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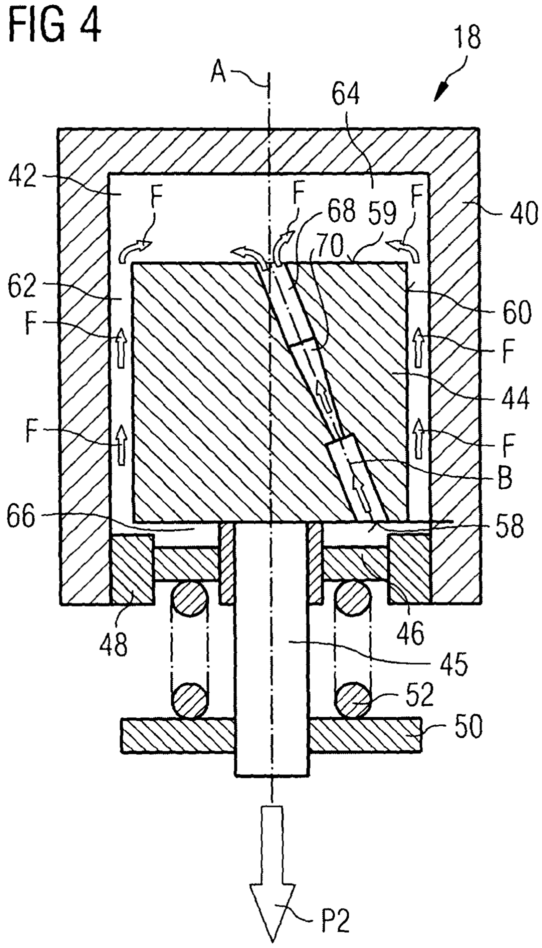
## (54) Thermal compensation arrangement and injection valve

(57) Thermal compensation arrangement (12) comprising a housing (14) including a first central longitudinal axis (A), the housing (14) comprising a cavity (22), a solid state actuator unit (16) being arranged in the cavity (22) and having a first axial end (16a) and a second axial end (16b), the second axial end (16b) acting as a drive side of the actuator unit (16), and a thermal compensation unit (18) being arranged in the cavity (22) and being coupled to the first axial end (16a) of the actuator unit (16). The thermal compensation unit (18) comprises a casing (40) being coupable to the housing (14) and comprising a recess (42), a piston (44) axially movable in the recess (42) and being coupable to the actuator unit (16), the piston (44) having a first front surface (58) facing the solid state actuator unit (16) and a second front surface (59) facing away from the first front surface (58), a gap (62) being formed in the recess (42) and extending in radial direction between the piston (44) and the casing (40), and a piston channel (68) being arranged in the piston (44) and extending from the first front surface (58) to the second front surface (59) of the piston (44) thereby enabling a fluid flow through the piston channel (68). The piston channel (68) comprises a converging section (70), which converges towards the first front surface (58) of the piston (44).

FIG 4



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## Description

**[0001]** The invention relates to a thermal compensation arrangement and an injection valve.

**[0002]** Injection valves are in wide spread use, in particular for internal combustion engines where they may be arranged in order to dose the fluid into an intake manifold of the internal combustion engine or directly into the combustion chamber of a cylinder of the internal combustion engine.

**[0003]** Injection valves for an internal combustion engine comprise actuator units. In order to inject fuel, the actuator unit is energized so that a fluid flow through the fluid outlet portion of the injection valve is enabled.

**[0004]** In order to enhance the combustion process in view of the creation of unwanted emissions, the respective injection valve may be suited to dose fluids under very high pressures. The pressures may be in case of a gasoline engine, for example in the range of up to 200 bar or in the case of diesel engines in the range of up to 2,000 bar. The injection of fluids under such high pressures has to be carried out very precisely.

**[0005]** The object of the invention is to create a thermal compensation arrangement and an injection valve that are simply to be manufactured and which facilitate a reliable and precise function of the injection valve.

**[0006]** These objects are achieved by the features of the independent claims. Advantageous embodiments of the invention are given in the sub-claims.

**[0007]** According to a first aspect the invention is distinguished by a thermal compensation arrangement comprising a housing including a first central longitudinal axis, the housing comprising a cavity, a solid state actuator unit being arranged in the cavity and having a first axial end and a second axial end, the second axial end acting as a drive side of the actuator unit and a thermal compensation unit being arranged in the cavity and being coupled to the first axial end of the actuator unit. The thermal compensation unit comprises a casing being coupable to the housing and comprising a recess, a piston axially movable in the recess and being coupable to the actuator unit, the piston having a first front surface facing the solid state actuator unit and a second front surface facing away from the first front surface, a gap being formed in the recess and extending in radial direction between the piston and the casing and a piston channel being arranged in the piston and extending from the first front surface to the second front surface of the piston thereby enabling a fluid flow through the piston channel. The piston channel comprises a converging section, which converges towards the first front surface of the piston.

**[0008]** This has the advantage that a reliable and precise function of the thermal compensation arrangement is enabled. Moreover, the thermal compensation arrangement may be easy to be manufactured. Due to the shape of the piston channel comprising the converging section, the thermal compensation arrangement has the advantage that a mechanical component to regulate a fluid flow, for example a flapper valve, is not required. Thereby, the assembly process line may be simplified. For example, a welding of a flapper valve to the piston may be obsolete. Thus, low production costs may be enabled. By leaving out a mechanical component such as a flapper valve, one source of faultiness of the thermal compensation arrangement may be left out due to a possible wearing of the mechanical component. Moreover, in the case of an axial movement of the piston in direction to the actuator unit a high fluid flow rate from a bottom recess section facing the first front surface to a recess section facing the second front surface is possible. Preferably, the recess of the casing is a cylindrical bore hole.

**[0009]** In an advantageous embodiment the piston channel comprises a second central longitudinal axis and is inclined in a direction of the second central longitudinal axis relative to the first central longitudinal axis.

**[0010]** This allows a good performance of the fluid flow from the bottom recess section facing the first front surface to the recess section facing the second front surface.

**[0011]** In a further advantageous embodiment the piston channel comprises a second central longitudinal axis, wherein the second central longitudinal axis extends at least partly parallel to the first central longitudinal axis.

**[0012]** This allows a good performance of the fluid flow from the bottom recess section facing the first front surface to the recess section facing the second front surface. Moreover, the piston channel may be easy to be manufactured.

**[0013]** According to a second aspect the invention is distinguished by an injection valve comprising the thermal compensation arrangement in accordance with the first aspect of the invention.

**[0014]** This has the advantage that a reliable and precise function of the injection valve is enabled.

**[0015]** Exemplary embodiments of the invention are explained in the following with the help of schematic drawings. These are as follows:

Figure 1, an injection valve in a longitudinal section view,

Figure 2, an enlarged view of a part of the injection valve according to figure 1 with a thermal compensation arrangement,

Figure 3, an enlarged view of a thermal compensation unit of the thermal compensation arrangement for the injection valve in a first operating condition, and

Figure 4, an enlarged view of the thermal compensation unit of the thermal compensation arrangement for the injection valve in a second operating condition.

**[0016]** Elements of the same design and function that appear in different illustrations are identified by the same reference characters.

**[0017]** An injection valve 10 (figure 1) that is used as a fuel injection valve for an internal combustion engine, comprises a thermal compensation arrangement 12, which comprises a housing 14, a solid state actuator unit 16 with a first axial end 16a and a second axial end 16b acting as a drive side of the actuator unit and a thermal compensation unit 18.

**[0018]** The housing 14 has a tubular shape. The actuator unit 16 is inserted into the housing 14 and comprises a piezo actuator, which changes its axial length depending on a control signal applied to it. The actuator unit 16 may, however, also comprise another type of actuator, which is known to person skilled in the art for that purpose. Such an actuator may be, for example, a solenoid.

**[0019]** The injection valve 10 comprises a valve body 20 with a first central longitudinal axis A. The housing 14 has a cavity 22 which is axially led through the valve body 20. On one of the free ends of the cavity 22, a fluid outlet portion 24 is formed which is closed or open depending on the axial position of a valve needle 26. The injection valve 10 further has a fluid inlet portion 28 which is arranged in the housing 14 and which is hydraulically coupled to the cavity 22 and a not shown fuel connector. The fuel connector is designed to be connected to a high pressure fuel chamber of an internal combustion engine, the fuel is stored under high pressure, for example, under the pressure above 200 bar.

**[0020]** The valve body 20 has a valve body spring rest 30 and the valve needle 26 comprises a valve needle spring rest 32, both spring rests 30, 32 supporting a main spring 34 being arranged between the valve body 20 and the valve needle 26.

**[0021]** The injection valve 10 is of an outward opening type. In an alternative embodiment, the injection valve 10 may be of an inward opening type. Between the valve needle 26 and the valve body 20 a bellow 36 is arranged which is sealingly coupling the valve body 20 with the valve needle 26. By this a fluid flow between the cavity 22 and a chamber 38 is prevented. Furthermore, the bellow 36 is formed and arranged in a way that the valve needle 26 is actuable by the actuator unit 16.

**[0022]** Figure 2 shows a longitudinal sectional view of the thermal compensation arrangement 12 arranged in the housing 14 and coupled to the actuator unit 16.

**[0023]** The thermal compensation unit 18 has a casing 40 of a cylindrical shape which has a recess 42, in which a piston 44 is arranged. The piston 44 is of a cylindrical shape and extends in the axial direction of the casing 40 and is coupled to the actuator unit 16 by a connecting bar 45. Preferably, the recess 42 of the casing 40 is a cylindrical bore hole.

**[0024]** The thermal compensation unit 18 comprises a sealing element 46 arranged in a piston rest 48 being part of the casing 40 and supporting the piston 44 in an initial state of the thermal compensation unit 18 as described below.

**[0025]** A spring retaining element 50 is mechanically coupled to the thermal compensation unit 18 by the connecting bar 45. A compensation spring 52 is arranged between the sealing element 46 of the thermal compensation unit 18 and a spring retaining element spring rest 54 of the spring retaining element 50 to support the compensation spring 52.

**[0026]** The thermal compensation arrangement 12 is rigidly coupled to the housing 14 of the injection valve 10 by a welding seam 56 extending circumferentially over a side surface 57 of the casing 40 of the thermal compensation arrangement 12.

**[0027]** Figure 3 and 4 show the thermal compensation unit 18 of the thermal compensation arrangement 12 in a longitudinal sectional and in large detailed view. The piston 44 of the thermal compensation arrangement 12 has a first front surface 58 facing the solid state actuator unit 16 and a second front surface 59 facing away from the first front surface 58 thereby facing away from the solid state actuator unit 16. The cylindrical shaped piston 44 furthermore has a lateral surface 60 extending between the first front surface 58 and the second front surface 59.

**[0028]** Between the lateral surface 60 of the piston 44 and the casing 40 of the thermal compensation unit 18, a gap 62 is formed being a part of the recess 42 of the casing 40. Between the second front surface 59 of the piston 44 and the casing 40 a recess section 64 is extending in axial direction. Between the first front surface 58 of the piston 44 and the sealing element 46 a bottom recess section 66 is arranged. The recess section 64 and the bottom recess section 66 are part of the recess 42 of the casing 40.

**[0029]** It will be described in the following that the recess section 64 and the bottom recess section 66 are changing their volumes in the case of an axial movement of the piston 44 in the casing 40.

**[0030]** A piston channel 68 is arranged in the piston 44 and extends from the first front surface 58 of the piston 44 to the second front surface 59 of the piston 44. The piston channel 68 allows a hydraulic coupling of the recess section 64 between the second front surface 59 of the piston 44 and the casing 40 and the bottom recess section 66 extending between the sealing element 46 and the first front surface 58 of the piston 44. The diameter of the gap 62 is much smaller than the diameter of the piston channel 68. In figure 3 and 4, the gap 62 is depicted with a much bigger diameter than it is compared to the dimensions of further depicted components in figure 3 and 4 to illustrate a fluid flow.

**[0031]** The piston channel 68 comprises a converging section 70, which converges towards the first front surface 58 of the piston 44. Preferably, the diminution of the diameter of the piston channel 68 along the converging section 70 ranges from 40% to 95% compared to the diameter of further parts of the piston channel 68. For example, the converging section 70 comprises an angle in the range of 3° to 15° compared to further parts of the piston channel 68.

**[0032]** The piston channel 68 comprises a second central longitudinal axis B and may be inclined in a direction of the second central longitudinal axis B relative to the first central longitudinal axis A. In a further exemplary embodiment, the second central longitudinal axis B extends at least partly parallel to the first central longitudinal axis A. This allows a good performance of the fluid flow from the bottom recess section 66 facing the first front surface 58 to the recess section 64 facing the second front surface 59.

**[0033]** In the following, the function of the injection valve 10 will be described:

**[0034]** The fuel is led from the fluid inlet portion 28 in the housing 14 towards the valve body 20 and then towards the fluid outlet portion 24.

**[0035]** The valve needle 26 prevents a fluid flow through the fluid outlet portion 24 in the valve body 20 in a closing position of the valve needle 26. Outside of the closing position of the valve needle 26, the valve needle 26 enables the fluid flow through the fluid outlet portion 24.

**[0036]** In the case that the actuator unit 16 has a piezo electric actuator, the piezo electric actuator may change its axial length if it gets energized. By changing its length the actuator unit 16 may exert a force on the valve needle 26. Due to the elasticity of the bellow 36 the valve needle 26 is able to move in axial direction out of the closing position. Outside the closing position of the valve needle 26 there is a gap between the valve body 20 and the valve needle 26 at an axial end of the injection valve 10 facing away from the actuator unit 16. The gap is forming a valve nozzle 72.

**[0037]** The main spring 34 can force the valve needle 26 via the valve needle spring rest 32 towards the actuator unit 16. In the case the actuator unit 16 is de-energized the actuator unit 16 shortens its length. Due to the elasticity of the bellow 36 the main spring 34 can force the valve needle 26 to move in axial direction in its closing position. It is depending on the force balance between the force on the valve needle 26 caused by the actuator unit 16 and the force on the valve needle 26 caused by the main spring 34 whether the valve needle 26 is in its closing position or not. If the valve needle 26 is not in its closing position a fuel flow is enabled through the valve nozzle 72.

**[0038]** The thermal compensation arrangement 12 serves two purposes: first the compensation of changes of the length of the actuator unit 16 due to thermal variations, which are comparably slow changes, and second providing stiffness against impulsive forces of the actuator unit 16 due to an energizing and a de-energizing of the actuator unit 16 to avoid an energy loss.

**[0039]** In the following the function of the thermal compensation arrangement 12 concerning the compensation of changes of the length of the actuator unit 16 due to thermal variations will be described in detail. If the temperature of the injection valve 10 increases during its operation, the injection valve 10, especially the housing 14, expands its axial length. In general, the housing 14, which is preferably made of stainless steel, expands more with the temperature than the actuator unit 16, which may comprise ceramic. The thermal compensation unit 18 is arranged in order to compensate that thermal expansion, especially of the housing 14 of the injection valve 10.

**[0040]** During the operation of the thermal compensation arrangement 12, the recess section 64 and the bottom recess section 66 are filled with fluid, preferably oil. The fluid in the recess section 64 and the bottom recess section 66 is pressurized by the compensation spring 52, which is arranged in such a way that the compensation spring 52 acts on the sealing element 46 and therewith the piston 44. There is the same pressure of the fluid in the recess section 64 and the bottom recess section 66 due to the piston channel 68 and the gap 62. The second front surface 59 of the piston 44 has a larger surface than the first front surface 58 of the piston 44 because of the connecting bar 45. The pressure acting on the larger surface of the second front surface 59 of the piston 44 causes a bigger force on the piston 44 then the pressure acting on the first front surface 58 of the piston 44. So, if there is no force acting on the thermal compensation unit 18 from the outside of the thermal compensation unit 18, the piston 44 is pressed towards the actuator unit 16. In that way, the connecting bar 45 never loses contact to the actuator unit 16.

**[0041]** If the thermal compensation unit 18 is arranged in the injection valve 10, it is arranged in such a way that the thermal compensation unit 18 is preloaded. So, the actuator unit 16 never loses contact to the connecting bar 45.

**[0042]** If the housing 14 reduces its axial length more with the changing temperature than the actuator unit 16, the force on the piston 44 is increasing. Simultaneously, the piston 44 in the recess 42 of the casing 40 is moved in axial direction in a first piston movement direction P1 (Fig. 3) away from the sealing element 46. The fluid in the recess 42 flows in a fluid flow direction F from the recess section 64 to the bottom recess section 66 via the piston channel 68 and the gap 62. When the piston 44 starts to move in the first piston direction P1, the piston 44 looses contact with the piston rest 48 allowing the fluid flowing from the gap 62 and the piston channel 68 to the bottom recess section 66 adjacent to the sealing element 46. During this the volume of the bottom recess section 66 is increasing while the volume of the recess section 64 is decreasing.

**[0043]** If the housing 14 expands more with the changing temperature than the actuator unit 16, the force on the piston 44 is decreasing. The fluid presses the piston 44 towards the actuator unit 16. Consequently, the piston 44 of the thermal compensation arrangement 12 is forced to move in a second piston movement direction P2 (Fig. 4) towards the sealing element 46. During this the volume of the recess section 64 is increasing and the volume of the bottom recess section 66 is decreasing. The fluid flows through the piston channel 68 into the recess section 64 between the second front surface 59 of the piston 44 and the casing 40. So the thermal expansion of the housing 14 can be compensated.

**[0044]** In the following the function of the thermal compensation arrangement 12 concerning the fast movements of the piston 44, for example due to energizing and de-energizing of the actuator unit 16, will be described in detail.

**[0045]** If the actuator unit 16 gets energized, it may expand only for few microseconds before it gets de-energized in a typical application for dosing fluid. This duration is too short for a substantive amount of the fluid to pass the gap 62 or the converging section 70 of the piston channel 68 in order to level out the pressure differences between the recess section 64 and the bottom recess section 66 substantially. Thus, only small movements are possible. In that duration, the piston 44 stays nearly in its position and the actuator unit 16 has a nearly solid base to act on so that the actuator unit 16 acts on the valve needle 26 in order to move the valve needle 26 out of its closing position.

**[0046]** In figure 3, the thermal compensation arrangement 12 is shown in an exemplary state. The shown state of the piston 44 is an ultimate state that is the lowest possible state of the piston 44 regarding the first longitudinal axis A in the illustration of figure 3. This means that the piston 44 is in contact with the piston rest 48 due to the spring forces of the compensation spring 52.

**[0047]** If the actuator unit 16 is energized and therefore changes its length to move the valve needle 26 out of the closing position simultaneously the piston 44 is subjected to an impulsive force in axial direction in the first piston movement direction P1 (Fig. 3) away from the sealing element 46. Due to the impulsive force, a pressure wave is caused in the recess section 64 between the second front surface 59 of the piston 44 and the casing 40 of the thermal compensation unit 18. As the converging section 70 of the piston channel 68 converges towards the first front surface 58 of the piston 44, the molecules of the fluid interact strongly, which prevents a sliding of the molecules of the fluid apart of each other, and a high viscous resistance is caused for the fluid flowing from the recess section 64 through the piston channel 68 to the bottom recess section 66. In addition, the comparatively small diameter of the gap 62 supports the high viscous resistance for the fluid flowing from the recess section 64 to the bottom recess section 66. Thus, a high damping coefficient is caused for the fluid flowing from the recess section 64 through the piston channel 68 or the gap 62 to the bottom recess section 66. Therefore, the piston 44 stays nearly in its position, in particular also in view of the impulsive character of the impulsive force which the piston 44 is subjected to, and the actuator unit 16 has a nearly solid base to act on.

**[0048]** If the actuator unit 16 is de-energized and consequently, the actuator unit 16 shortens its length to force the valve needle 26 to move in axial direction into its closing position, the piston 44 of the thermal compensation arrangement 12 is forced to move in a second piston movement direction P2 (Fig. 4) towards the sealing element 46. Due to the short duration of the impulsive force acting in the first piston movement direction P1 on the piston 44, the de-energizing mainly results in the compensation of the prior to this existing pressure difference between the fluid in the recess section 64 and the bottom recess section 66 and further only results in a comparatively small further pressure difference of opposite sign due to the very small change of position of the piston 44 during the short duration of the impulsive force. Thus, occurring forces return into their state as before energizing of the actuator unit 16 and the piston 44 returns into its position as it was before the actuator unit 16 was energized. As the converging section 70 of the piston channel 68 diverges towards the second front surface 59 of the piston 44, a lower viscous resistance is caused for the fluid flowing from the bottom recess section 66 through the piston channel 68 to the recess section 64 than flowing from the recess section 64 through the piston channel 68 to the bottom recess section 66. Therefore, a lower damping coefficient is caused for the fluid flowing from the bottom recess section 66 to the recess section 64 than from the recess section 64 to the bottom recess section 66 and a higher fluid flow rate is possible. Thus, a fluid flow is enabled such that the piston 44 returns into its position as it was before the actuator unit 16 was energized. Consequently, in view of the impulsive character of the impulsive force, which the piston 44 is subjected to, the piston 44 nearly stays in its position during an energizing and de-energizing of the actuator unit 16 such that the actuator unit 16 has a nearly solid base to act on.

**[0049]** The invention is not restricted by the explained embodiments. For example, the piston channel 68 and/or the converging section 70 of the piston channel 68 may comprise a different shape.

## Claims

**1.** Thermal compensation arrangement (12) comprising

- a housing (14) including a first central longitudinal axis (A), the housing (14) comprising a cavity (22),
- a solid state actuator unit (16) being arranged in the cavity (22) and having a first axial end (16a) and a second axial end (16b), the second axial end (16b) acting as a drive side of the actuator unit (16),
- a thermal compensation unit (18) being arranged in the cavity (22) and being coupled to the first axial end (16a) of the actuator unit (16), the thermal compensation unit (18) comprising
- a casing (40) being coupable to the housing

(14) and comprising a recess (42),
- a piston (44) axially movable in the recess (42) and being coupable to the actuator unit (16), the piston (44) having a first front surface (58) facing the solid state actuator unit (16) and a second front surface (59) facing away from the first front surface (58),
- a gap (62) being formed in the recess (42) and extending in radial direction between the piston (44) and the casing (40),
- a piston channel (68) being arranged in the piston (44) and extending from the first front surface (58) to the second front surface (59) of the piston (44) thereby enabling a fluid flow through the piston channel (68), wherein the piston channel (68) comprises a converging section (70), which converges towards the first front surface (58) of the piston (44).

**2.** Thermal compensation arrangement (12) in accordance with claim 1, with the piston channel (68) comprising a second central longitudinal axis (B) being inclined in a direction of the second central longitudinal axis (B) relative to the first central longitudinal axis (A).

**3.** Thermal compensation arrangement (12) in accordance with claim 1, with the piston channel (68) comprising a second central longitudinal axis (B), wherein the second central longitudinal axis (B) extends at least partly parallel to the first central longitudinal axis (A).

**4.** Injection valve (10) comprising the thermal compensation arrangement (12) in accordance with one of the preceding claims.

FIG 1

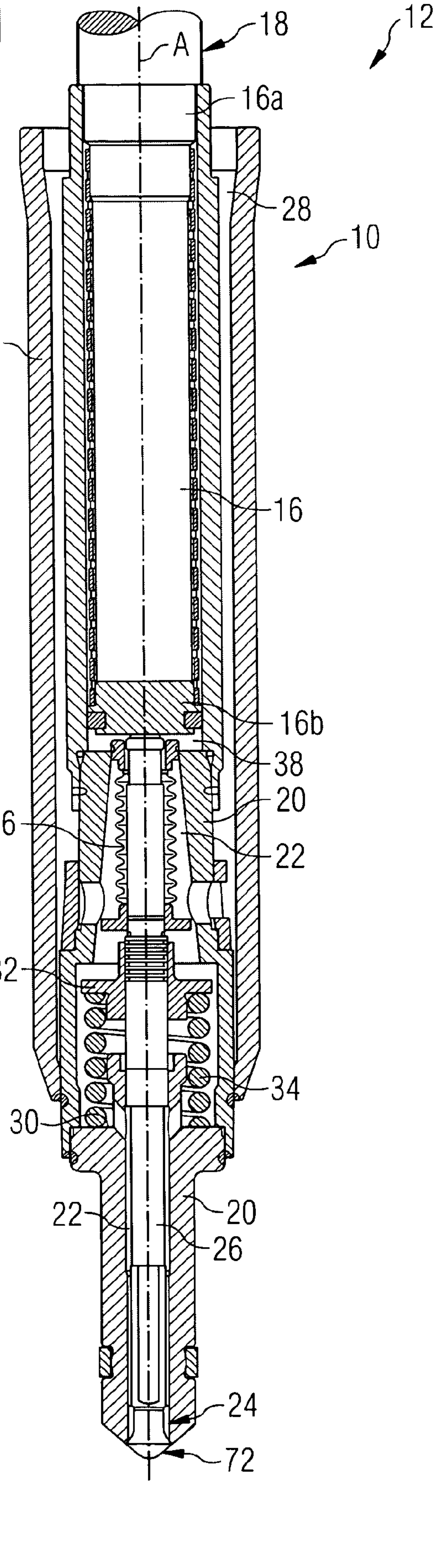


FIG 2

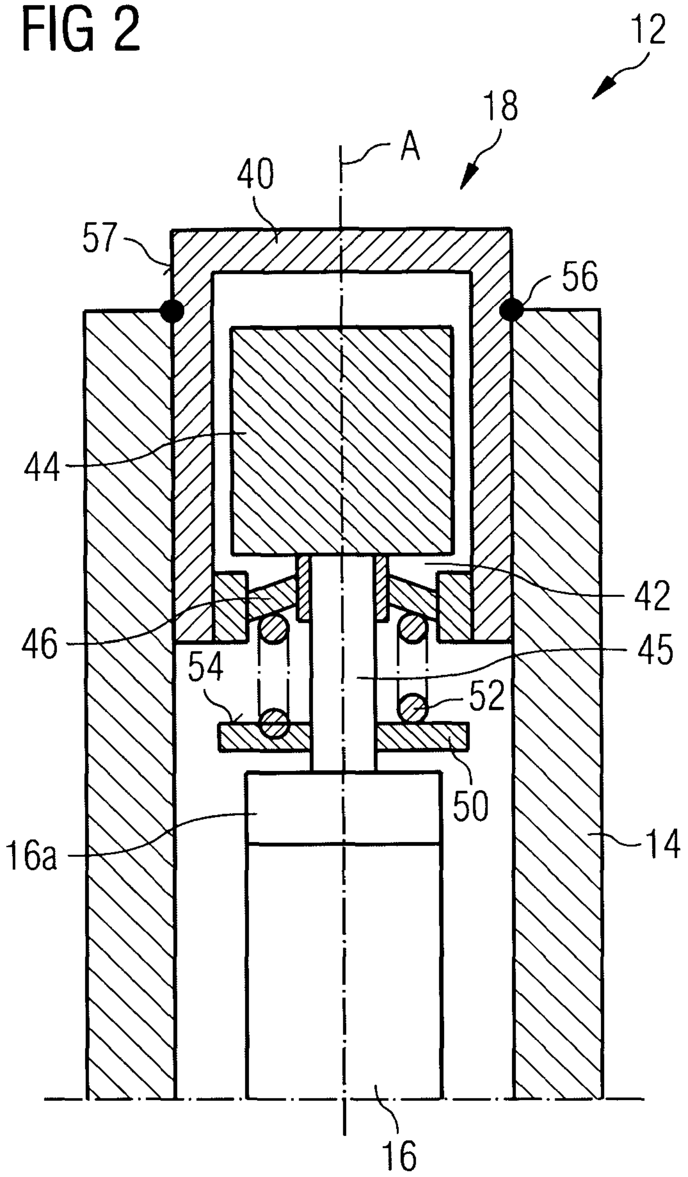


FIG 3

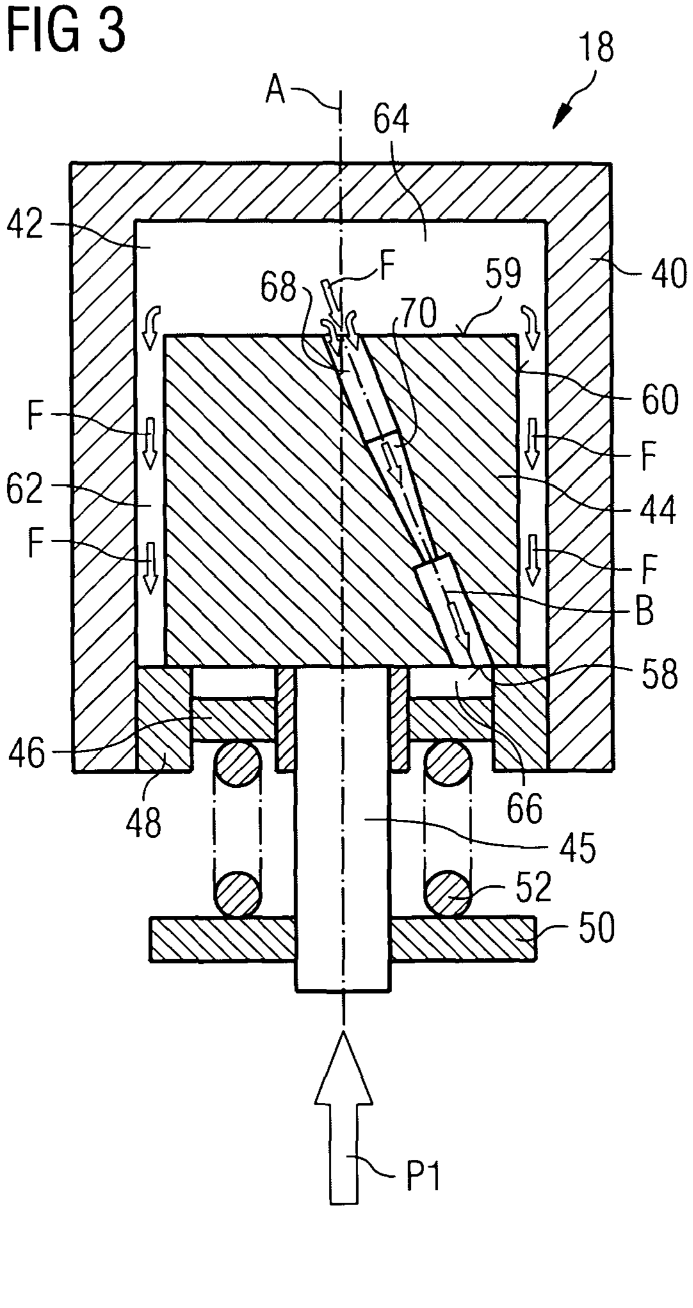
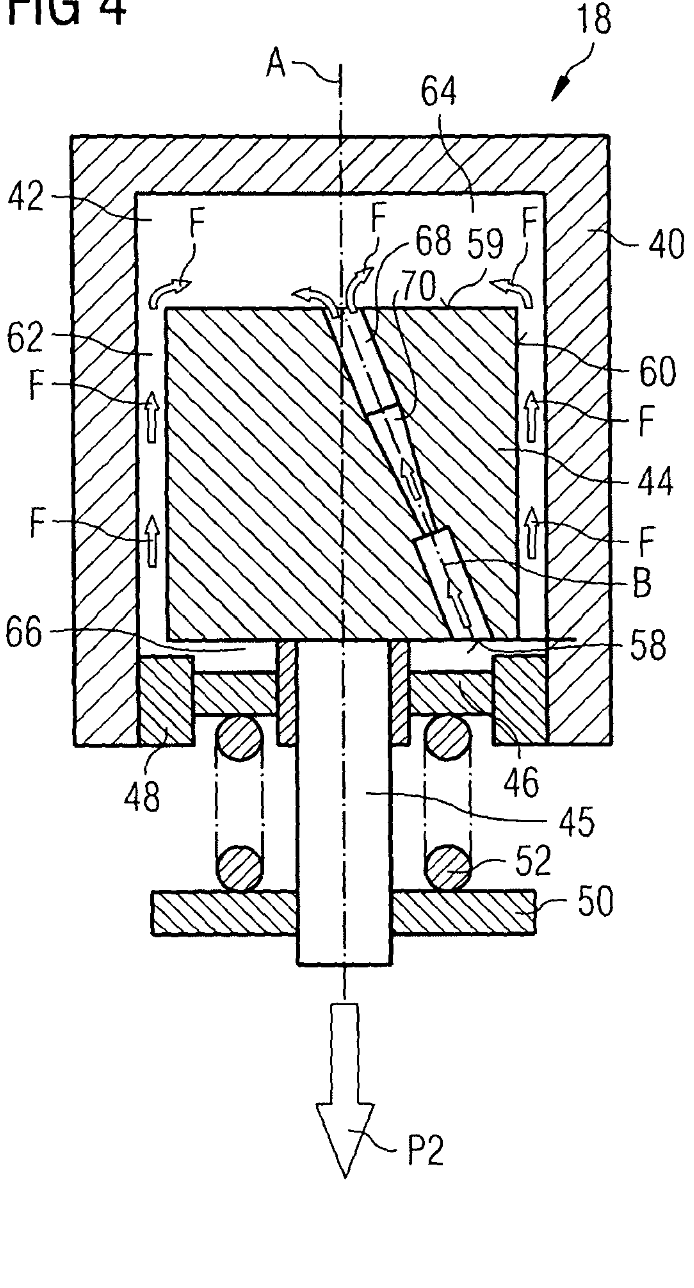


FIG 4



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# EUROPEAN SEARCH REPORT

Application Number
EP 08 01 2064

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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| | | | F02M |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 30 December 2008 | Landriscina, V |

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