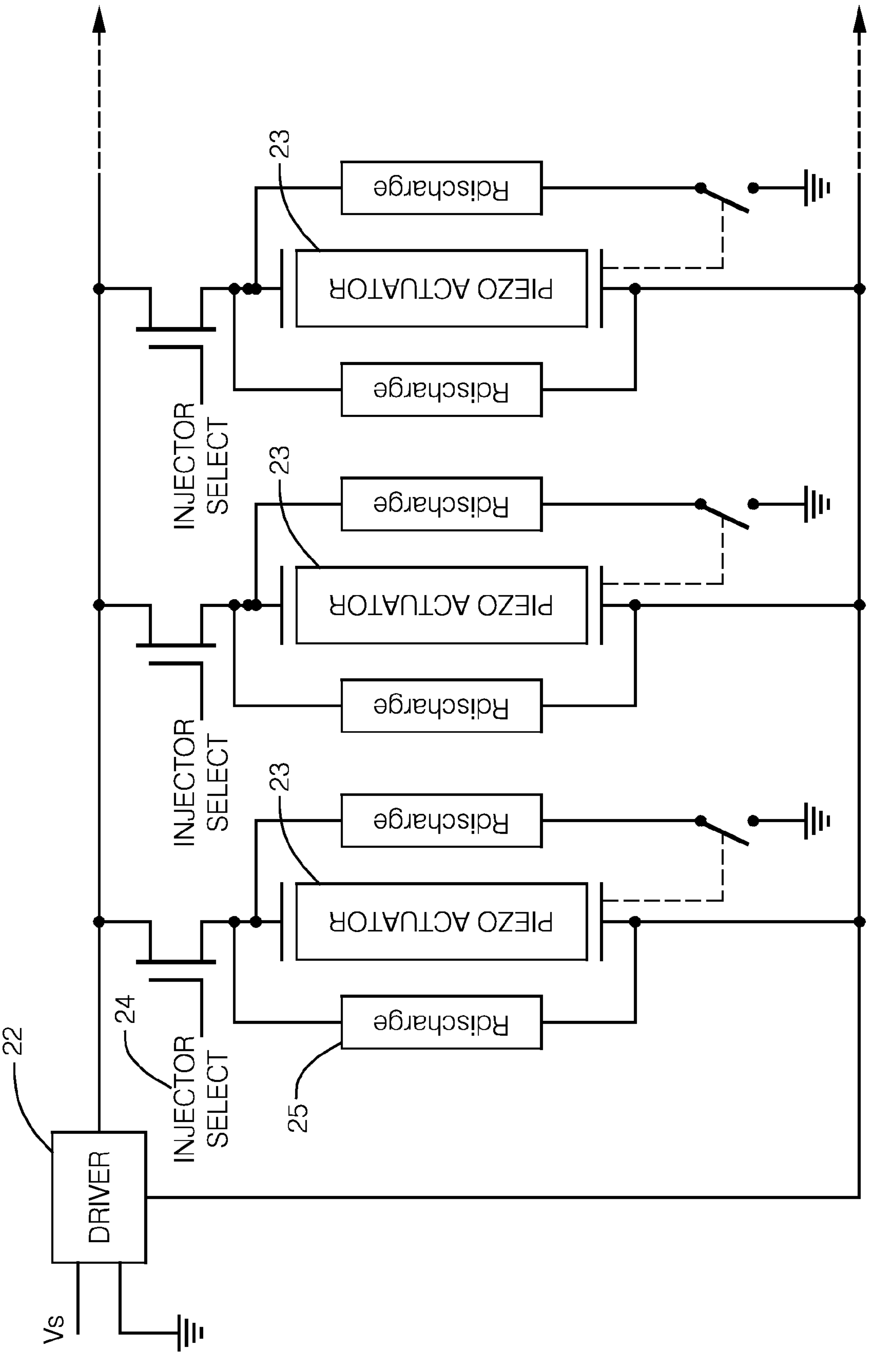

DRIVER
Vs
22
24
25
23
INJECTOR SELECT
PIEZO ACTUATOR
Rdischarge

FIG. 7C

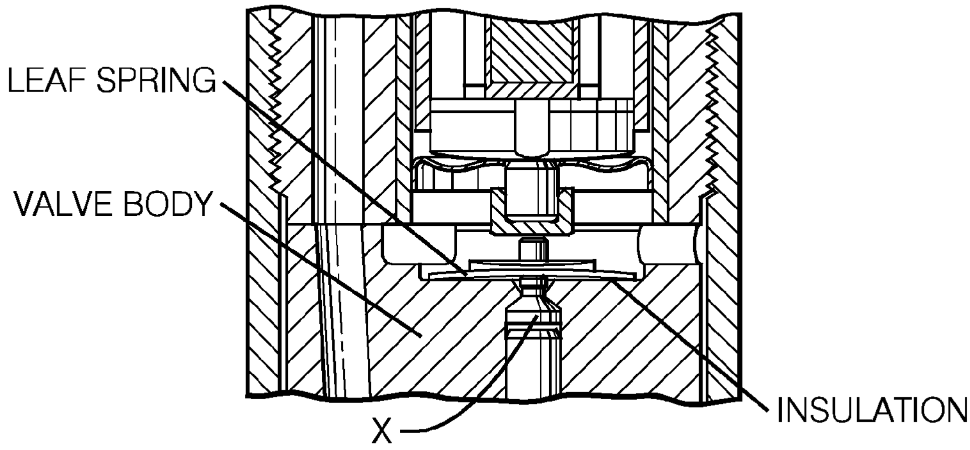

LEAF SPRING
VALVE BODY
X
INSULATION

FIG. 8

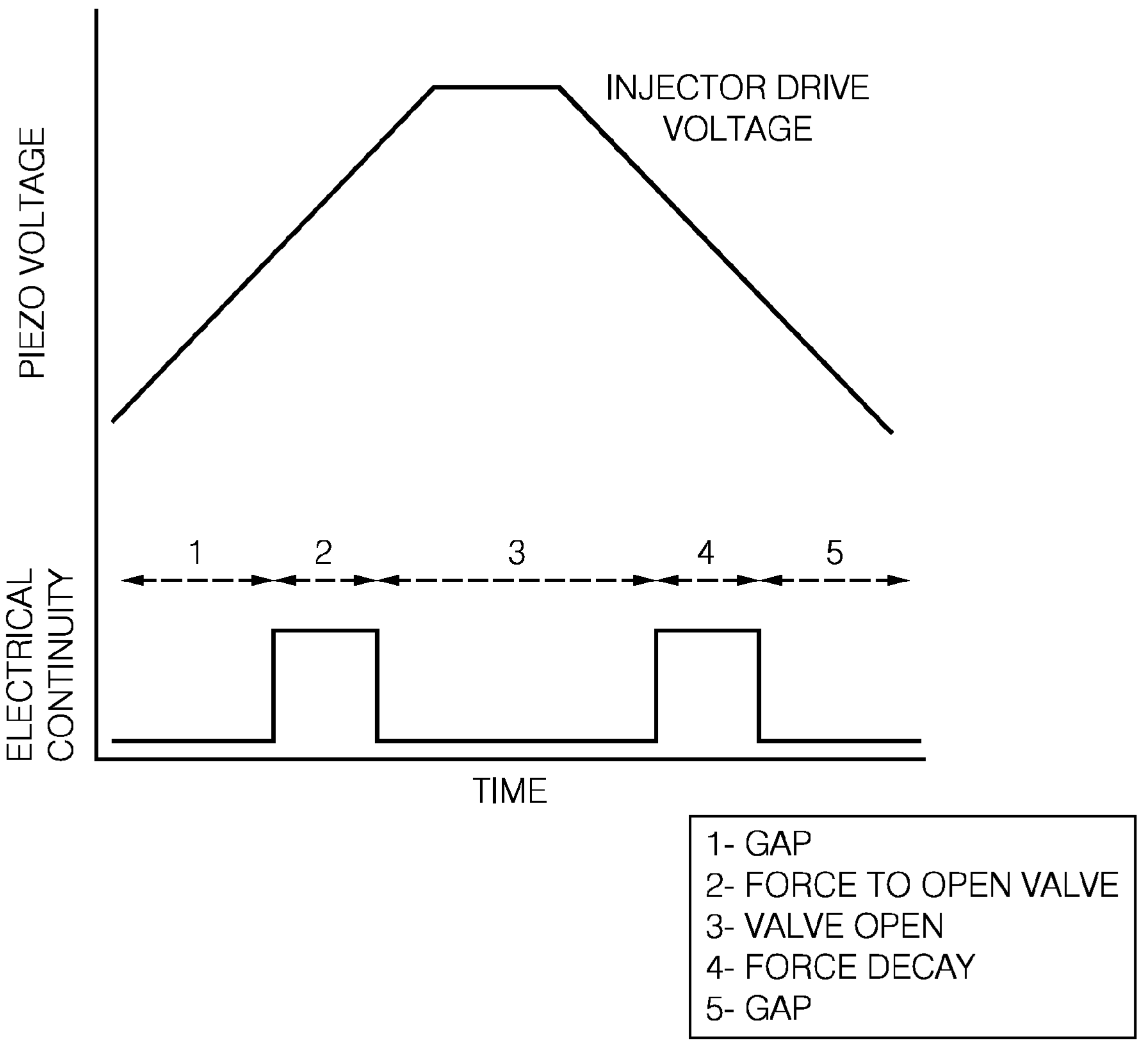

INJECTOR DRIVE
VOLTAGE
PIEZO VOLTAGE
1
2
3
4
5
ELECTRICAL
CONTINUITY
TIME
1- GAP
2- FORCE TO OPEN VALVE
3- VALVE OPEN
4- FORCE DECAY
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FIG. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 15 15 9321

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 199 29 589 A1 (AVL LIST GMBH [AT]) 13 January 2000 (2000-01-13) * column 2, line 51 - column 4, line 46; figures 1,2 * * abstract * -----	1-21	INV. F02M57/00 F02M61/16 F02D41/20
X	DE 101 29 375 A1 (MTU FRIEDRICHSHAFEN GMBH [DE]) 2 January 2003 (2003-01-02) * paragraph [0010] - paragraph [0012]; figures 1,2 * * abstract * -----	1-4,6,7, 10,12, 15,17,19	
A	DE 199 05 340 A1 (SIEMENS AG [DE]) 10 August 2000 (2000-08-10) * the whole document * -----	1-21	
A	WO 03/052260 A1 (BOSCH GMBH ROBERT [DE]; LISKOW UWE [DE]) 26 June 2003 (2003-06-26) * the whole document * -----	1-21	

TECHNICAL FIELDS SEARCHED (IPC)

F02M
F02D

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	12 August 2015	Hermens, Sjoerd

CATEGORY OF CITED DOCUMENTS

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12-08-2015

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 19929589 A1	13-01-2000	AT 2962 U2	26-07-1999
		DE 19929589 A1	13-01-2000
DE 10129375 A1	02-01-2003	AT 283974 T	15-12-2004
		DE 10129375 A1	02-01-2003
		EP 1397592 A1	17-03-2004
		US 2004149840 A1	05-08-2004
		WO 03001049 A1	03-01-2003
DE 19905340 A1	10-08-2000	DE 19905340 A1	10-08-2000
		FR 2789821 A1	18-08-2000
WO 03052260 A1	26-06-2003	DE 10162250 A1	03-07-2003
		EP 1458971 A1	22-09-2004
		JP 4272996 B2	03-06-2009
		JP 2005513324 A	12-05-2005
		KR 20040068253 A	30-07-2004
		US 2004118951 A1	24-06-2004
		WO 03052260 A1	26-06-2003

EPO FORM P0459

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