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(72) Inventors:
• **Coppo, Marco**
10126 Torino (IT)
• **Negri, Claudio**
13100 Vercelli (IT)

(71) Applicant: **OMT Officine Meccaniche Torino S.p.A.**
10090 Cascine Vica - Rivoli TO (IT)

(74) Representative: **Marchitelli, Mauro**
Via Maria Vittoria 18
10123 Torino (IT)

(54) **Electrically-controlled fuel injector for large diesel engines**

(57) An electrically controlled fuel injector for large diesel engines, comprising:

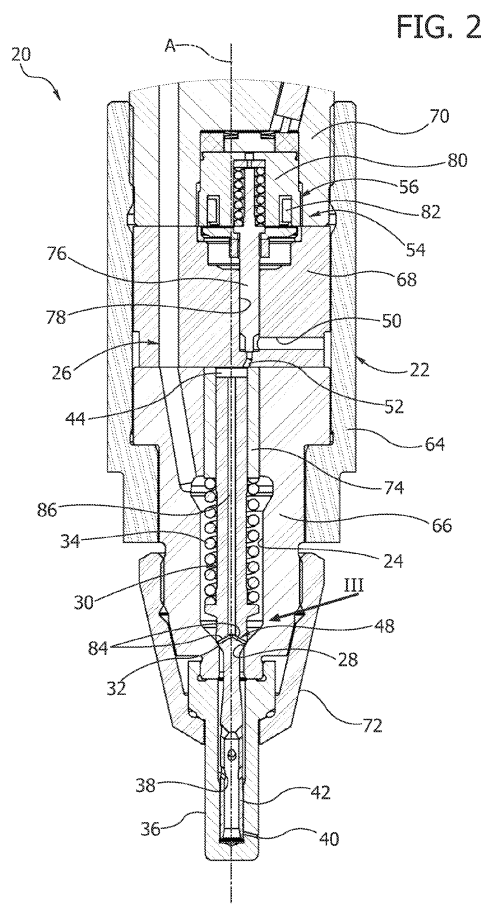
- a body (22) having a delivery chamber (24) connected to a fuel supply line (26) and provided with a conical valve seat (28);

- a needle (30) extending through said delivery chamber (24) and having a conical sealing surface (32) cooperating with said valve seat (28), the needle (30) being movable along a longitudinal axis (A) between a closed position wherein said conical sealing surface (32) abuts against said conical valve seat (28) and an open position wherein said conical sealing surface (32) is spaced apart from said conical valve seat (28), wherein the hydraulic pressure into said delivery chamber (24) generates a first hydraulic force pushing the needle (30) towards its open position;

- a control chamber (44) connected to said fuel supply line (26) through an inlet flow restrictor (48) and connected to a discharge line (50) through an outlet flow restrictor (52), wherein the hydraulic pressure into said control chamber (44) generates a second hydraulic force pushing the needle (30) towards its closed position;

- an electrically-operated control valve (54) for selectively opening and closing hydraulic communication between said control chamber (44) and a low pressure volume (14);

wherein said inlet flow restrictor (48) includes a variable choking section (60), movable between a choked position corresponding to a fully closed position of the needle (30) an un-choked position corresponding to an initial opening of the needle (30).



Description

Background of the invention

[0001] The present invention relates to an electrically-controlled fuel injector for large diesel engines. The invention relates in particular to a fuel injector for common-rail injection systems for large two-stroke diesel engines, such as diesel engines for marine propulsion.

[0002] A common-rail high-pressure injection system comprises a pump, usually with a fixed displacement, designed to pressurize the fuel in a high-pressure accumulator (common-rail), which supplies the injectors. The injectors are equipped with a valve seat and with a needle which can move in the injector body between a closed position and an open position. The position of the needle is determined by the intensity of two hydraulic forces, which are generated by the action of pressurized fluid on appropriate surfaces of influence.

[0003] The pressurized fuel in a delivery chamber upstream of the valve seat acts in the direction of raising the needle from its seat and hence in the opening direction. An electrically-operated control valve modulates the hydraulic pressure in a control chamber, which generates a force acting in the direction of closing the injector. The activation of the control valve causes a reduction of the pressure in the control chamber to the point where the force acting to open the injector seat prevails over the force acting to close the injector seat, causing the needle to rise from the valve seat and hence fuel injection.

[0004] The working principle of an electrically-controlled injector envisages that the control chamber is connected to the high-pressure line by means of an inlet flow restrictor and to a discharge line by means of an outlet flow restrictor.

[0005] The sizes of the inlet and outlet flow restrictors must be chosen so that, when the control valve is opened, the pressure in the control chamber can drop to values low enough to make sure that the force in the closing direction becomes smaller than the one in the opening direction. Once this happens, the needle opens the injector seat, thus enabling fuel passage to the chamber downstream of the injector seat (the so-called sac), from which fuel is injected in the combustion chamber through the injection holes.

[0006] When the injector opens the sac is pressurised to a considerable fraction of the available rail pressure, thus incrementing the force that acts in the opening direction, because now the surface of influence of the high pressure fuel encompasses the full cross section area of the needle.

[0007] When the injector needs to be closed the control valve position is reset, thereby disabling the connection between the control chamber and the low pressure fuel line. The control chamber pressure rises again but, for the reasons explained above, it needs to reach a much higher value than the one necessary to initiate the opening phase before the needle starts moving again towards

its seat.

[0008] The needle speed during the closing phase is constrained by technical requirements, and the desired value can be achieved with the right sizing of the inlet flow restrictor in relation to the cross section area of the needle in the control chamber.

[0009] It follows that the only parameter that can be tuned to achieve the required depressurisation of the control chamber to initiate injector opening is the size of the outlet flow restrictor. The larger the difference between pressure influence areas in the opening and closing direction when the needle is closed, the larger the outlet flow restrictor should be.

[0010] This implies that the size of the outlet flow restrictor increases as the needle seat diameter to control chamber diameter ratio approaches unity.

[0011] A larger outlet flow restrictor poses more problems in terms of control valve design and injector efficiency because in two-way poppet valves commonly used in these applications the control chamber pressure acts in the direction of opening the valve. A larger outlet flow restrictor requires a larger poppet (otherwise the passage through the valve becomes the main restriction), and this leads to larger surfaces of influence of the control chamber pressure. In the end, this increases the force demands on the spring (to keep the valve closed in absence of the command signal) and on the actuator that needs to overcome the spring force. This also implies that larger components must be used, and this is not always acceptable due to geometrical constraints on the engine, and control valve speed requirements (for example, larger and stronger solenoids are usually slower).

[0012] In addition, a larger outlet flow restrictor leads to a higher flow rate discharged by the injector for performing injection control. Clearly this is a cause of efficiency loss, as the energy spent to pressurise this fuel is wasted by expanding it through the control circuit.

[0013] These problems become even more serious in large two-stroke diesel engines because the seat diameter to control chamber diameter ratio is quite high, due to the presence on the needle of a slide valve used to reduce unburnt hydrocarbons (UHC) and particulate emissions, which forces the seat diameter to be larger than the slide valve diameter. This leads to the choice of a larger outlet flow restrictor, which involves larger discharged flow rates.

[0014] These issues make it difficult to apply the proven common rail technology to injectors for large two-stroke engines.

Summary of the invention

[0015] The object of the present invention is to provide a solution to the problems described above.

[0016] In accordance with the present invention, this object is achieved by a fuel injector having the features of claim 1.

[0017] The present invention allows to optimise the

performance of electronic injectors for large diesel engines. In particular, the invention allows to minimise the control flow rate that the electronic control valve needs to discharge to keep the injector open during the injection cycle.

[0018] The reduction in control flow brings two main advantages:

- (i) it is possible to use smaller and faster electronic actuators (solenoids or piezoelectric stacks), which can be incorporated in the injector body, and
- (ii) the injector efficiency increases; this leads to an increase in the overall engine efficiency as the auxiliary power demand decreases.

Brief description of the drawings

[0019] Further characteristics and advantages of the present invention will become clear in the course of the detailed description which follows, given purely by way of non-limiting example, with reference to the annexed drawings, wherein:

- figure 1 is a schematic diagram showing the operating principle of an injector according to the present invention,
- figure 2 is an axial cross-section of a first embodiment of an injector according to the present invention,
- figure 3 is an enlarged view of the part indicated by the arrow III in figure 1,
- figure 4 is an axial cross-section of a second embodiment of an injector according to the present invention,
- figure 5 is an enlarged view of the part indicated by the arrow V in figure 4, and
- figure 6 is an enlarged view of the part indicated by the arrow VI in figure 5.

Description of the embodiments of the invention

[0020] Referring to figure 1, an injection system for a diesel engine is indicated by the reference number 10. The injection system comprises a feed pump 12 which intakes fuel from a low pressure fuel tank 14 and delivers pressurized fuel to a high-pressure common rail 16. The common rail 16 is connected to a plurality of high-pressure pipes 18 (only one of which is shown in figure 1), each of which is connected to a respective injector 20.

[0021] The injector 20 comprises a body 22 having a delivery chamber 24 connected to the high-pressure pipe 18 through a fuel supply line 26. The delivery chamber 24 is provided with a conical valve seat 28.

[0022] The injector 20 comprises a needle 30 extending through the delivery chamber 24 and having a conical sealing surface 32 cooperating with the valve seat 28. The needle 30 is movable along a longitudinal axis A between a closed position and an open position. In the

closed position the sealing surface 32 abuts against the valve seat 28 and in the open position the sealing surface 32 is spaced apart from the valve seat 28. A spring 34 pushes the injector needle 30 towards the closed position. The hydraulic pressure of the fuel contained in the delivery chamber 24 generates a first hydraulic force pushing the injector needle 30 towards its open position.

[0023] The body 22 comprises an atomizer 36 having a longitudinal bore or sac 38 in fluid communication with the delivery chamber 24 through the valve seat 28. The atomizer has one or more injection holes 40. The needle 30 has a slide valve 42 which extends into the sac 38.

[0024] The injector 20 has a control chamber 44 sealed from the delivery chamber 24. The control chamber 44 is connected to the fuel supply line 26 through an inlet line 46 including an inlet flow restrictor 48. The control chamber 44 is also connected to a discharge line 50 including an outlet flow restrictor 52. The hydraulic pressure into the control chamber 44 generates a second hydraulic force pushing the injector needle 30 towards its closed position.

[0025] An electrically-operated two-way control valve 54 selectively opens and closes hydraulic communication between the control chamber 44 and a low pressure volume, for instance formed by the tank reservoir 14. The control valve 54 is controlled by an electric actuator 56, which receives control signals by an electronic control unit 58.

[0026] When the control valve 54 is closed, the pressure in the control chamber 44 and in the delivery chamber 24 is equal to the rail pressure. Given that the surface of influence of the pressure in the control chamber 44 is larger than the one in the delivery chamber 24, the force pushing the needle 30 towards its closed position is greater than the force pushing the needle 30 towards its open position. When the control valve 54 is open, the pressure in the control chamber 44 is reduced and the force pushing the needle 30 towards its open position becomes greater than the force pushing the needle 30 towards its closed position. Hence, the needle 30 moves away from the valve seat 28, the pressurized fuel contained in the delivery chamber 24 is admitted into the sac 38 of the atomizer 36 and it is injected through the injection holes 40 once the needle has been lifted enough for the slide valve to uncover them.

[0027] In order to initiate the opening of the needle 30 it is necessary to reduce the pressure in the control chamber 44 to a value that is considerably lower than the one which is sufficient to keep the needle 30 in the open position after the needle 30 has lifted enough to pressurise the sac 38.

[0028] In accordance with the prior art, this would require a large outlet flow restrictor 52. However, a large size of the outlet flow restrictor 52 is actually required only during a tiny fraction of the injection phase. As a matter of fact, as soon as the needle 30 lifts enough to pressurise the sac 38, the force pushing the needle 30 towards its open position increases greatly and the pres-

sure in the control chamber 44 can be kept at a higher level.

[0029] On the basis of these considerations, the present invention provides a design in which the inlet flow restrictor 48 includes a variable choking section, movable between a choked position corresponding to a fully closed position of the injection needle 30 an un-choked position corresponding to a position of initial opening of the needle 30. Therefore, the inlet flow restrictor 48 is considerably choked when the needle 30 abuts against the valve seat 28. The choking is then reduced and eventually eliminated in the first stage of the needle stroke.

[0030] In figure 1 the arrow 60 schematically represents the variable choking section of the inlet flow restrictor 48 and the dotted line 62 represents the fact that the variable choking section 60 is controlled by the movement of the needle 30.

[0031] In preferred embodiments of the invention the inlet flow restrictor 48 comprises at least one orifice movable with the needle 30 and the variable choking section 60 comprises a gap formed between a first surface movable with the needle 30 and a second surface fixed with respect to the body 22.

[0032] In the solution according to the invention a smaller outlet flow restrictor 52 is enough to bring the pressure in the control chamber 52 to a level sufficient to trigger the injector opening. Ideally, if the inlet flow restrictor 48 were completely choked, any size of the outlet flow restrictor 52 would be sufficient to completely discharge the control chamber 44 (it would only be a matter of time). Then, when the needle 30 lifts and the opening force increases due to sac pressurisation, the inlet flow restrictor 48 opens fully and the pressure of the control chamber 44 stabilises at a value closer to the level at which the closing phase would begin.

[0033] In addition to solving the problem of a large fuel flow rate discharged through a large outlet flow restrictor, the solution according to the present invention has the additional benefit of reducing the injector switching time, because the pressure level in the control chamber 44 during the injection is kept close to the level necessary to trigger injector closure, which is important in multi-shot and ultra low load operation.

[0034] A first embodiment of the present invention is shown in Figure 2.

[0035] In the example represented in figure 2 the body 22 comprises a locking nut 64, a lower body portion 66, an intermediate body portion 68 and an upper body portion 70. The body portions 66 and 68 are fixed to the upper body portion 70 by means of the locking nut 64. The atomizer 36 is fixed to the lower body portion 66 by means of a threaded bush 72.

[0036] In the following description and in the claims the reference to "lower", "upper", "above", "below" and the like refer to the position of the injector shown in the drawings and generally corresponding to the position of use. It is however understood that the injector can be mounted in any position and that the reference to spatial

positions is not intended to limit the scope of the invention.

[0037] An upper portion of the needle 30 is slidably guided into a bushing 74 carried by the lower body portion 66. The spring 34 is housed into the delivery chamber 24 and is compressed between the bushing 74 and a radial shoulder of the needle 30.

[0038] The control chamber 44 is contoured by a top front surface of the needle 30, a cylindrical wall portion of the bushing 74 and a front surface of the intermediate portion 68. The outlet flow restrictor is formed by an orifice 52 formed in the intermediate body portion.

[0039] The control valve 54 comprises an axially movable stem 76 which is slidable into a guide bore 78 of the intermediate body portion 68. In this exemplary embodiment the electric actuator 56 includes a magnetic core 80 and a coil 82.

[0040] The inlet flow restrictor 48 comprises one or more orifices 84 formed in the area of the needle 30 bearing the conical sealing surface 32. The or each orifice 84 has a radially inner end communicating with an elongated bore 86 formed into the needle 30. The upper end of the elongated bore 86 opens into the control chamber 44.

[0041] As better shown in the enlarged detail of figure 3, the radially outer end of the or each orifice 84 is open on the conical sealing surface 32 of the needle 30, immediately above the area where the sealing surface 32 abuts the valve seat 28.

[0042] The variable choking section 60 is formed by a gap 88 formed between the sealing surface 32 of the needle 30 and the valve seat 28. The size of the gap 88 is minimum when the needle 30 is closed and increases as the needle moves away from the valve seat 28. Accordingly, the or each orifice 84 is choked when the needle is closed and becomes un-choked after an initial opening of the needle 30.

[0043] The elongated bore that connects the inlet flow restrictor 48 to the control chamber 44 plays an active role in ensuring the proper functionality of the invention by delaying the response of the inlet flow restrictor 48 to a drop of pressure in the control chamber 44 by the time it takes for the depression wavefront to travel from the control chamber 44 to the inlet flow restrictor 48 outlet and back. This allows enough time for pressurisation of the sac 38, thereby managing to open the needle 30 with the smallest possible size of the outlet flow restrictor 52.

[0044] A remarkable advantage of this solution is that its cost of implementation is negligible as it uses a seat that is already present in the injector.

[0045] Compared to a traditional configuration, an injector using the present invention can operate with up to 60% less control flow rate which, in terms of overall engine efficiency, is equivalent to a 0.26% increase.

[0046] The main benefit to be gained by such optimisation is the reduction of the forces needed to seal and operate the control valve 44, which allows to use fast and compact actuators that can be integrated in the injector body. This is essential for obtaining an injector that can

operate with the fast switching times required in multi-shot mode.

[0047] A second embodiment of the present invention is shown in figure 4. The elements corresponding to the ones previously disclosed are indicated by the same reference numbers.

[0048] The solution shown in figure 4 is a more conventional common rail injector arrangement in which a separate control piston 90 is used to keep the needle 30 closed. The lower end of the control piston 90 abuts against the upper end of the needle 30. The control piston 90 moves axially together with the needle 30. The body 22 comprises a sleeve 92 set between the lower body portion 66 and the intermediate body portion 68. The spring 34 is set in a low pressure chamber formed between the sleeve 92 and the control piston 90.

[0049] The control chamber 44 is contoured by a top front surface of the control piston 90, a cylindrical wall portion of the sleeve 92 and a front surface of the intermediate portion 68. The outlet flow restrictor is formed by an orifice 52 formed in the intermediate body portion 68. The control valve 54 remains unchanged with respect to the first embodiment.

[0050] As better shown in figure 5, the inlet flow restrictor 48 comprises a first annular groove 94 formed on a cylindrical inner surface 96 of the sleeve 92 and a second annular groove 98 formed on a cylindrical outer surface 100 of the control piston 90. The first annular groove 94 is connected to the fuel supply line 26 by a first orifice 102 formed in the sleeve 92. The second annular groove 98 is connected to the control chamber 44 by means of second and third orifices 104 and 106 formed in the control piston 90.

[0051] When the needle 30 is closed the first and second annular grooves 94, 98 are offset from each other, as shown in figure 5. When the control piston 90 moves upwardly the first and second annular grooves 94, 98 are at least partially overlapped.

[0052] As better shown in figure 6, the variable choking section 60 is formed by an annular gap 108 formed between the cylindrical inner surface 96 of the sleeve 92 and the cylindrical outer surface 100 of the control piston 90. When the needle 30 is closed the control chamber 44 communicates with the fuel supply line 26 through two paths: one including the annular gap 108, the first annular groove 94 and the first orifice 102, the other including the third and second orifices 106 and 104, the second annular groove 98, the annular gap 108, the first annular groove 94 and the first orifice 102.

[0053] The annular gap 108 chokes the inlet flow restrictor 48 in the closed position of the needle 30. During the initial opening of the needle 30 the choking of the inlet flow restrictor is eliminated as the first and second annular grooves 94, 98 overlap.

[0054] The size of the annular gap 108 and the length of overlap between the first and second annular grooves 94, 98 are conveniently chosen to allow the pressurisation of the sac 38 before a significant flow rate through

the inlet flow restrictor 48 is established.

[0055] The second embodiment is simpler in construction and offers the additional flexibility of choosing different diameters for needle 30 and control chamber 44. Compared to the first embodiment, the second embodiment has the disadvantage that high pressure fuel leakages occur when the injector is closed, due to the fuel flow within the clearances between needle, control piston and their respective sleeves, that ends up in the spring chamber and, from there, it is discharged to tank.

Claims

1. An electrically controlled fuel injector for large diesel engines, comprising:

- a body (22) having a delivery chamber (24) connected to a fuel supply line (26) and provided with a conical valve seat (28);
- a needle (30) extending through said delivery chamber (24) and having a conical sealing surface (32) cooperating with said valve seat (28), the needle (30) being movable along a longitudinal axis (A) between a closed position wherein said conical sealing surface (32) abuts against said conical valve seat (28) and an open position wherein said conical sealing surface (32) is spaced apart from said conical valve seat (28), wherein the hydraulic pressure into said delivery chamber (24) generates a first hydraulic force pushing the needle (30) towards its open position;
- a control chamber (44) connected to said fuel supply line (26) through an inlet flow restrictor (48) and connected to a discharge line (50) through an outlet flow restrictor (52), wherein the hydraulic pressure into said control chamber (44) generates a second hydraulic force pushing the needle (30) towards its closed position;
- an electrically-operated control valve (54) for selectively opening and closing hydraulic communication between said control chamber (44) and a low pressure volume (14) through the discharge line 50;

characterized in that said inlet flow restrictor (48) includes a variable choking section (60), movable between a choked position corresponding to a fully closed position of the needle (30) an un-choked position corresponding to an initial opening of the needle (30).

2. A fuel injector according to claim 1, **characterized in that** said inlet flow restrictor (48) comprises at least one orifice (84; 104, 106) movable with the needle (30) and that said variable choking section (60) comprises a gap (88; 108) formed between a surface (32; 100) movable with the needle (30) and a surface

(28; 96) fixed with respect to the body (22).

control piston (90).

3. A fuel injector according to claim 2, **characterized in that** said inlet flow restrictor (48) comprises at least one orifice (84) formed in an area of the needle (30) bearing said conical sealing surface (32). 5
4. A fuel injector according to claim 3, **characterized in that** said orifice (84) has a radially inner end communicating with an elongated bore (86) formed into the needle (30), the elongated bore (86) having an upper end open into said control chamber (44). 10
5. A fuel injector according to claim 3, **characterized in that** said orifice (84) has a radially outer end open on the conical sealing surface (32) of the needle (30), immediately above the area where the sealing surface (32) abuts the valve seat (28). 15
6. A fuel injector according to any of claims 2 to 5, **characterized in that** said variable choking section (60) is formed by a gap (88) formed between the conical sealing surface (32) of the needle (30) and the conical valve seat (28). 20
25
7. A fuel injector according to claim 2, **characterized in that** a control piston (90) is slidably guided into a sleeve (92) and is movable with the needle (30), the control piston (90) being set between the control chamber (44) and the needle (30). 30
8. A fuel injector according to claim 7, **characterized in that** the inlet flow restrictor (48) comprises a first annular groove (94) formed on a cylindrical inner surface (96) of said sleeve (92) and a second annular groove (98) formed on a cylindrical outer surface (100) of the control piston (90). 35
9. A fuel injector according to claim 8, **characterized in that** the first annular groove (94) is connected to the fuel supply line (26) by a first orifice (102) formed in the sleeve (92) and the second annular groove (98) is connected to the control chamber (44) by means of second and third orifices (104, 106) formed in the control piston (90). 40
45
10. A fuel injector according to claim 9, **characterized in that** in the closed position of the needle (30) the first and second annular grooves (94, 98) are offset from each other, and in a position of initial opening of the needle (30) the first and second annular grooves (94, 98) are at least partially overlapped. 50
11. A fuel injector according to any of claims 8 to 10, **characterized in that** the variable choking section (60) is formed by an annular gap (108) formed between the cylindrical inner surface (96) of the sleeve (92) and the cylindrical outer surface (100) of the 55

FIG. 1

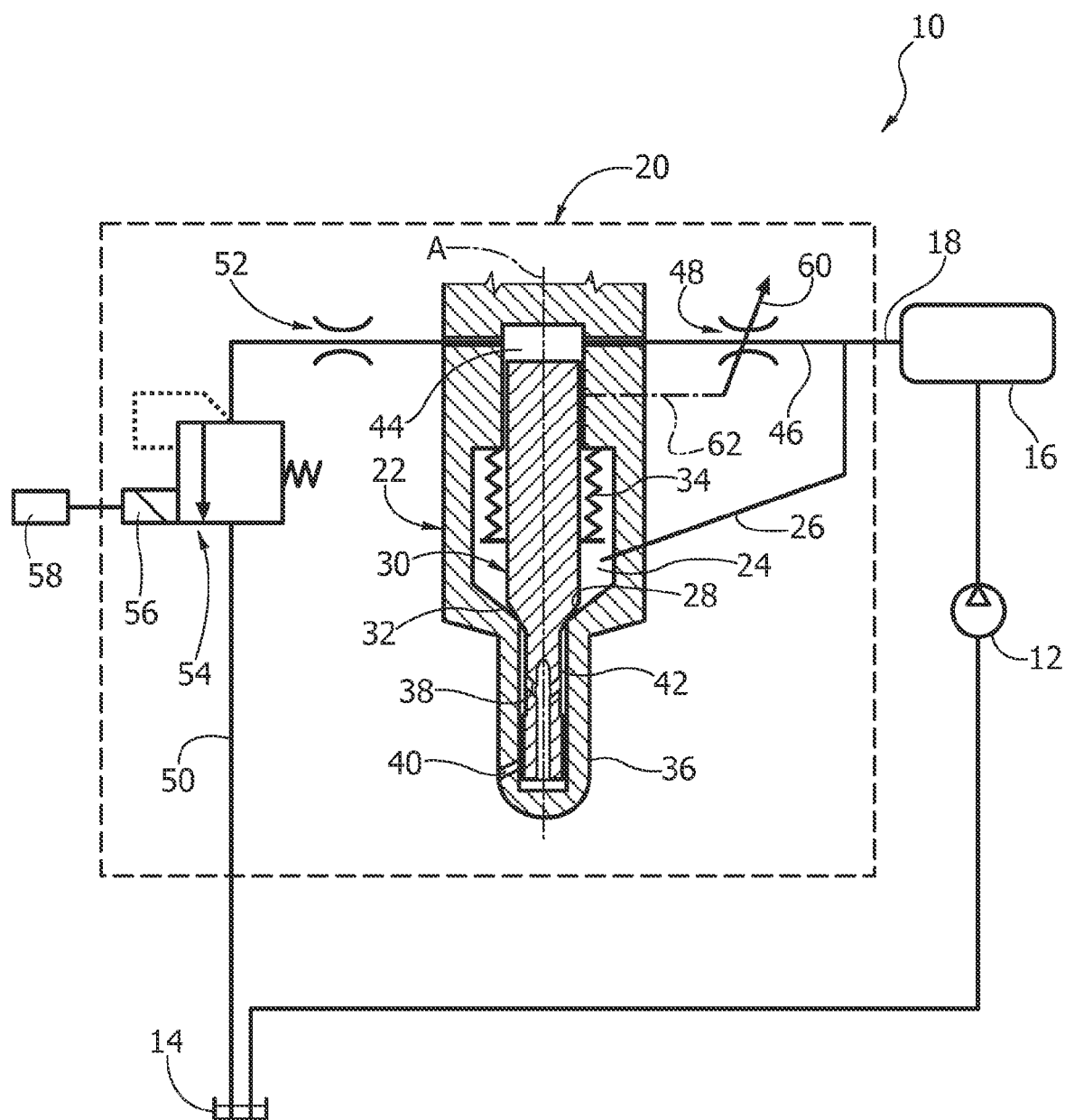


FIG. 2

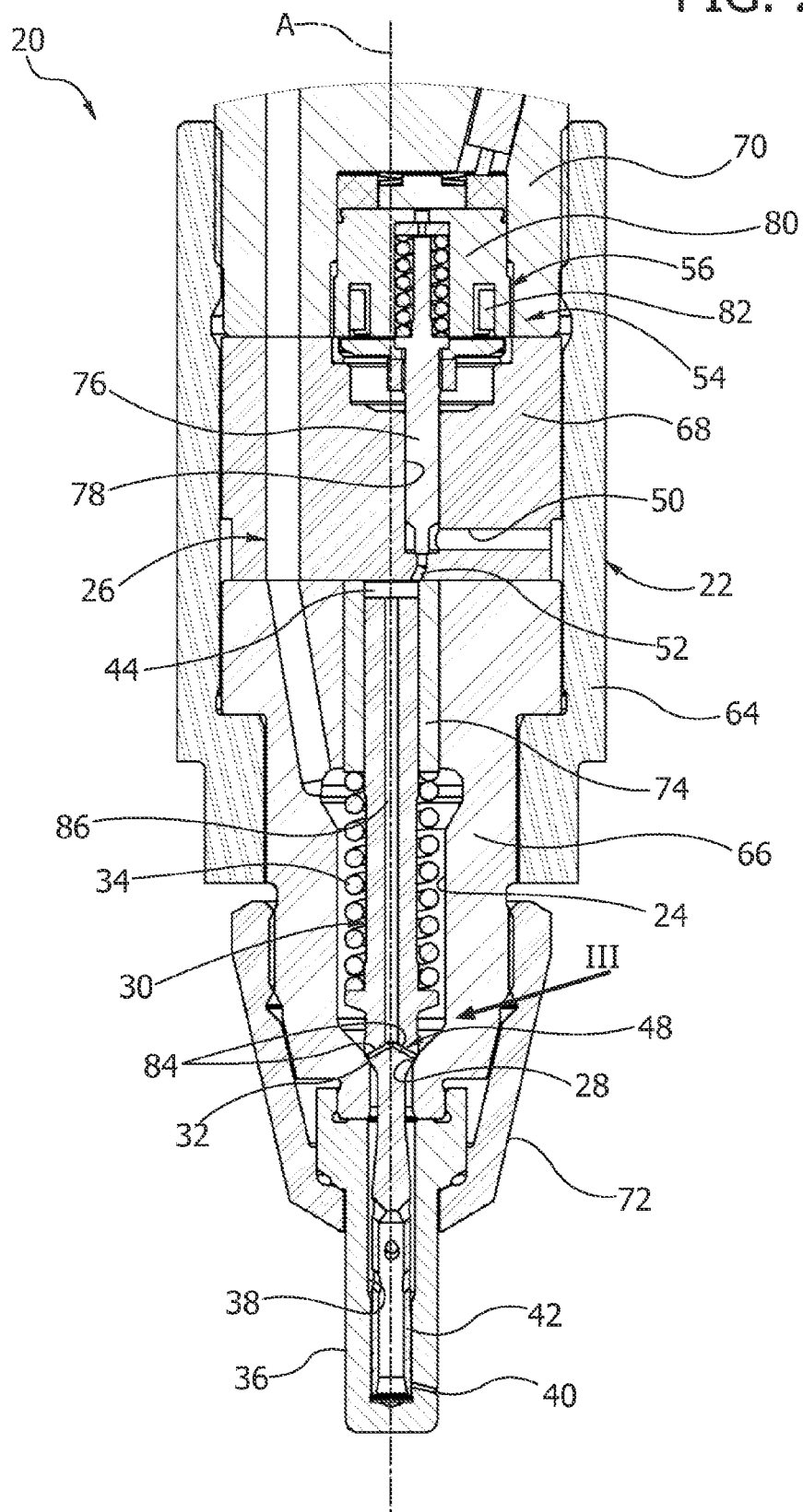


FIG. 3

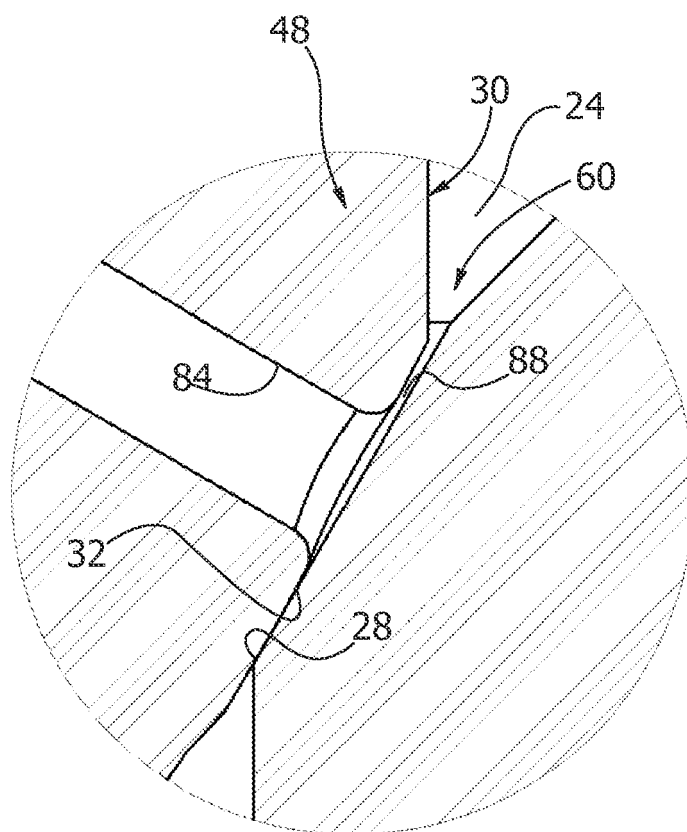


FIG. 4

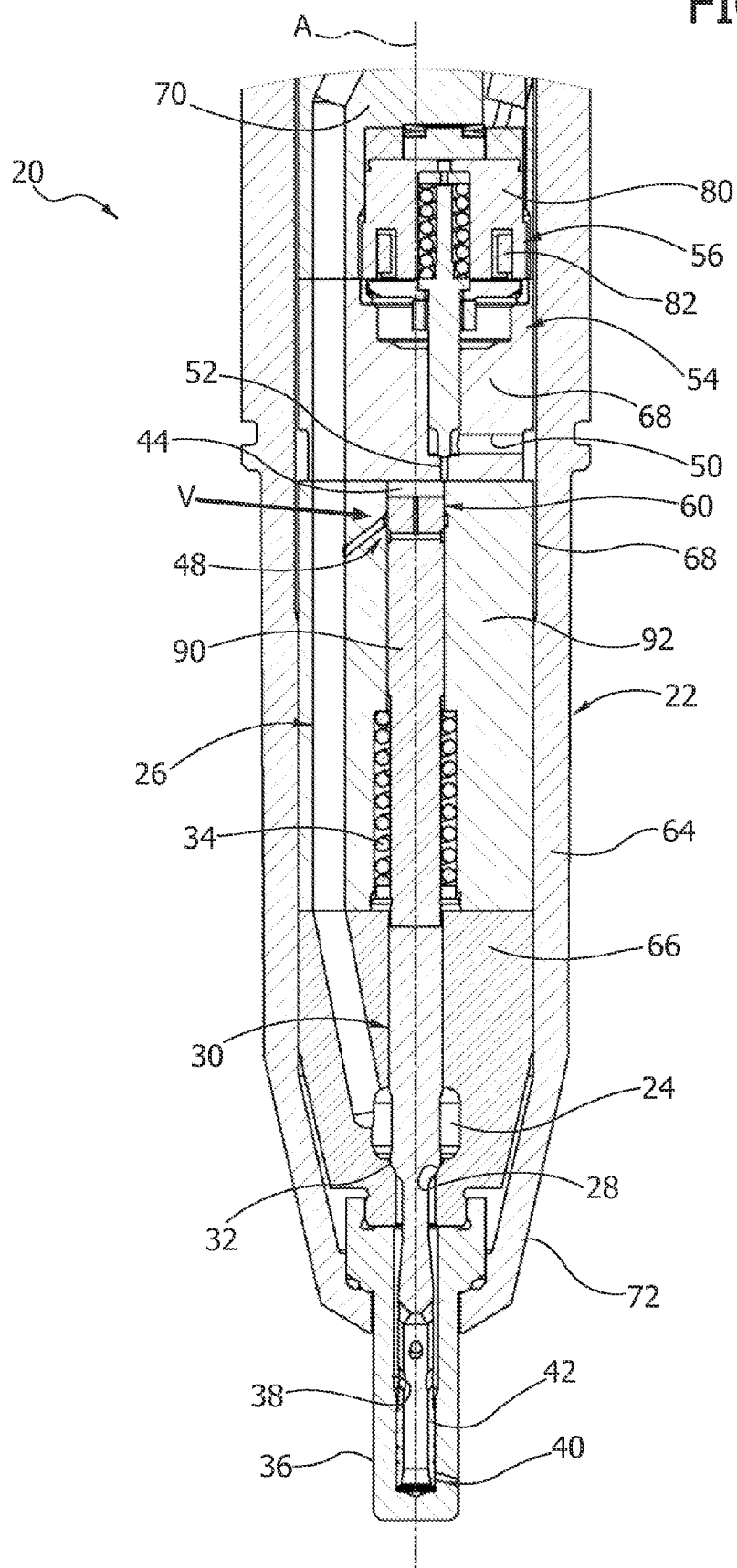


FIG. 5

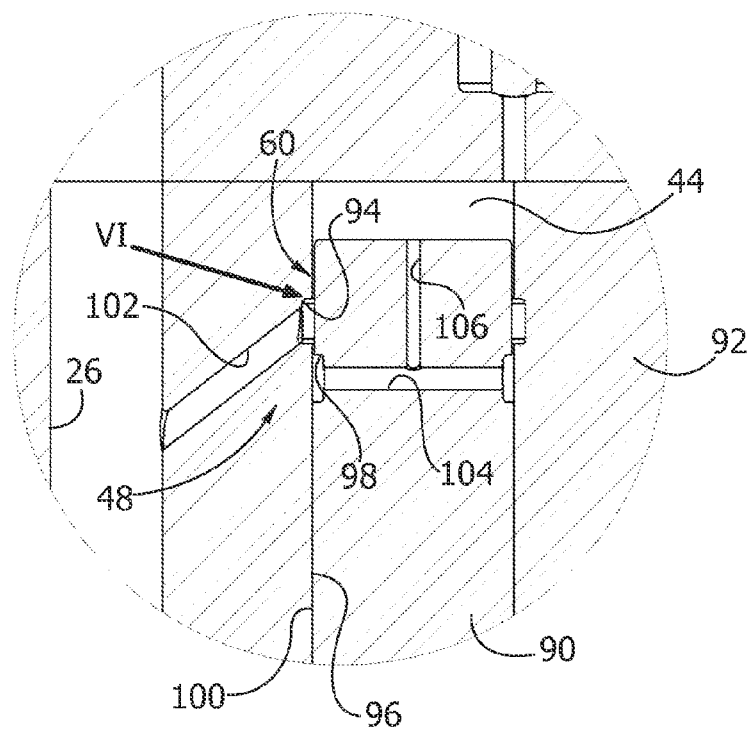
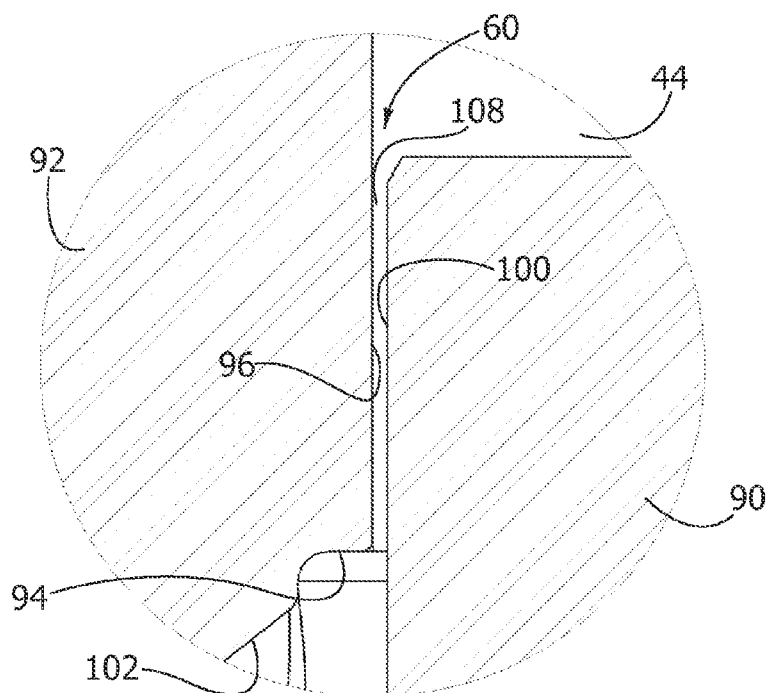


FIG. 6





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Application Number
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 22 July 2011	Examiner Godrie, Pierre
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 11 15 9584

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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