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(54) **Fuel injector equipped with a metering servovalve for an internal-combustion engine**

(57) A fuel injector (1) has an injector body (2) and a control rod (10), which is movable in the injector body (2) along an axis (3) for controlling opening/closing of a nozzle that injects fuel into a cylinder of an engine; the injector body (2) houses a metering servovalve (5) having a control chamber (26), which is axially delimited by the control rod (10) and communicates with an inlet (4) and with a discharge duct (42); the metering servovalve (5) is provided with an open/close element (47), which is axially slidable on an axial guide (38), from which the discharge duct (42) gives out, to open and close the discharge duct (42) and consequently vary the pressure in the control chamber (26); the discharge duct (42) has at least two calibrated restrictions (53, 44) which have calibrated passage sections and are set in series with respect to one another for splitting the pressure drop along the discharge duct (42); the hole or holes that defines/define the last calibrated restriction is/are divergent.

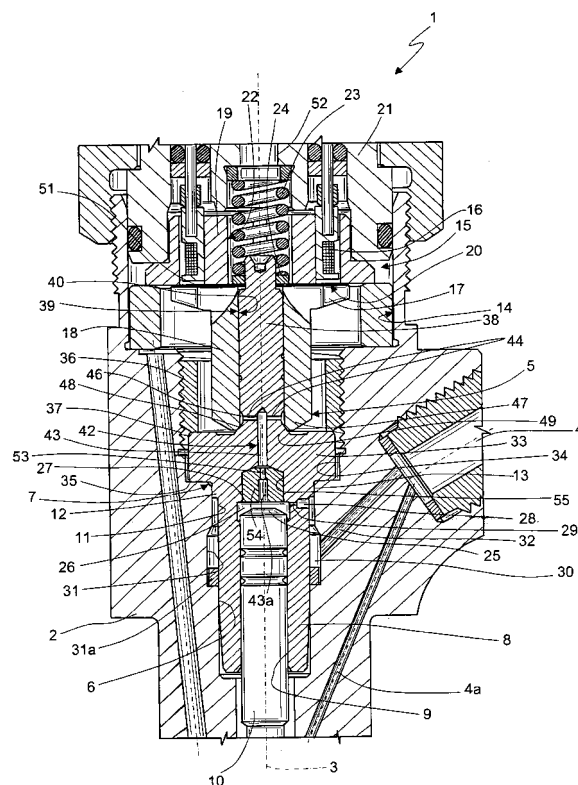


Fig.1

Description

[0001] The present invention relates to a fuel injector equipped with a metering servovalve for an internal-combustion engine.

[0002] Normally, injectors for internal-combustion engines comprise a metering servovalve having a control chamber, which communicates with a fuel inlet and with a fuel-discharge duct. The metering servovalve comprises an open/close element, which is axially movable under the action of an electric actuator to open/close an outlet opening of the discharge duct and vary the pressure in the control chamber. The pressure in the control chamber, in turn, controls opening/closing of a terminal nozzle of the injector to introduce the fuel into a corresponding cylinder.

[0003] The discharge duct has a calibrated stretch, which is of particular importance for proper operation of the metering servovalve. In particular, in said calibrated stretch, the flow rate of a fluid is associated to a predefined pressure differential.

[0004] In injectors that are currently produced, the calibrated stretch of the discharge duct is obtained by making a perforation via electron discharge machining (EDM), followed by a finishing operation, necessary for eliminating any possible perforation defects that, albeit small, would in any case result in large errors on the pressure drop in fuel flow and, consequently, in the flow rate of fuel leaving the control chamber. In addition, the finishing operation has the purpose of stabilizing the flow rate of fluid that traverses the calibrated stretch: in practice, it is a sort of "ageing" aimed at guaranteeing robustness of operation.

[0005] In particular, the finishing operation is of an experimental nature and is carried out by getting an abrasive liquid to flow through the hole made via EDM, setting the pressure upstream and downstream of the hole, and detecting the flow rate: the flow rate tends to increase progressively with the abrasion caused by the liquid on the lateral surface of the hole, until a preset design value is reached. At this point, the flow is interrupted: in use, the final passage section obtained will come to define, to a close approximation, a pressure drop equal to the difference in pressure set upstream and downstream of the hole during the finishing operation and a flow rate of fuel leaving the control chamber equal to the preset design value.

[0006] In the injector disclosed in the patent No. EP1612403, the discharge duct has an outlet made in an axial stem that guides the open/close element, said stem being defined by a sliding sleeve. The calibrated stretch of the discharge duct is coaxial with the axial stem and is made in a perforated plate, which axially delimits the control chamber. Downstream of said calibrated stretch, the discharge duct comprises an axial stretch and then two opposed radial stretches, which define, together, a relatively large passage section for the discharged fuel. Considering, for example, a fuel supply

pressure of approximately 1600 bar to the injector, when the metering servovalve is open, i.e., when the sleeve that defines the open/close element is raised in the open position, the incoming fuel that flows into the control chamber determines a pressure drop that causes the pressure to reach approximately 700-800 bar in the control chamber; then, between the upstream and downstream ends of the calibrated stretch of the discharge duct, the fuel pressure drops from approximately 700-800 bar to just a few bar.

[0007] Experimentally, it is found that, on account of the high pressure drop across the calibrated stretch of the discharge duct, there is the onset of cavitation. In other words, the fuel pressure upstream of the discharge environment drops below the vapour pressure, in the region, and immediately downstream, of the outlet of the calibrated stretch, where the rate of flow of fuel is maximum and the pressure is minimum.

[0008] In the area where the open/close element must provide tightness against the axial stem, it is possible to distinguish three undesirable phenomena:

- on account of the rapid increase in the passage section, the pressure tends to rise and the previously formed vapour bubbles tend to implode; when this phenomenon takes place at the surfaces that define the seal, it causes undesirable wear on said surfaces;
- during closing of the open/close element, contact between the surfaces that define the seal takes place in the presence of vapour, namely in "dry" conditions, with consequent impact that leads to further wear; and
- once again on account said "dry" conditions, moreover, given that the damping effect of the liquid ceases, the open/close element rebounds, and this leads to a delay in closing of the servovalve, with a consequent undesirable increase in the amount of fuel injected with respect to the amount set down in the design stage.

[0009] To sum up, the wear deriving from the phenomena set forth above, reduces enormously the service life of the injector, whilst the rebounds during closing render the injector imprecise.

[0010] In addition, in order to generate a pressure drop of approximately 700-800 bar, the calibrated stretch must have an extremely small diameter, which is extremely complex to obtain precisely and in a constant way between the various injectors.

[0011] To overcome the above drawbacks, the European patent application No. 08425460.6, filed in the name of the present applicant, proposes provision of two or more calibrated restrictions set in series along the discharge duct: in this case, the pressure drop, which, in use, occurs between the control chamber and the discharge environment when the open/close element is in the opening position, is split into as many pressure drops

as are the calibrated restrictions set in series along the discharge duct.

[0012] Unfortunately, when the calibrated restrictions are just two, also said solution is not altogether satisfactory, because cavitation phenomena in any case arise downstream of the second calibrated restriction (i.e., the one closer to the sealing area).

[0013] In fact, one of the main factors that determines onset or otherwise of cavitation is defined by the ratio between the pressure upstream and the pressure downstream of the calibrated restriction. Even if it were assumed that it is possible theoretically to split the total pressure drop into 95% on the first calibrated restriction and 5% on the second calibrated restriction, with a pressure of the control chamber of approximately 700-800 bar, there is, upstream of the second calibrated restriction, a pressure of approximately 40-35 bar and, downstream, a pressure close to the atmospheric pressure of the discharge environment. Consequently, the ratio between the pressure upstream and the pressure downstream of the second calibrated restriction is in any case high and such as to cause cavitation phenomena, even if said phenomena are markedly reduced as compared to solutions in which the pressure drop is not split into two.

[0014] The aim of the present invention is to provide a fuel injector equipped with a metering servovalve for an internal-combustion engine, which will enable improvement of the solution described above, reducing the presence of cavitation, i.e., formation of fuel vapour, and hence wear in the sealing area between the open/close element and the axial stem, to a minimum.

[0015] According to the present invention, a fuel injector for an internal-combustion engine is provided, as defined in Claim 1.

[0016] For a better understanding of the present invention, a preferred embodiment will now be described, purely by way of non-limiting example, with reference to the attached drawings, wherein:

- Figure 1 shows, in cross section and with parts removed, a preferred embodiment of the fuel injector equipped with a metering servovalve for an internal-combustion engine, according to the present invention;
- Figure 2 shows a detail of Figure 1 at an enlarged scale;
- Figure 3 is similar to Figure 2 and shows a variant of the embodiment of Figure 1 at a further enlarged scale;
- Figures 4 to 9 are similar to Figure 3 and show respective variants of the embodiment of Figure 1;
- Figure 10 is similar to Figure 1 and shows, at an enlarged scale, a second preferred embodiment of the injector according to the present invention;
- Figure 11 is similar to Figure 10 and shows a variant of the embodiment of Figure 10;
- Figure 12 is similar to Figure 2 and shows a third preferred embodiment of the injector according to

the present invention;

- Figure 13 shows a variant of the embodiment of Figure 12;
- Figure 14 is similar to Figure 1 and shows a fourth preferred embodiment of the injector according to the present invention;
- Figure 15 shows a detail of Figure 14, at an enlarged scale; and
- Figures 16 and 17 are diagrams that illustrate two holes defining respective calibrated restrictions included in the metering servovalve according to the present invention.

[0017] With reference to Figure 1, the reference number 1 designates, as a whole, a fuel injector (partially shown) for an internal-combustion engine, in particular a diesel engine. The injector 1 comprises a hollow body or casing 2, commonly referred to as "injector body", which extends along a longitudinal axis 3, and has a lateral inlet 4 designed to be connected to a duct for delivery of fuel at a high pressure, for example at a pressure of around 1600 bar. The casing 2 terminates with an injection nozzle (not shown in the figure), which is in communication with the inlet 4 through a duct 4a, and is designed to inject fuel into a corresponding engine cylinder.

[0018] The casing 2 defines an axial cavity 6, in which a metering servovalve 5 is housed, comprising a valve body, made of a single piece and designated by the reference number 7.

[0019] The valve body 7 comprises a tubular portion 8 defining a blind axial hole 9 and a centring ridge 12, which radially projects with respect to a cylindrical outer surface of the portion 8 and is coupled with an internal surface 13 of the body 2.

[0020] A control rod 10 is able to slide axially in a fluid-tight way in the hole 9 to control, in a way known and not shown, an needle open/close element that opens and closes the injection nozzle.

[0021] The casing 2 defines another cavity 14 coaxial with the cavity 6 and housing an actuator 15, which comprises an electromagnet 16 and a notched-disk armature 17 operated by the electromagnet 16. The armature 17 is made of a single piece with a sleeve 18, which extends along the axis 3. On the other hand, the electromagnet 16 comprises a magnetic core 19, which has a surface 20 that is perpendicular to the axis 3 and defines an axial stop for the armature 17, said magnetic core 19 being held in position by a support 21.

[0022] The actuator 15 has an axial cavity 22 housing a helical compression spring 23, which is preloaded so as to exert a thrust on the armature 17 in the axial direction opposite to the attraction exerted by the electromagnet 16. The spring 23 has one end resting against an internal shoulder of the support 21, and the other end acting on the armature 17 via axial interposition of a washer 24.

[0023] The metering servovalve 5 comprises a control chamber 26 radially delimited by the lateral surface of

the hole 9 of the tubular portion 8. The control chamber 26 is axially delimited on one side by a terminal surface 25 of the rod 10, which advantageously has the shape of a truncated-cone, and on the other side by a bottom surface 27 of the hole 9.

[0024] The control chamber 26 is in permanent communication with the inlet 4 through a duct 28 made in the portion 8 to receive pressurized fuel. The duct 28 comprises a calibrated stretch 29 and gives out on one side into the control chamber 26 in the proximity of the bottom surface 27 and on the other side into an annular chamber 30, radially delimited by the surface 11 of the portion 8 and by an annular groove 31 of the internal surface of the cavity 6. The annular chamber 30 is axially delimited on one side by the ridge 12 and on the other by a gasket 31a. Giving out into the annular chamber 30 is a duct 32 made in the body 2 and in communication with the inlet 4.

[0025] The valve body 7 comprises an intermediate axial portion defining an external flange 33, which projects radially with respect to the ridge 12, is housed in a portion 34 of the cavity 6 of oversized diameter, and is located axially in contact with an internal shoulder 35 of the cavity 6. The flange 33 is gripped against the shoulder 35 by a threaded ring nut 36, screwed into an internal thread 37 of the portion 34 in order to guarantee fluid tightness against the shoulder 35.

[0026] The valve body 7 also comprises a guide element for the armature 17 and the sleeve 18. Said element is defined by a substantially cylindrical stem 38 having a diameter much smaller than that of the flange 33. The stem 38 projects in cantilever fashion from the flange 33, along the axis 3 on the side opposite to the tubular portion 8, i.e., towards the cavity 22. The stem 38 is externally delimited by a lateral surface 39, which comprises a cylindrical portion for guiding axial sliding of the sleeve 18. In particular, the sleeve 18 has an internal cylindrical surface 40, coupled to the lateral surface 39 of the stem 38, that is substantially fluid-tight, i.e., via a coupling with an appropriate diametral play, from example of less than 4 μm , or else via interposition of specific sealing elements.

[0027] The control chamber 26 is in permanent communication with a fuel-discharge duct, designated as a whole by the reference number 42.

[0028] The duct 42 comprises a blind axial stretch 43, made along the axis 3 in the valve body 7 (partly in the flange 33 and partly in the stem 38). The duct 42 also comprises at least one outlet stretch 44, which is radial, starts from the stretch 43, and defines, at the opposite end, an outlet opening onto the lateral surface 39, in a position corresponding to a chamber 46 defined by an annular groove made in the lateral surface 39 of the stem 38.

[0029] In particular, in the embodiment of Figures 1 and 2, two sections 44 are provided that are diametrically opposite to each other.

[0030] The chamber 46 is obtained in an axial position adjacent to the flange 33 and is opened/closed by a terminal portion of the sleeve 18, which defines an open/

close element 47 for the duct 42. In particular, the open/close element 47 terminates with an internal surface 48 shaped like a truncated cone, which is designed to engage a surface 49 shaped like a truncated cone between for connection between the flange 33 and the stem 38 to define a sealing area.

[0031] The sleeve 18 slides on the stem 38, together with the armature 17, between an advanced end-of-travel position and a retracted end-of-travel position. In the advanced end-of-travel position, the open/close element 47 closes the annular chamber 46 and thus the outlet of the stretches 44 of the duct 42. In the retracted end-of-travel position, the open/close element 47 opens the chamber 46 sufficiently to allow the stretches 44 to discharge fuel from the control chamber 26 through the duct 42 and the chamber 46. The passage section left open by the open/close element 47 has the shape of a truncated cone and is at least three times larger than the passage section of a single stretch 44.

[0032] The advanced end-of-travel position of the sleeve 18 is defined by the surface 48 of the open/close element 47 coming to bear upon the surface 49 having the shape of a truncated cone for connection between the flange 33 and the stem 38. Instead, the retracted end-of-travel position of the sleeve 18 is defined by the armature 17 axially coming to bear upon the surface 20 of the core 19, with interposition of a nonmagnetic gap plate 51. In the retracted end-of-travel position, the chamber 46 is set in communication with a discharge duct of the injector (not shown), through an annular passage between the ring nut 36 and the sleeve, through the notches in the armature 17, through the cavity 22, and through an opening 52 of the support 21.

[0033] When the electromagnet 16 is energized, the armature 17 shifts towards the core 19, together with the sleeve 18, so that the open/close element 47 opens the chamber 46. The fuel is then discharged from the control chamber 26: in this way, the pressure of the fuel in the control chamber 26 drops, causing axial displacement of the rod 10 towards the bottom surface 27, and hence opening of the injection nozzle.

[0034] Instead, by de-energizing the electromagnet 16, the spring 23 brings the armature 17, together with the open/close element 47, into the advanced end-of-travel position of Figure 1. In this way, the chamber 46 is closed, and the pressurized fuel arriving from the duct 28 re-establishes the high pressure in the control chamber 26 so that the rod 10 moves away from the bottom surface 27 and governs closing of the injection nozzle. In the advanced end-of-travel position, the fuel exerts a substantially zero resultant axial thrust on the sleeve 18, since the pressure in the chamber 46 acts only radially on the lateral surface 40 of the sleeve 18.

[0035] In order to control the rate of variation of pressure in the control chamber 26 upon opening and closing of the open/close element 47, the duct 42 comprises calibrated restrictions. By the term "restriction" is understood a portion of duct in which the passage section avail-

able as a whole for the fuel is smaller than the passage section that the flow of fuel encounters upstream and downstream of said portion of duct. In particular, if the fuel passes through a single hole, the restriction is defined by said single hole. On the other hand, if the fuel passes through a plurality of holes, which are arranged parallel to one another, and hence subject to the same pressure drop between upstream and downstream, the restriction is defined by the entirety of said holes.

[0036] Instead, by the term "calibrated" is meant the fact that the passage section is provided precisely so as to define exactly a predetermined flow of fuel leaving the control chamber 26 and so as to cause a predetermined pressure drop between upstream to downstream.

[0037] In particular, for holes having relatively small diameters, the calibration may be achieved in a precise manner by a finishing operation of an experimental nature, which is carried out by getting an abrasive liquid to flow in the hole previously made (for example, by EDM or laser), setting a pressure upstream and downstream of said hole, and detecting the rate of flow: the flow rate tends to increase progressively with the abrasion caused by the liquid on the lateral surface of the hole (hydro-erosion or hydro-abrasion), until a pre-set design value is reached. At this point, the flow is interrupted: in use, if there is a pressure upstream of the hole equal to the one set during the finishing operation, the final passage section obtained comes to define a pressure drop equal to the difference in pressure set between upstream and downstream of the hole during the finishing operation and a fuel flow rate equal to the preset design flow rate.

[0038] For example, the restrictions of the duct 42 have a diameter of between 150 and 300 μm , whereas the stretch 43 of the duct 42 is obtained in the valve body 7 by means of a normal drill, without particular precision, to obtain a diameter that is at least four times larger than the diameter of the calibrated restrictions.

[0039] The calibrated restrictions are at least two and are arranged in series with respect to one another along the duct 42 (in the attached drawings, the diameter of the calibrated restrictions is shown only qualitatively and not in scale) so as to obtain respective successive pressure drops when the open/close element is in its retracted end-of-travel position. Obviously, between two consecutive calibrated restrictions, the duct 42 comprises a widened intermediate portion, i.e., with a passage section greater than that of both of the calibrated restrictions.

[0040] In the embodiment of Figures 1 and 2, one of the calibrated restrictions is defined by the combination of the two stretches 44, whilst the other is designated by the reference number 53 and is obtained in an element separate from the valve body 7 and subsequently fixed in a position corresponding to the bottom surface 27 of the hole 9. In particular, the calibrated restriction 53 is provided in a cylindrical bushing 54 made of a relatively hard material, defining an insert housed in a seat 55 of the valve body 7 and set flush with the bottom surface 27. The bushing 54 has an outer diameter such as to

enable insertion and fixing by interference fit in the seat 55 after the finishing operation described above.

[0041] The calibrated restriction 53 extends axially for just part of the length of the bushing 54 and occupies a position adjacent to stretch 43, whereas the rest of the bushing 54 has an axial stretch 43a of larger diameter, for example, equal to that of stretch 43 in the valve body 7. The volume of the stretch 43a comes to be added to the one defined by the bottom of the hole 9 to define the volume of the control chamber 26. On the basis of the optimal volume required for the control chamber 26, the bushing 54 could be reversed so as to have the calibrated restriction 53 that gives out directly onto the bottom of the hole 9, as appears from the variants of Figures 7 and 8.

[0042] According to a variant (not illustrated), the calibrated restriction 53 may also be located in an intermediate axial position along the bushing 54.

[0043] According to the variant in Figure 3, a single stretch 44 with a calibrated passage section is provided. In particular, this passage section is equal to the sum of the passage sections of the stretches 44 of the embodiment illustrated in Figures 1 and 2. Furthermore, the calibrated restriction 53 is obtained in a bushing 54a throughout its axial length. The bushing 54a has an outer diameter substantially corresponding to that of the stretch 43, and is driven into this stretch 43 so that its bottom surface is flush with the bottom surface 27 of the hole 9.

[0044] According to the variant in Figure 4, the calibrated restriction 53 is obtained axially on a plate 56 located in the control chamber and resting axially against the valve body 7. Since the travel of the rod 10 for opening and closing the nozzle of the injector 1 is relatively small, the plate 56 may be held in contact with the bottom surface 27 by means of a compression spring 57 forced between the plate 56 and the terminal surface 25 of the rod 10. The fact that the terminal surface 25 is shaped like a truncated cone enables it to perform the function of centring of the compression spring 57. Preferably, the plate 56 has a diameter smaller than that of the hole 9, whilst the compression spring 57 has the shape of a truncated cone.

[0045] According to a variant (not illustrated), the hole 9 comprises a bottom portion having a diameter corresponding to the outer diameter of the plate 56: in this case, the plate 56 could be fixed by interference fit in said bottom portion.

[0046] According to the variants in Figures 5 and 6, the duct 42 has an axial hole of relatively large diameter, made in the flange 33, to facilitate manufacture. According to the variant of Figure 5, said axial hole of relatively large diameter is designated by the reference number 58 and terminates axially at an area of connection between the stem 38 and the flange 33. Instead of the stretches 44, the duct 42 comprises two holes 59, which are diametrically opposed, define a calibrated restriction, and are inclined with respect to the axis 3 by a certain angle so as to put the chamber 46 in direct communication with

the bottom of the hole 58. Preferably, the angle of inclination with respect to the axis 3 is of between 30° and 45°.

[0047] By causing the hole 58 to be completely within the flange 33 of the valve body 7, the stem 38 proves to be more robust as compared to the embodiment of Figures 1 and 2. The diameter of the stem 38, and hence the diameter of the annular sealing area between the sleeve 18 and the stem 38 may consequently be reduced, with obvious benefits in limiting any leakage in said seal in dynamic conditions. In particular, with this solution, the diameter of the sealing area can now be reduced to a value of between 2.5 and 3.5 mm without the stem 38 becoming structurally weak.

[0048] Furthermore, by reducing the axial length and widening the diameter of the hole 58 with respect to the stretch 43, the operations of making the hole 58 and subsequent cleaning to remove swarf are facilitated. Advantageously, the hole 58 has a diameter of between 8 and 20 times that of the calibrated restriction 53. In this way, the intersection of the holes 59 with the bottom of the hole 58 during drilling of the holes 59 is facilitated.

[0049] The calibrated restriction 53 is made in a cylindrical bushing 61 and extends throughout the length of the bushing 61. The bushing 61 is driven, i.e., force fitted, into an axial seat 60 after the hole 58 has been cleaned. The seat 60 has a diameter larger than that of the hole 58 and a length smaller than that of the hole 58 so that drive fitting is facilitated; the bushing 61 could have a slight conical external chamfer (not shown) on the side fitting into the flange 33 to facilitate its axial insertion into the seat 60.

[0050] According to the variant of Figure 6, the axial hole of relatively larger diameter is designated by the reference number 63 and defines the initial stretch of a blind axial hole 62. The inlet of the stretch 63 houses a bushing 64 force fitted therein and having the calibrated restriction 53, which extends throughout the axial length of the bushing 64. Like the bushing 61, the bushing 64 could have a slight external conical chamfer (not shown) on the side fitting into the flange 33.

[0051] The hole 62 also comprises a blind stretch 66, having a diameter smaller than that of the stretch 63, extending beyond the flange 33 into the stem 38, and defining a calibrated restriction. The diameter of the stretch 66 is greater than that of the calibrated restriction 53: for example, it is approximately twice that of the calibrated restriction 53. Notwithstanding the larger diameter, it is possible to obtain a pressure drop of the same order of magnitude as that caused by the calibrated restriction 53 by calibrating in an appropriate way the length of the stretch 66.

[0052] Since the diameter of the stretch 66 is in any case relatively small, the diameter of the stem 38 and hence the diameter of the seal with the sleeve 18 can be reduced with respect to the solution of Figures 1 and 2. Also in this configuration, advantageously the diameter of the sealing area can be reduced down to a value of between 2.5 and 3.5 mm according to the materials cho-

sen and the type of heat treatment adopted.

[0053] The duct 42 also comprises two diametrically opposed radial stretches 67, which are made so as to define a passage section larger than that of the stretch 66 and without any particular machining precision. The stretches 67 give out directly into the calibrated stretch 66, on one side, and into the chamber 46, on the other.

[0054] According to variants of Figures 5 and 6 (not illustrated), the bushings 61 and 64 are replaced by bushings similar to the one designated by the reference number 54 in Figure 1.

[0055] The variants illustrated in Figures 7 and 8 differ from those illustrated in Figures 5 and 6 in that the calibrated restriction 53 is obtained in a bushing, 61a and 64a, respectively, and extends for a relatively small part of the axial length of the bushing 61a and 64a. The calibrated restriction 53 is adjacent to the bottom surface 27 so that the volume of the control chamber 26 is exclusively defined by the volume at the bottom of the hole 9.

[0056] The remaining part of the bushing 61a and 64a has an axial hole 68 made with a diameter greater than that of the calibrated restriction 53, without any particular machining precision.

[0057] In the variant illustrated in Figure 7, the hole 58 and the seat 60 are replaced by a blind axial hole 58a, which is made entirely within the flange 33 like the hole 58 in Figure 6, but defines a cylindrical seat completely engaged by the bushing 61a. Likewise, in the variant illustrated in Figure 8, the stretch 63 is completely engaged by the bushing 64a.

[0058] In the variants illustrated in Figure 7 and Figure 8, the bushing 61a and 64a is press-fitted into the hole 58a and into the stretch 63, respectively, until it bears upon a conical end narrowing of the hole 58a and of the stretch 63, respectively.

[0059] In the variant illustrated in Figure 9, as compared to that illustrated in Figure 8, the stretches 67 are replaced by stretches 67a that define a calibrated restriction, the stretch 66 is replaced by a stretch 66a made without any particular precision and having a passage section larger than that of the stretches 67a, and the calibrated restriction 53 is made in a plate 69, having a relatively small thickness and made of a relatively hard material, and is housed at the bottom of the stretch 63.

[0060] The plate 69 is not interference fitted, but is axially gripped to the bottom of the stretch 63 by an insert defined by a sleeve 70, which is interference fitted to the inlet of the stretch 63, is made of a relatively soft material to facilitate drive fitting, and defines a through hole, the volume of which comes to form part of the control chamber 26.

[0061] In the embodiment of Figure 10, where possible, the components of the injector 1 are designated by the same reference numbers as the ones used in Figure 1. In this embodiment, the valve body 7 is replaced by three distinct pieces: a tubular body 75 (partially shown), which delimits the control chamber 26 radially and termi-

nates with an external flange 33a axially resting against the shoulder 35, a disk 33b, which delimits the control chamber 26 axially on the opposite side of the terminal surface 25 and axially rests against the end of the body 75, and a distribution and guide body 76, which is made of a single piece and comprises the stem 38 and a base defining an external flange 33c. The flange 33c is axially gripped via the ring nut 36 and is axially delimited by a surface 77, which axially rests against the disk 33b, in a fluid-tight way and in a fixed position.

[0062] The stem 38 extends axially in cantilever fashion from the base 33c in the opposite direction with respect to the disk 33b and comprises the calibrated restriction defined by the holes 44. The blind stretch 43 is provided partly in the base 33c and partly in the stem 38; the calibrated restriction 53 and the stretch 43a are provided in the disk 33b.

[0063] According to a variant of Figure 10 (not illustrated), the stretches 44 are inclined like the stretches 59 shown in Figures 5 and 7.

[0064] According to a further variant of Figure 10 (not illustrated), the stretches 44 are made without any particular precision, whilst the calibrated restriction is made in the stretch 43, in a way similar to what has been shown as regards the stretch 66 of Figures 6 and 8.

[0065] In the variant represented in Figure 11, the body 76 is replaced by a body 78 that differs from the body 76 in that it comprises a seat 55a made in the flange 33c through the surface 77.

[0066] The stretch 43 is coaxial with the seat 55a and gives out directly into the seat 55a. The seat 55a has a diameter greater than that of the stretch 43 and is engaged by an insert defined by a cylindrical bushing 54b, which is interference fitted in the seat 55b and set flush with the surface 77 of the base 33c.

[0067] The bushing 54b defines a calibrated restriction 79, set in series to the calibrated restrictions 44 and 53. The calibrated restriction 79 extends for only part of the axial length of the bushing 54b and is in a position adjacent to the stretch 43. The rest of the bushing 54b has an axial stretch 43b, having a diameter greater than that of the calibrated restrictions and communicating directly with stretch 43a.

[0068] According to variants of Figure 11 (not illustrated), the stretches 44 are inclined like the stretches 59 in Figures 5 and 7; or else the stretches 44 are made without any particular precision, whilst the calibrated restriction is made in the stretch 43, as in Figures 6 and 8.

[0069] In the embodiment of Figure 12, the components of the injector 1 are designated, wherever possible, by the same reference numbers as the ones used in Figure 2. In this embodiment, the valve body 7 is replaced by two distinct pieces, one defined by the distribution body 76 of Figure 10 and the other by a valve body 80.

[0070] The valve body 80 radially and axially delimits the control chamber 26 and comprises a terminal portion 82 provided with the ridge 12 and an external flange 33d axially gripped between the flange 33c and the shoulder

35 (not shown).

[0071] The calibrated restriction 53 is made in the portion 82 and gives out into two coaxial stretches 83 and 84 of the duct 42. The stretches 83 and 84 have a diameter greater than that of the calibrated restriction 53 and substantially equal to that of the stretch 43. The stretch 83 is defined by a hole in the portion 82 and communicates directly with the control chamber 26; the stretch 84 is defined by a seal ring 85, which is housed in a seat 86 and rests against the surface 77 to define fluid-tight seal of the duct 42 between the bodies 80 and 76. Alternatively, by appropriately reducing the diameter of the stretch 84, the fluid tightness can again be obtained through metal-to-metal contact between the bodies 80 and 76 without any seal ring.

[0072] According to variants of Figure 12 (not illustrated), the calibrated restriction 53 is obtained in an insert axially driven into the portion 80 from the side facing the control chamber 26, as in the solutions represented in Figures 1, 2, 3, 4 and 9, or from the side facing the base 33c. In addition, as an alternative to the stretches 44, the calibrated restriction of the body 76 is defined by outlet stretches inclined like the stretches 59 of Figures 5 and 7, or by a blind axial stretch like the stretch 66 of Figures 6 and 8.

[0073] According to further variants of Figure 12, a third calibrated restriction is provided inside the body 76 or inside the valve body 80 and is located axially and in series between the calibrated restrictions 53 and 44.

[0074] One of said variants is shown in Figure 13: the flange 33c has a circular seat 90, which is obtained along the surface 77 coaxially with the seat 86 and has the same diameter as the seat 86. The seat 90 houses a disk 91, which has an axial hole 92 defining the third calibrated restriction.

[0075] The disk 91 is kept axially resting against the bottom of the seat 90 by a seal ring 85a, provided instead of the ring 85. The ring 85a has a rectangular or square cross section, with an outer diameter substantially equal to the diameter of the seats 90 and 86 and engages both of the seats 90 and 86 to define a centring member between the two bodies 80 and 76. In other words, the ring 85a provides three functions: axial centring between the bodies 80 and 76 during coupling, sealing between the bodies 80 and 76 around the fuel flow in the duct 42, and positioning of the disk 91 in the seat 90.

[0076] In the embodiment of Figures 14 and 15, the components of the injector 1 are designated, wherever possible, by the same reference numbers as the ones used in Figures 1 and 2.

[0077] The axial end of the valve body 7, opposite to the portion 8, has an axial recess 139, which is defined by a surface 149 substantially shaped like a truncated cone and houses an open/close element 147.

[0078] The open/close element 147 is axially movable in response to the action of the actuator 15, in a way known and not described in detail, to open/close an axial outlet of the duct 42. The open/close element 147 has a

spherical external surface 148, which engages the surface 149 when the open/close element 147 is located in its advanced end-of-travel position or closing position so as to define a sealing area.

[0079] In a way similar to what has been described for the embodiment of Figures 1 and 2, the duct 42 comprises a calibrated restriction 53 made in an element that is separate from the valve body 7, in particular in the bushing 54 that is inserted in the seat 55 of the valve body 7 and is set flush with the bottom surface 27.

[0080] The axial stretch 43 is made in the flange 33 and exits in an axial stretch 144 of the duct 42. The stretch 144 defines a calibrated restriction set in series to, and coaxial with, the calibrated restriction 53. At the opposite end, the stretch 144 exits in a final axial stretch 130, which has a passage section larger than that of the stretch 144 and defines the outlet of the duct 42 onto the surface 149.

[0081] In all the arrangements described above, the pressure drop, which, in use, occurs in the control chamber 26 and in the discharge duct when the open/close element 47 is in the open position, is split into as many pressure drops as are the calibrated restrictions set in series along the duct 42.

[0082] Thanks to the sequence of calibrated restrictions, the pressure drop is split into two or more successive pressure drops: the cavitation phenomena, and hence phenomena of evaporation of the flow of fuel, are prevented or at least limited. The greater the number of calibrated restrictions, the smaller the likelihood of cavitation occurring.

[0083] As mentioned above, for a hole defining a calibrated restriction, a close correlation exists between the rate of flow and the difference in pressure upstream and downstream of said hole. In particular, up to a threshold value of the pressure drop, the following relation applies:

where:

$$Q = c_{efflus} A_{foro} \sqrt{\frac{2\Delta p}{\rho}}$$

ρ is the density of liquid;

c_{efflus} is the coefficient of outflow of hole (experimentally obtainable);

A_{foro} is the cross passage section of the hole, Δp is the difference in pressure between upstream and downstream of the hole,

Q is the flow rate.

[0084] In the injector 1, the total pressure drop of the flow of fuel from the control chamber 26 to the discharge environment is known. The European patent application No. 08425460.6 describes how to split this pressure drop into two or more differentials. It is thus possible to obtain to a first approximation the value of the diameters of the calibrated restrictions, once the percentages into which

the total pressure drop between the two holes or restrictions in series is to be split and once the flow rate from the control chamber 26 have been set.

[0085] The further the calibrated restrictions are from the sealing area defined by the surfaces 48 and 49, the greater the likelihood of avoiding the presence of vapour and cavitation in the region of said seal.

[0086] To reduce the risks of presence of vapour in the sealing area (Figure 17), the pressure drop associated to the first calibrated restriction is set so as to be greater than the subsequent ones. Consequently, the first calibrated restriction (designated by the reference number 53 in Figures 1 to 13) will have a passage section smaller than the subsequent calibrated restrictions.

[0087] In particular, in the case of two calibrated restrictions, the calibrated restriction 53 is associated to a pressure drop of at least 60% of the total pressure drop and, conveniently, 80%. To obtain a distribution of 80% on the first calibrated restriction (hole 53) and of 20% on the second calibrated restriction, the ratio between the passage section of the second calibrated section and that of the first calibrated section is approximately equal to 2.

[0088] According to the present invention, as illustrated in Figures 16 and 17 (schematically and without respecting a scale of proportionality with the actual sizes, for reasons of clarity), at least part of the holes that define the calibrated restrictions are provided with a flaring such as to reduce further the risks of presence of vapour in the region of the sealing area.

[0089] In particular, the hole or holes 44, 59, 66, 67a, 144 that define the last calibrated restriction (i.e., the one closest to the sealing area) are defined by a slight flaring 200, of a conical type, so as to be divergent, except possibly for their inlet 201 and their outlet 202, which can be chamfered or radiused, on account of the specific technologies used for providing and/or calibrating said holes.

[0090] The divergence of the holes 44, 59, 66, 67a, 144 corresponds to a slight increase in the passage section in the direction of advance of the flow of fuel so that it favours a reduction in the rate of flow of fuel and a rise in the pressure; this phenomenon tends to reduce the amount of bubbles of vapour at outlet from the calibrated restriction, and hence tends to limit the cavitation in the sealing area.

[0091] The divergence must not in any case be excessive, to prevent detachment of the flow of fuel from the internal surface of the flaring 200. By way of example, the conicity is comprised between 4% and 15% (understood as the ratio between the difference of the diameters and the length of the divergent stretch in percentage terms).

[0092] In practice, a conicity of 4-15% can be easily obtained by making a hole by means of EDM, or else via laser, hence with extremely low additional costs as compared to the known art.

[0093] Even with said conicity, it is necessary to subject the holes to a calibration, which stabilizes the coef-

ficient of outflow and renders operation of the hole during the service life of the injector stable and foreseeable. If a hydro-erosion treatment is used, said treatment stabilizes the coefficient of outflow and generates a slightly convergent mouth.

[0094] Advantageously, also the holes 53, 92, 79 are purposely provided with a flaring or conicity so as to pay attention to the production technologies and prevent the geometrical shape obtained for said holes from being left to chance and the conicity or cylindricity of the holes from possibly being subject to variations from one injector to another in one and the same production lot, on account of the inevitable imprecisions in machining. This attention to the geometrical shape of the calibrated restrictions has consequently repercussions in an equalization of the behaviour of the various injectors.

[0095] Preferably, as regards the first calibrated restriction, i.e., the one closest to the control chamber 26, a tapering 205 (for example, conical) is chosen instead of a flaring, except possibly for its inlet 206 and its outlet 207, which can be chamfered or radiused, on account of the specific technologies used for obtaining and/or calibrating said hole 53.

[0096] The convergence of the calibrated hole 53 favours an increase in the rate of flow of the fuel and a further reduction in pressure, and favours inlet of the lines of flow of the fuel that flows in the discharge duct 42.

[0097] A possible cavitation and formation of vapour at outlet from the first calibrated restriction does not affect the service life of the injector 1 in so far as the phenomenon would be relatively far from the sealing area between the open/close element 47 and the stem 38.

[0098] As mentioned above, once the downstream pressure has been fixed for each calibrated restriction, the relation

$$Q = c_{efflus} A_{foro} \sqrt{\frac{2\Delta p}{\rho}}$$

applies for values Δp lower than a given threshold; beyond said threshold, and for a given passage section, the flow rate Q tends to remain constant and independent of the ratio between the pressures downstream/upstream of the restriction: when this operating condition arises, the flow that traverses said passage section is said to be "choked" or cavitating, and entails onset of cavitation.

[0099] In the case of a number of restrictions in series, once the pressure downstream of the last restriction has been fixed and if it is assumed to increase progressively the pressure upstream of the first calibrated restriction, the total pressure drop is split between the various restrictions in such a way as to respect the equation given above: the flow rate increases until in one of the various

restrictions in series the aforesaid threshold for the value Δp is reached, and then the flow becomes choked. Once this condition arises, the flow rate does not increase any longer, even though the pressure upstream of the first calibrated restriction increases.

[0100] Considering as restriction (variable and not calibrated) also the passage section defined in the region of the sealing area between the open/close element and the fluid-tightness seat, there are three restrictions in series: the flow becomes in any case choked in a region corresponding to the second calibrated restriction (corresponding to the holes 44 of Figure 1) in any operating condition of the injector. As mentioned above, the divergence of the second calibrated restriction "smooths" the phenomenon of cavitation and prevents the flow in the passage section defined between the open/close element and the fluid-tightness seat from possibly being cavitating.

[0101] Thanks to the cavitation in the region of the last calibrated restriction, the flow rate Q will be substantially equal to the one set in the design stage, and will not be affected by the pressure and by operation of all the other restrictions, which "adapt" to the flow rate Q set by the holes 44.

[0102] From what has been set forth above, it emerges that the flaring of the holes 44 is provided to smooth the phenomenon of cavitation due to the pressure drop associated to the last calibrated restriction so as to reduce the risks of presence of vapour in the sealing area. In other words, in the holes 44 that define the last calibrated restriction, the divergence reduces the rate of flow of fuel and consequently tends to recompress the fuel to reduce the phenomenon of cavitation in the region of the sealing area of the open/close element.

[0103] The flow of the second calibrated restriction will always be choked, i.e., cavitating; in this way, the flow rate Q that traverses the restrictions in series will be constant and independent of the different conditions of pressure that are set up in the control chamber 26 as the operating conditions of the engine vary. All this results in a robustness and stability of operation of the injector.

[0104] The fact that the holes of the calibrated restrictions are not cylindrical enables a more stable operation of the injector over time, because a cylindrical hole, without any conicity, is in general more subject to erosion. In addition, from the constructional standpoint, no hole can ever be perfectly cylindrical; consequently, it is better to provide a hole with a pre-set conicity instead of providing a cylindrical hole with an uncertainty on the geometrical tolerances.

[0105] Finally, it is clear that modifications and variations may be made to the injector 1 described herein, without thereby departing from the scope of protection of the present invention, as defined in the attached claims.

[0106] In particular, the balanced-type metering servovalve 5 of Figures 1-13 could comprise an open/close element defined by an axial pin sliding in a sleeve fixed

with respect to the casing 2 and defining the final part of the duct 42. An adjustment spacer could be provided between the bodies 76 and 80 in the embodiment of Figure 12, even though in this case additional finishing and surface-hardening operations would be required.

[0107] The actuator 15 could be replaced by a piezoelectric actuator, which, when subjected to a voltage, increases its own axial dimension to actuate the sleeve 18 in order to open the outlet of the duct 42.

[0108] In addition, the chamber 46 could be at least partially dug in the surface 40, but always with a shape such that the open/close element 47 defined by the sleeve 18 is subject to a zero pressure resultant along the axis 3 when it is located in the closing end-of-travel position.

[0109] The axes of the stretches 44 could lie in different planes, and/or could not all be set equal distances apart from one another about the axis 3, and/or the calibrated holes could be limited to just a part of the stretches 44.

[0110] The duct 42 might not be symmetrical with respect to the axis 3; for example, the stretches 44 could have different cross sections and/or diameters, but always calibrated and flared or tapered to generate an appropriate pressure drop.

Claims

1. A fuel injector (1) for an internal-combustion engine; the injector terminating with a nozzle for injecting fuel into a corresponding cylinder of the engine and comprising:

- a hollow injector body (2) extending in an axial direction (3);
- a metering servovalve (5) housed in said injector body (2) and comprising:

- a) an electric actuator (15);
- b) a control chamber (26) communicating with an inlet (4) for the fuel and with a discharge duct (42) for the fuel; the pressure of said control chamber (26) governing opening/closing of said nozzle;
- c) an open/close element (47), axially movable in response to the action of said electric actuator (15) between a closing position, in which an outlet of said discharge duct (42) is closed, and an opening position, in which said discharge duct (42) is open, to vary the pressure in said control chamber (26); said discharge duct (42) comprising at least two calibrated restrictions (53, 44) which have calibrated passage sections set in series with respect to one another so as to cause, in use, respective successive pressure drops when said discharge duct (42) is open;

said injector being **characterized in that**, considering the direction of the flow leaving said control chamber (26) and entering said discharge duct (42), the last of said calibrated restrictions is defined by at least one hole (44), which is flared.

2. The injector according to Claim 1, **characterized in that** the divergence of said hole (44) is defined by a conicity comprised between 4% and 15%.
3. The injector according to any one of the preceding claims, **characterized in that** the first of said calibrated restrictions is defined by a flared or tapered hole (53).
4. The injector according to Claim 3, **characterized in that**, considering the direction of the flow leaving said control chamber (26) and entering said discharge duct (42), the hole (53) of the first calibrated restriction is tapered.
5. The injector according to Claim 4, **characterized in that** the convergence of the hole (53) of said first calibrated restriction is defined by a conicity comprised between 4% and 15%.
6. The injector according to any one of the preceding claims, **characterized in that** said calibrated restrictions (53, 44) are defined by respective bodies (54, 7) distinct from one another.
7. The injector according to Claim 6, **characterized in that** one of said bodies is defined by an insert (54) coupled by interference fit.
8. The injector according to Claim 6, **characterized in that** one of said bodies is defined by a plate (56; 33b) delimiting axially, on one side, said control chamber (26).
9. The injector according to any one of the preceding claims, **characterized in that** said discharge duct (42) is provided in a fixed position with respect to said injector body (2).
10. The injector according to Claim 9, **characterized by** comprising a guide (38) located in a fixed position with respect to said injector body (2) and having a lateral surface (39) that guides said open/close element between said opening position and closing position; said discharge duct (42) defining an outlet opening located on said lateral surface (39) in a position such as to generate a substantially zero resultant axial force by the fuel when said open/close element is located in said closing position.
11. The injector according to any one of the preceding

claims, **characterized in that**, considering the direction of the flow leaving said control chamber (26) and entering said discharge duct (42), the first of said calibrated restrictions (53) is associated to a pressure drop greater than the pressure drops to which the subsequent calibrated restrictions (44) are associated.

12. The injector according to Claim 11, **characterized in that** said discharge duct has just two calibrated restrictions, and **in that** the ratio between the cross passage section of the second calibrated restriction (44) and that of the first calibrated restriction (53) is approximately equal to 2.

Amended claims in accordance with Rule 137(2) EPC.

1. A fuel injector (1) for an internal-combustion engine; the injector terminating with a nozzle for injecting fuel into a corresponding cylinder of the engine and comprising:

- a hollow injector body (2) extending in an axial direction (3);
- a metering servovalve (5) housed in said injector body (2) and comprising:

- a) an electric actuator (15);
- b) a control chamber (26) communicating with an inlet (4) for the fuel and with a discharge duct (42) for the fuel; the pressure of said control chamber (26) governing opening/closing of said nozzle;
- c) an open/close element (47), axially movable in response to the action of said electric actuator (15) between a closing position, in which an outlet of said discharge duct (42) is closed, and an opening position, in which said discharge duct (42) is open, to vary the pressure in said control chamber (26);

said discharge duct (42) comprising at least two calibrated restrictions (53, 44) which have calibrated passage sections set in series with respect to one another so as to cause, in use, respective successive pressure drops when said discharge duct (42) is open;

said injector being **characterized in that**, considering the direction of the flow leaving said control chamber (26) and entering said discharge duct (42), the first of said calibrated restrictions is defined by a tapered hole (53) and the last of said calibrated restrictions is defined by at least one flared hole (44).

2. The injector according to Claim 1, **characterized in that** the divergence of said flared hole (44) is de-

fined by a conicity comprised between 4% and 15%.

3. The injector according to Claim 1 or 2, **characterized in that** the convergence of the tapered hole (53) is defined by a conicity comprised between 4% and 15%.

4. The injector according to any one of the preceding claims, **characterized in that** said calibrated restrictions (53, 44) are defined by respective bodies (54, 7) distinct from one another.

5. The injector according to Claim 4, **characterized in that** one of said bodies is defined by an insert (54) coupled by interference fit.

6. The injector according to Claim 4, **characterized in that** one of said bodies is defined by a plate (56; 33b) delimiting axially, on one side, said control chamber (26).

7. The injector according to any one of the preceding claims, **characterized in that** said discharge duct (42) is provided in a fixed position with respect to said injector body (2).

8. The injector according to Claim 7, **characterized by** comprising a guide (38) located in a fixed position with respect to said injector body (2) and having a lateral surface (39) that guides said open/close element between said opening position and closing position; said discharge duct (42) defining an outlet opening located on said lateral surface (39) in a position such as to generate a substantially zero resultant axial force by the fuel when said open/close element is located in said closing position.

9. The injector according to any one of the preceding claims, **characterized in that**, considering the direction of the flow leaving said control chamber (26) and entering said discharge duct (42), the first of said calibrated restrictions (53) is associated to a pressure drop greater than the pressure drops to which the subsequent calibrated restrictions (44) are associated.

10. The injector according to Claim 9, **characterized in that** said discharge duct has just two calibrated restrictions, and **in that** the ratio between the cross passage section of the second calibrated restriction (44) and that of the first calibrated restriction (53) is approximately equal to 2.

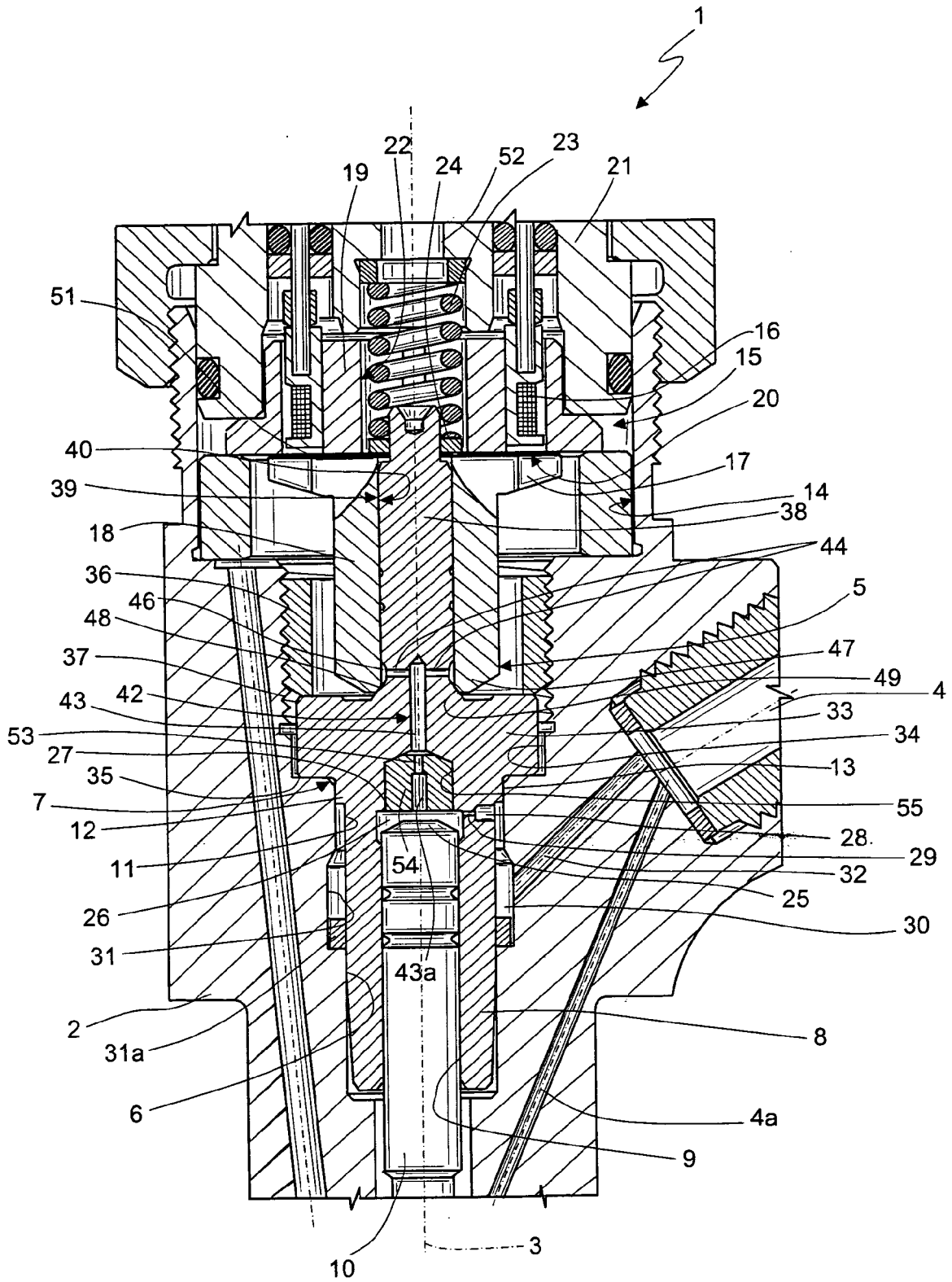


Fig.1

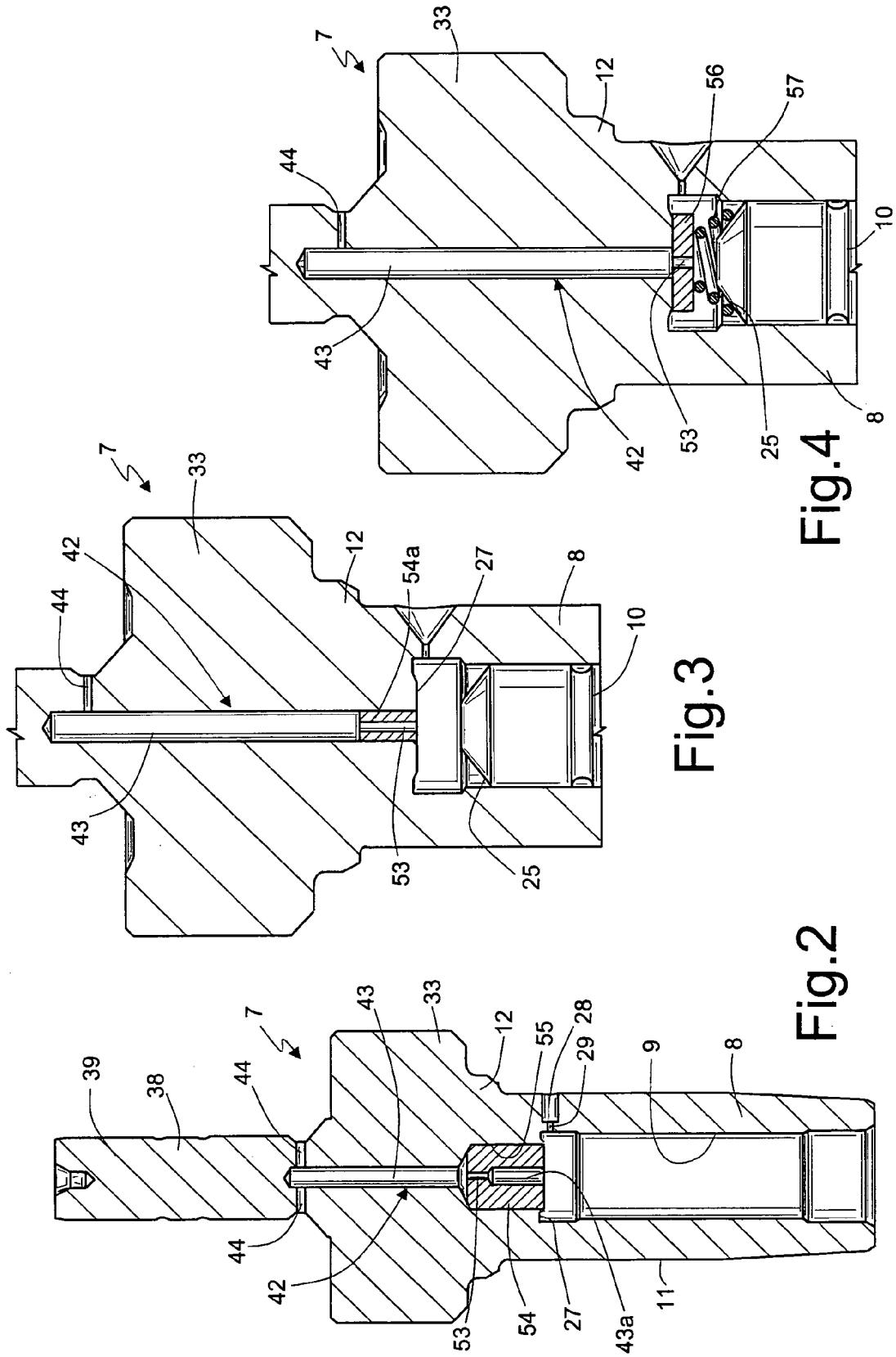


Fig.4

Fig.3

Fig.2

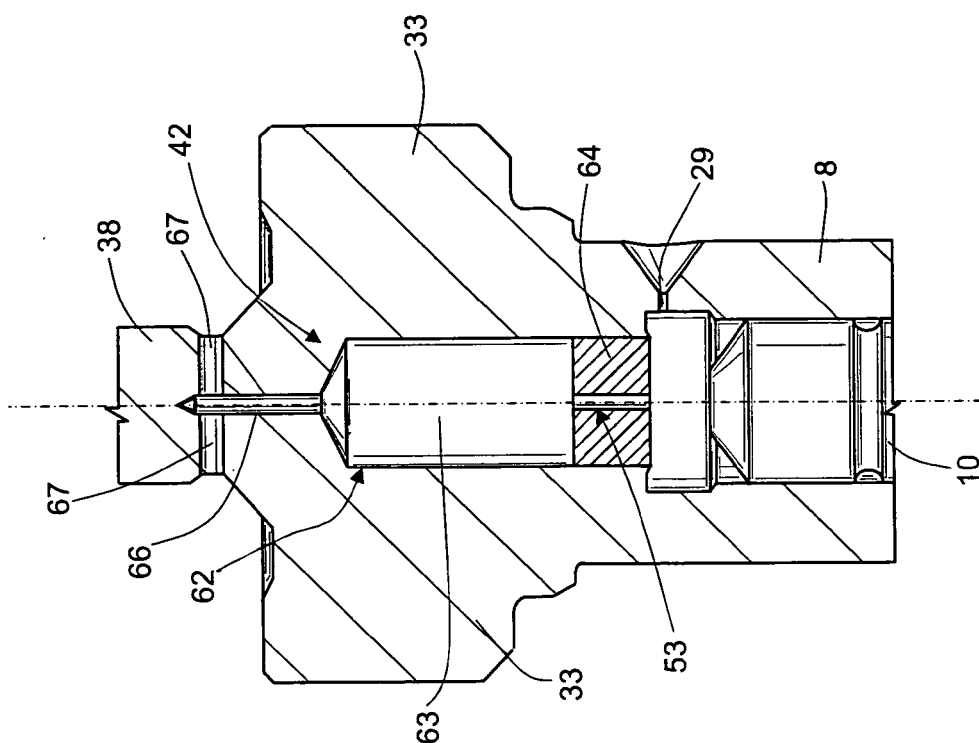


Fig. 6

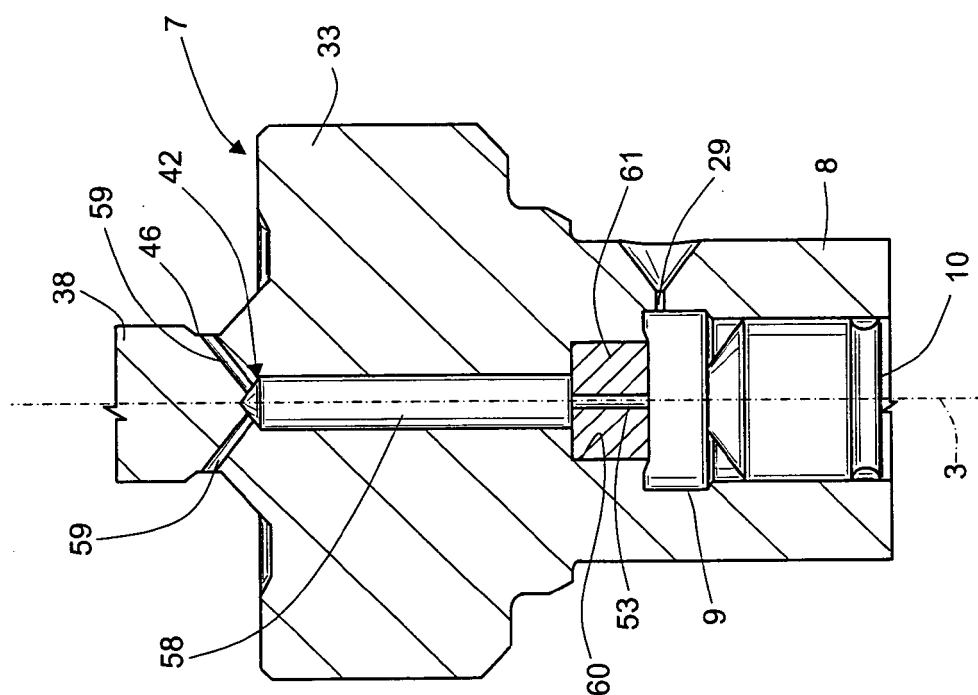


Fig. 5

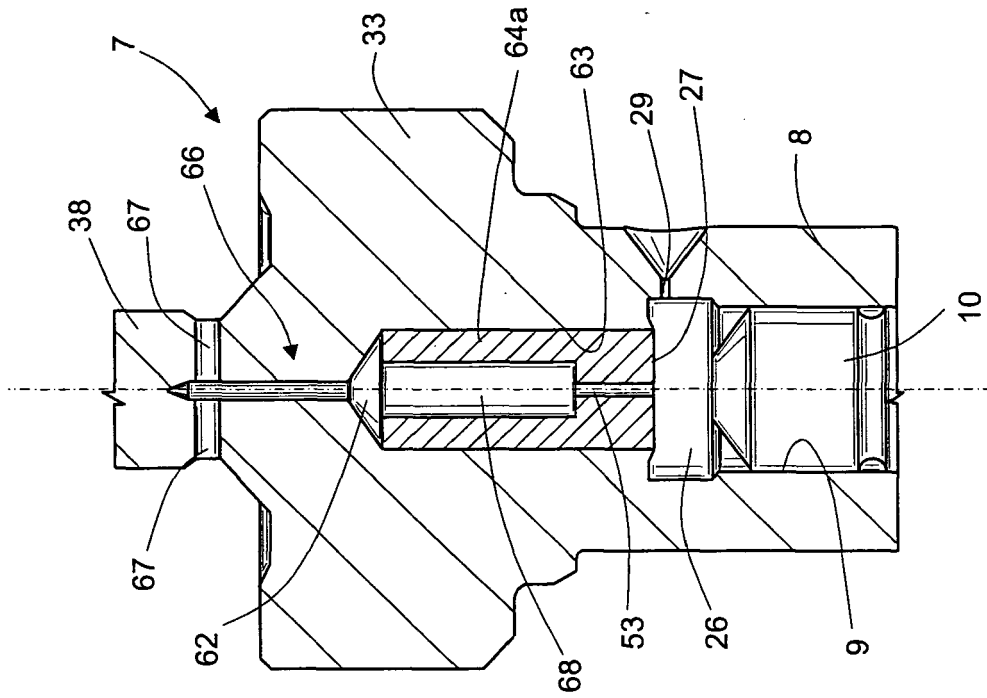


Fig. 8

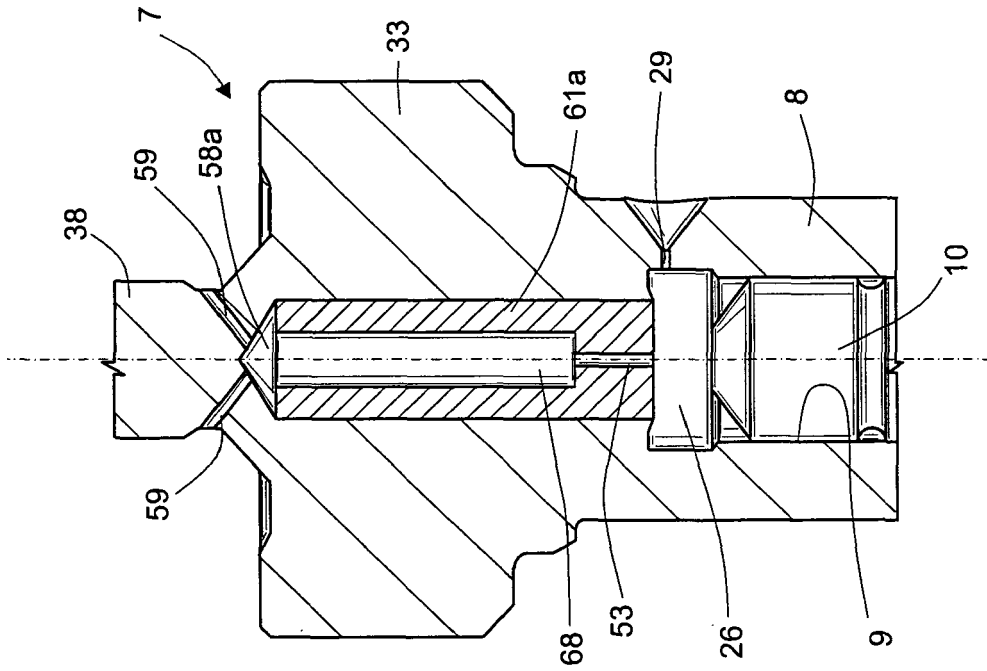


Fig. 7

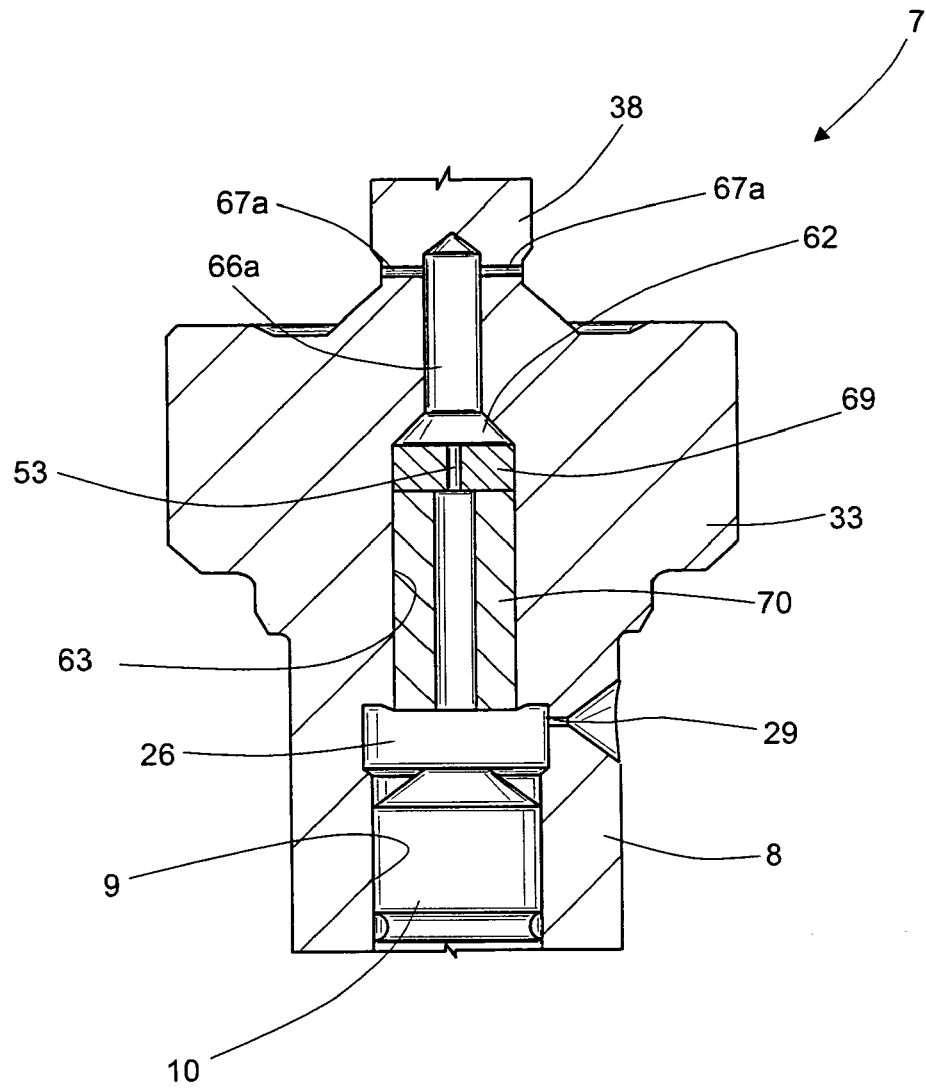


Fig.9

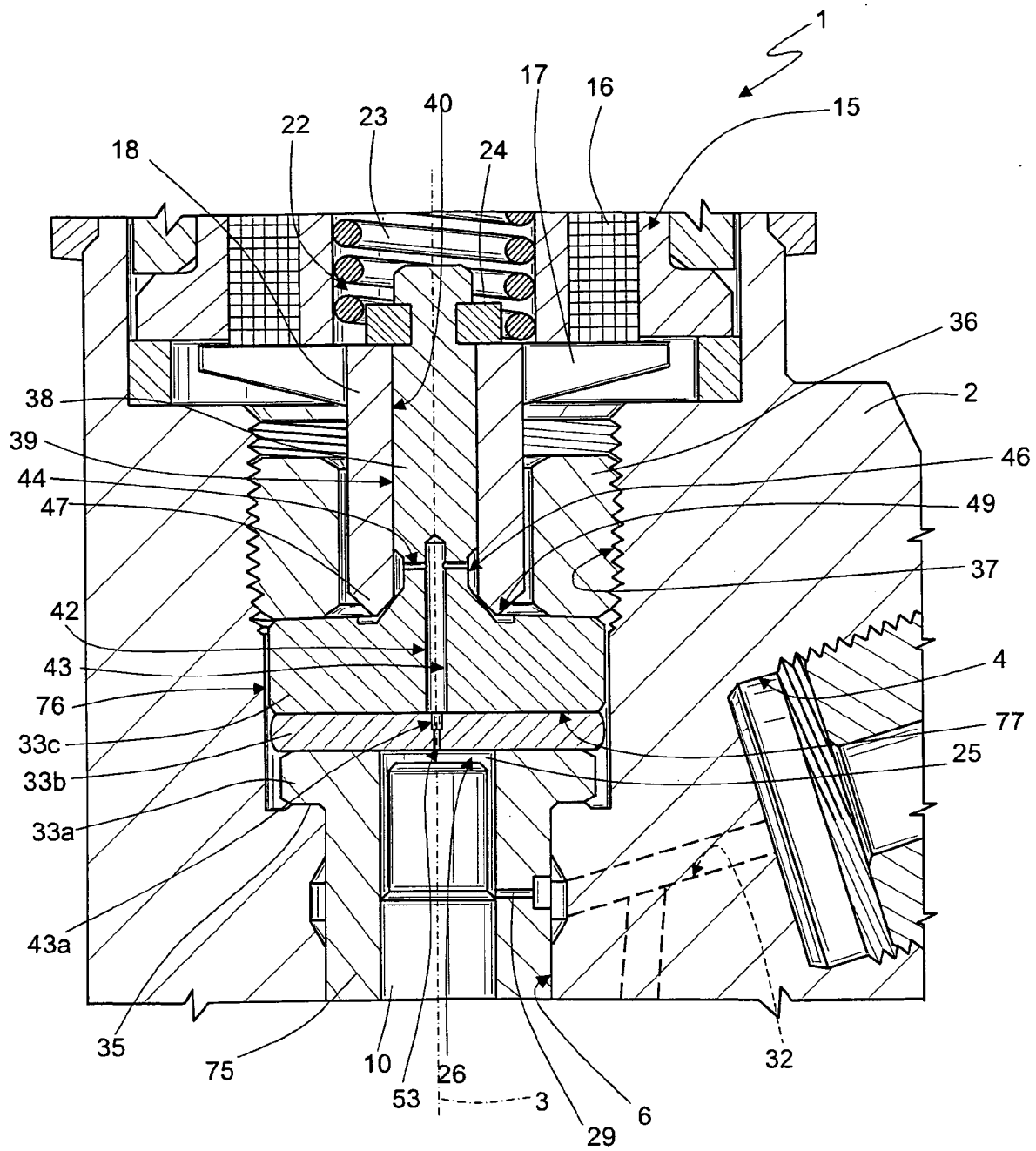


Fig.10

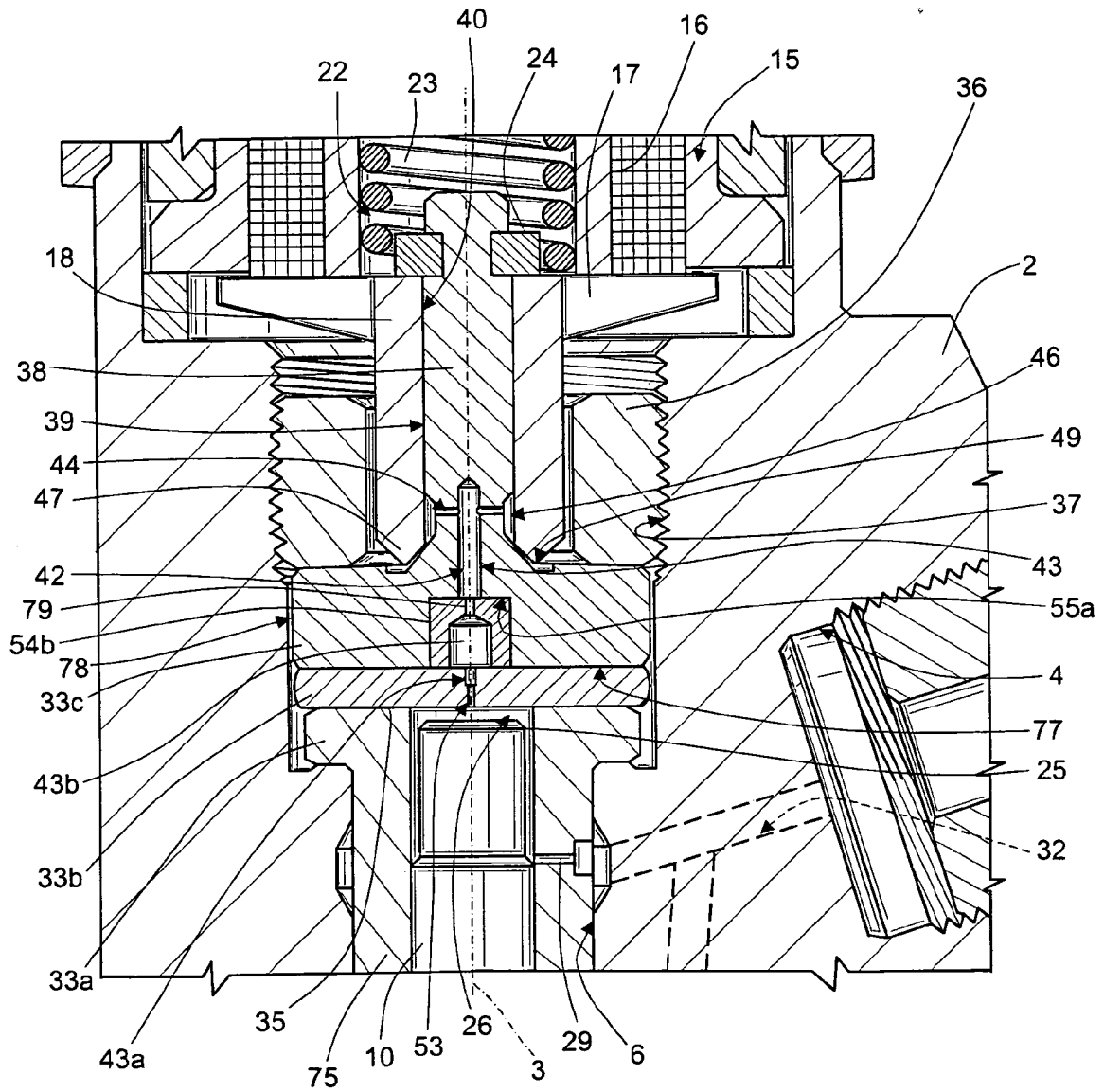
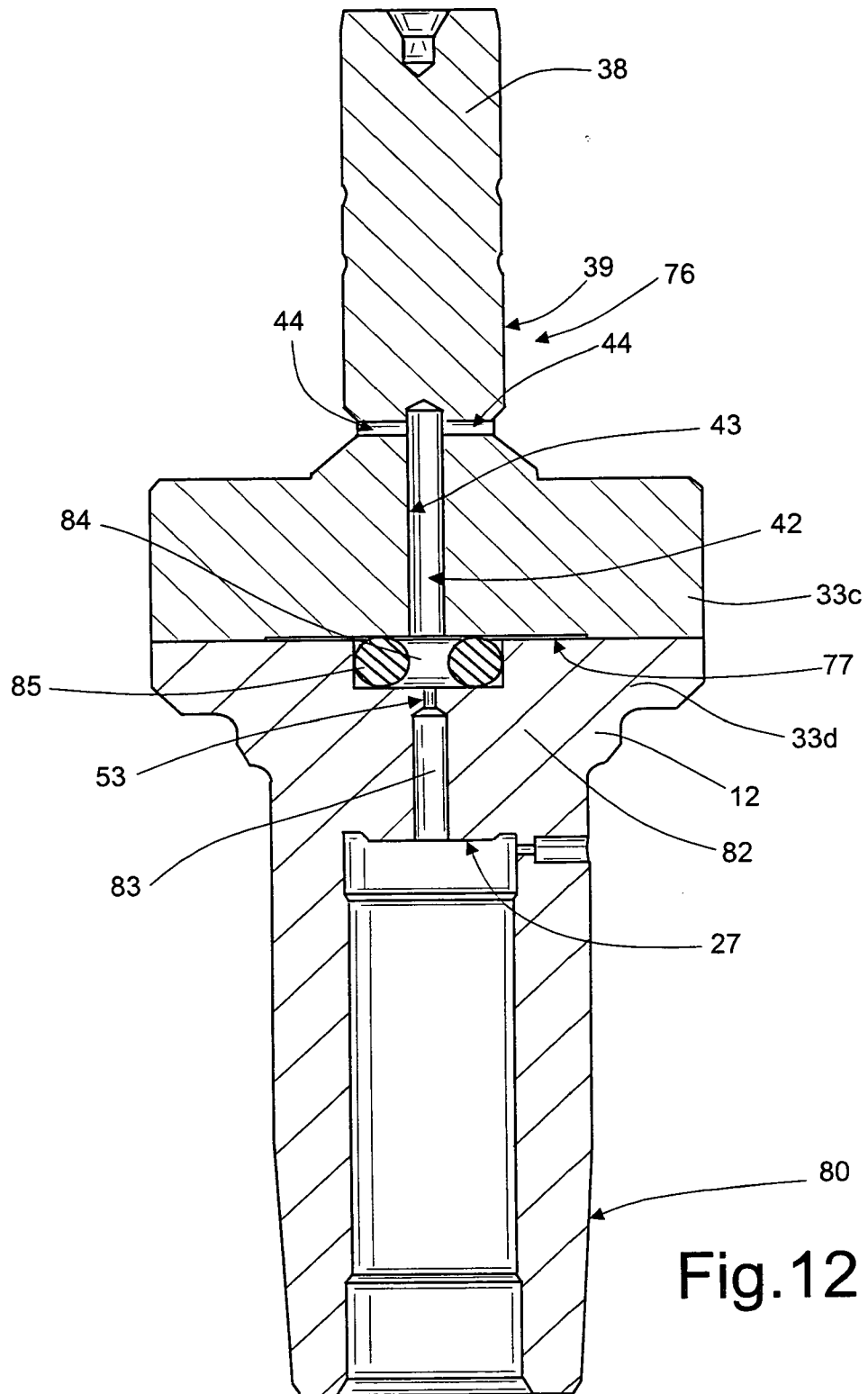
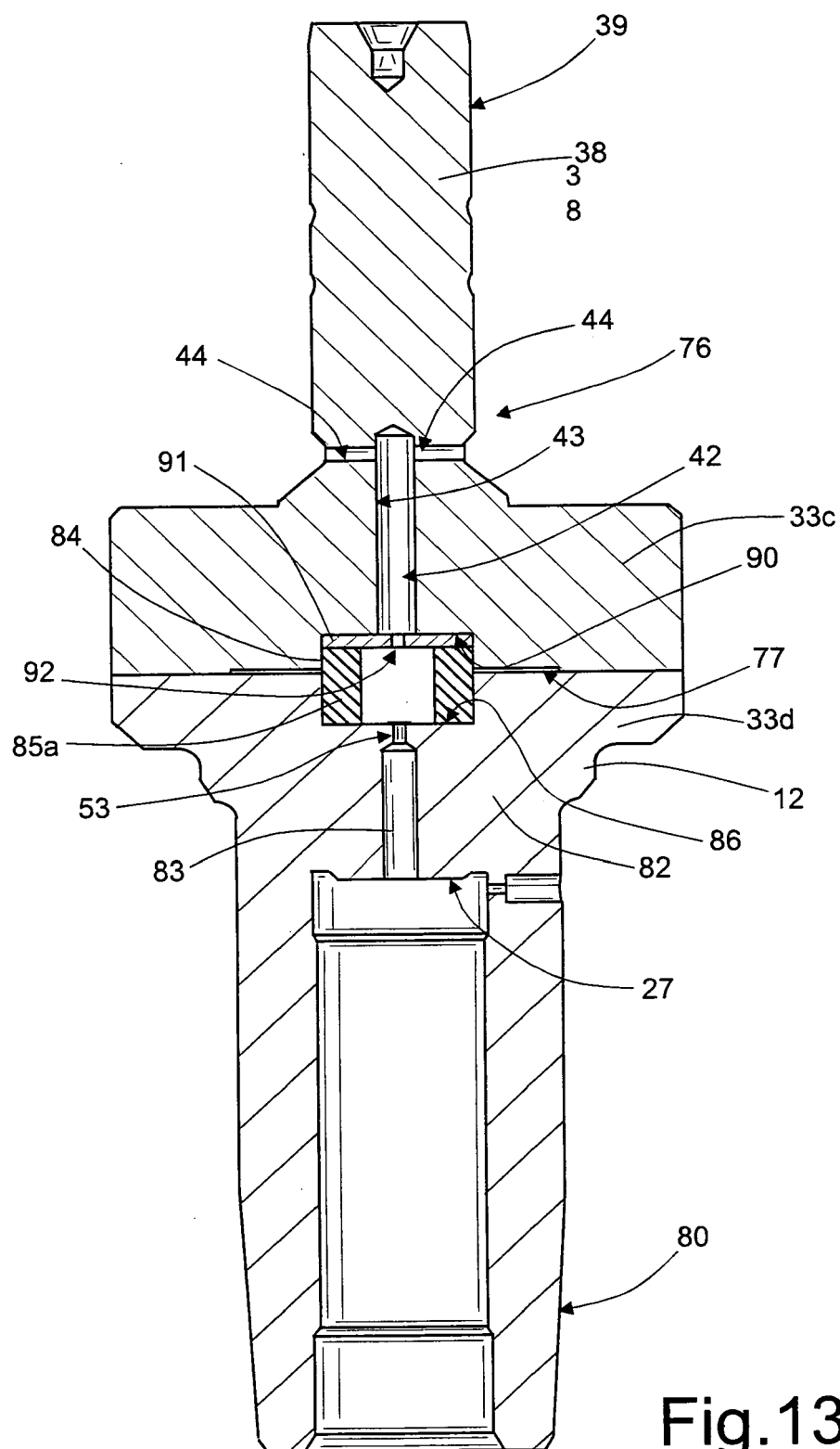


Fig.11





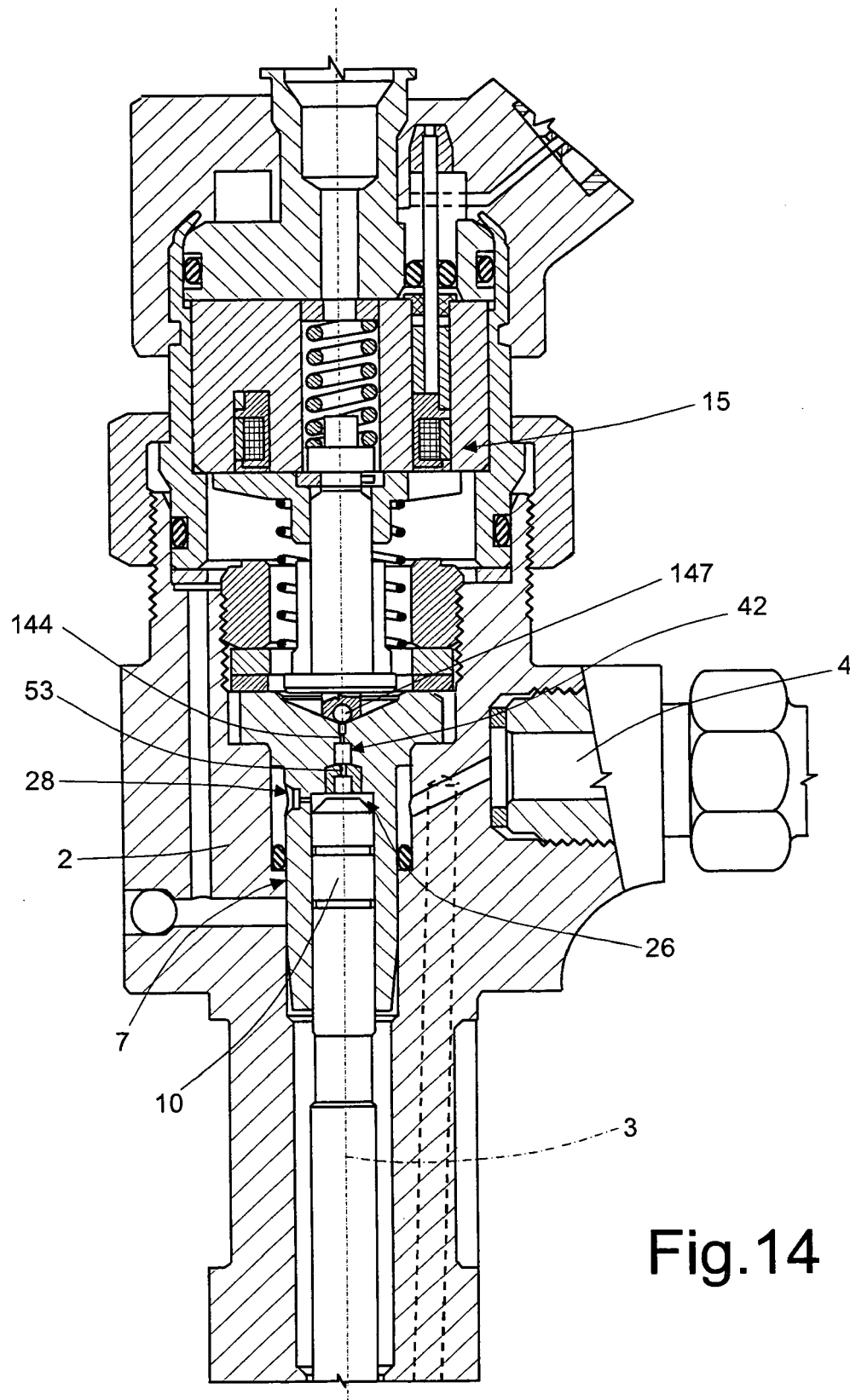


Fig.14

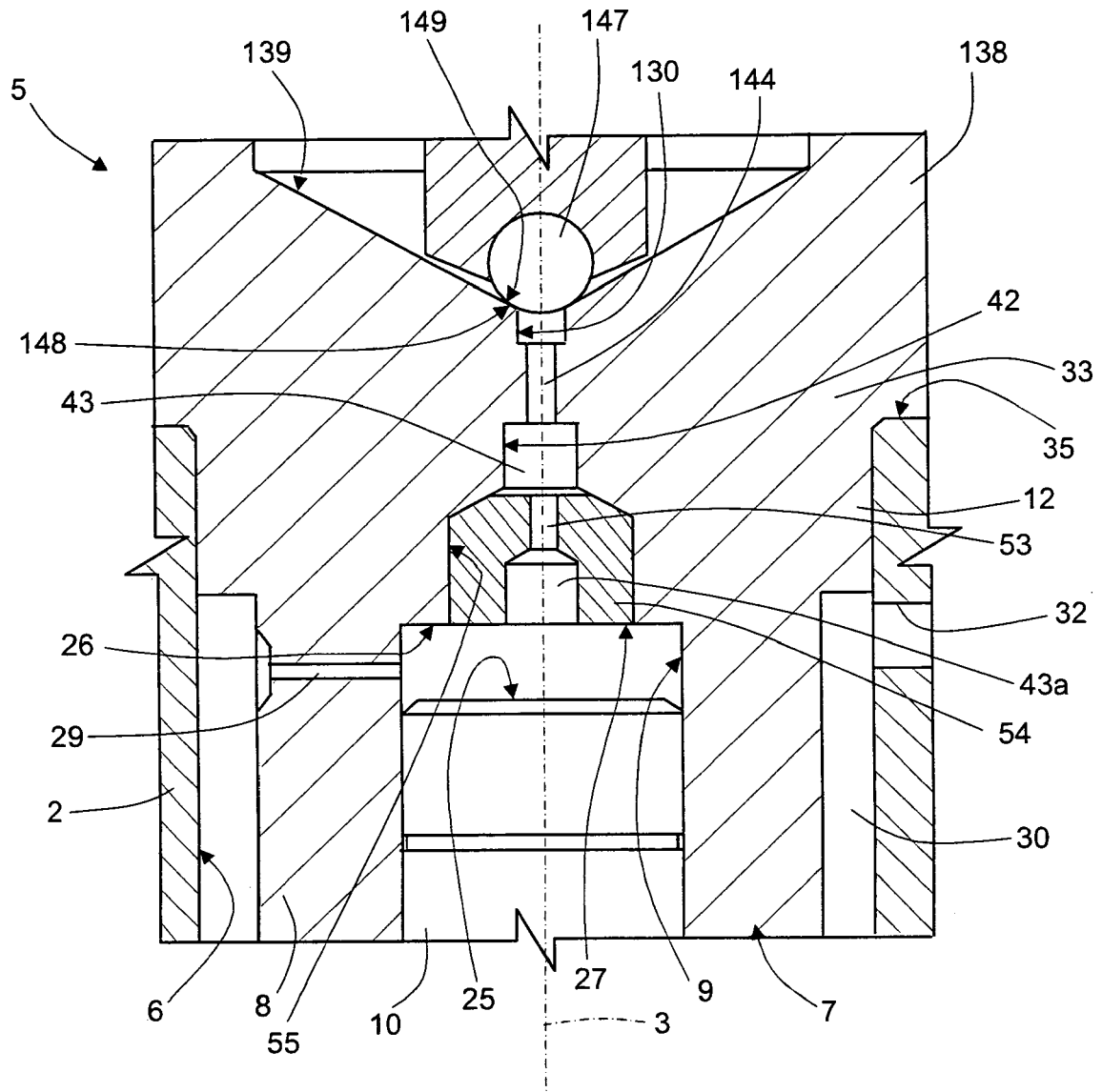


Fig.15

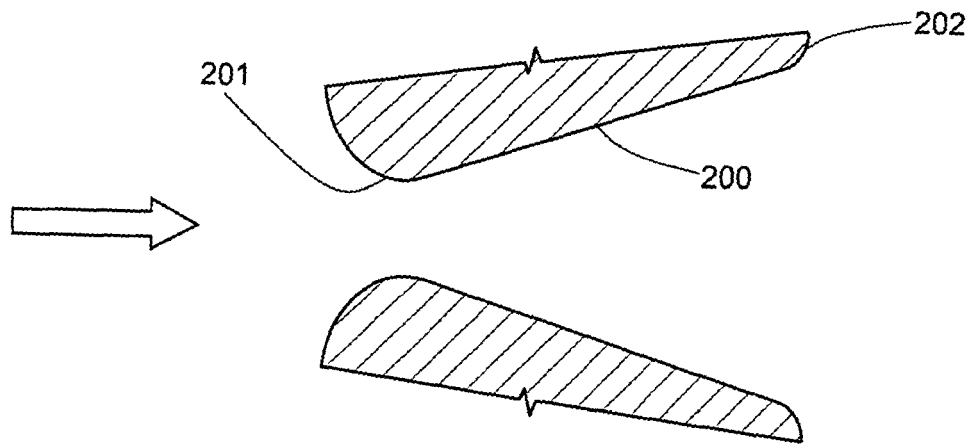


Fig.16

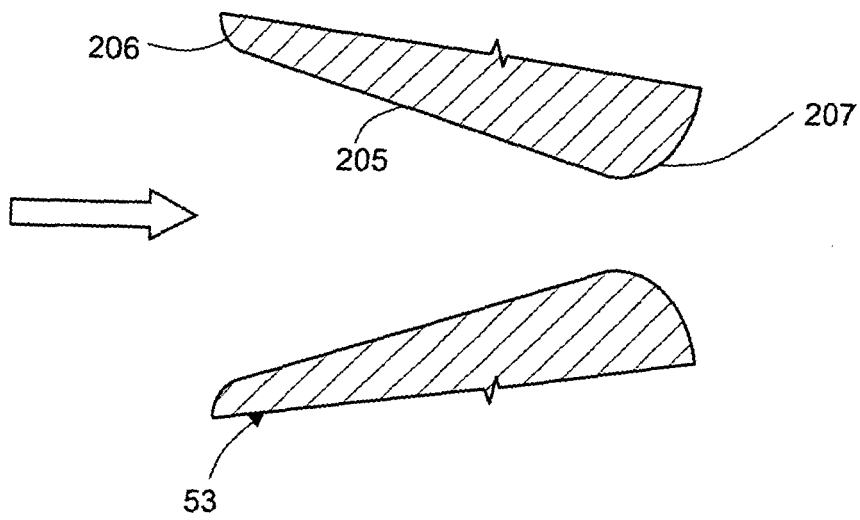


Fig.17



EUROPEAN SEARCH REPORT

Application Number
EP 09 42 5297

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Place of search Munich		Date of completion of the search 5 February 2010	Examiner Etschmann, Georg
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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