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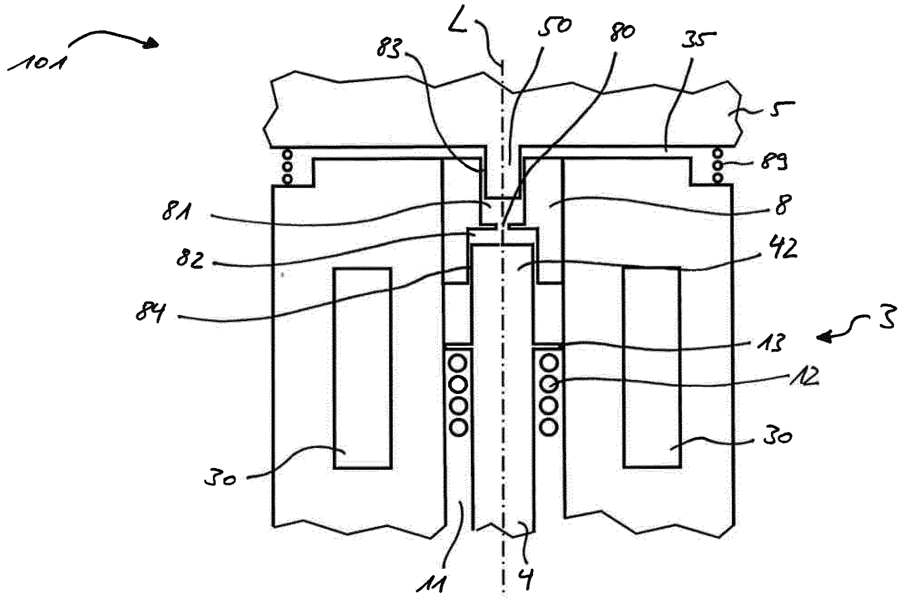
(54) **Injection valve**

(57) An injection valve (101, 102) is described, the injection valve (101, 102) comprising a valve assembly (1) and a fluid inlet tube (2) with a recess (20) connected to the valve assembly (1), the valve assembly (1) comprising a valve body (10) having a central longitudinal axis (L), the valve body (10) comprising a cavity (11) with a fluid outlet portion (14), a valve needle (4) arranged in the cavity (11) and movable along the central longitudinal axis (L) between a closing position and opening positions, the valve needle (4) preventing a fluid flow through the fluid outlet portion (14) in the closing position and releasing the fluid flow through the fluid outlet portion (14) in opening positions, an electro-magnetic actuator unit (3) being designed to actuate an armature (5) which is arranged in the cavity (11) and is axially moveable relative to the valve needle (20) along the longitudinal axis (L), wherein the armature (5) is hydraulically coupled to the valve needle (4) and is operable to move the valve needle (4) to an opening position by exerting a hydraulic force when being actuated by the electro-magnetic actuator unit (3).

FIG. 2



EP 2 863 044 A1

Description

[0001] The invention is related to an injection valve, in particular to a direct driven electro-magnetic outward opening injection valve.

[0002] Direct driven electro-magnetic outward opening injection valves have an injection nozzle that is opened in an outward direction by lifting a valve needle from a seat plate by the action of an electro-magnetic actuator. Such outward opening injectors can be very sensitive to parameter changes and therefore difficult to control in stable opening positions. For instance, they can be very sensitive to pressure deviations due to a high nozzle sealing diameter. Usually, an outward opening injector has a linear flow-lift characteristic with a high flow so that small deviations in the needle lift lead to high quantity deviations. Due to the high sensitivity, the injector does not reach a stable position at another level when the opening force differs but begins to oscillate, which leads to non-linearities in the so-called Ti-Map, which represents the dependency of the injection quantity from the opening time ("Ti") of the valve. Further, it is very difficult to control an outward opening injector with an extended ballistic current profile. By increasing not or too much the hold current value, the known outward opening injectors usually do not reach a stable position.

[0003] It is known to use a needle stopper, which limits the needle lift in order to hold the valve needle in a certain predetermined opening position. However, by using a needle stopper, non-linearities with an S-shape appear in the Ti-Map when the needle reaches the stopper due to the impact of the needle on the stopper. Further, due to the contact stiffness between the needle and the stopper, a small deformation of the stopper can be observed after the needle has contacted the stopper, which leads to oscillations of the needle lift causing ripples in the Ti-Map. In case of a high-flow nozzle with a linear flow-lift characteristic, small deviations in the stopper or needle position lead to high injection quantity deviations. Simulations have shown that, when using a rigid stopper, typical oscillations of the needle lift are on the order of +/- 2 μm, which can lead to a quantity deviation of the injection quantity of more than +/- 5%, so that the detection of the absolute lift value is necessary.

[0004] By using a flexible needle stopper, the needle displacement is defined by a damped oscillation until the needle rests in a stable position. The lower the stopper stiffness is the higher the oscillation amplitude is, so that decreasing the stopper stiffness helps to decrease the S-shaped non-linearities but leads to increased ripples for higher injection times.

[0005] An object to be solved is to provide an injection valve that avoids or at least reduces the above-mentioned problems.

[0006] This object is, inter alia, achieved with an injection valve according to independent claim 1. Further embodiments and configurations are subject matter of the dependent claims.

[0007] According to an embodiment, an injection valve comprises a fluid inlet tube with a recess. The fluid inlet tube is connected to a valve assembly, which comprises a valve body having a central longitudinal axis. The central longitudinal axis defines an "axial direction" so that a movement in an axial direction denotes a movement along the central longitudinal axis.

[0008] According to a further embodiment, the valve body comprises a cavity with a fluid outlet portion. A valve needle is arranged in the cavity of the valve body and is movable in the cavity along the central longitudinal axis between a closing position and opening positions, the valve needle preventing a fluid flow through the fluid outlet portion in a closing position and releasing the fluid flow through the fluid outlet portion in other positions which are the opening positions.

[0009] According to a further embodiment, the injection valve comprises an electro-magnetic actuator unit being designed to actuate an armature, which is arranged in the cavity and is axially moveable relative to the valve needle along the longitudinal axis. The armature is hydraulically coupled to the valve needle and can move the valve needle to an opening position by exerting a hydraulic force when being actuated by the electro-magnetic actuator unit. In particular, when being actuated by the electro-magnetic actuator unit, the armature moves the valve needle to an opening position completely by a hydraulic force. This means that the armature has no direct or indirect mechanical connection or contact to the valve needle for actuating the valve needle but acts on the valve needle only by pressing on a fluid, which, in turn, presses on the valve needle.

[0010] According to a further embodiment, the injection valve comprises a coupling member hydraulically coupling the armature to the valve needle. The coupling member is arranged between the armature and the valve needle and forms a first chamber with the armature and a second chamber with the valve needle, wherein the first and second chambers are filled with a fluid and the first chamber and the second chamber are hydraulically coupled by an orifice in the coupling member. In particular, the armature can comprise a pin, which forms a piston in the first chamber. An end portion of the valve needle distal from the fluid outlet portion can form a piston in the second chamber. When the armature is moved towards the valve needle, the fluid in the first chamber is pressed through the orifice in the coupling member into the second chamber, thereby exerting a pressure force on the valve needle so that the valve needle is moved in an axial direction to an opening position.

[0011] Simulations have shown that an injection valve as described herein, which in particular can be embodied as a direct driven electro-magnetic outward opening injection valve and which can be driven completely in a so-called ballistic mode, which means that during the complete opening time the valve needle is in motion and that no stopper is required, shows a linear Ti-map behavior. Thus, irregularities in the Ti-map, as described above, can be avoided.

[0012] Further exemplary embodiments are explained in the following with the aid of schematic drawings. In the Figures,

Figure 1	shows an injection valve in a longitudinal sectional view,
Figure 2	shows a detail view of a section of an injection valve,
Figures 3 to 6	show exemplary simulation results for the injection valve of Figure 2,
Figure 7	shows a detail view of a section of an injection valve.

[0013] In these figures, elements of the same design and/or function are identified by the same reference numerals.

[0014] Figure 1 shows an injection valve 100 according to an exemplary embodiment. In this exemplary embodiment, the injection valve 100 is embodied as an injection valve of outward opening type and may in particular be suitable for dosing fuel to an internal combustion engine. The embodiment of Figure 1 is shown in order to describe the general principle of a direct driven electro-magnetic outward opening injection valve.

[0015] The injection valve 100 comprises a valve assembly 1 and an inlet tube 2 hydraulically and mechanically connected to the valve assembly 1. The valve assembly 1 includes a valve body 10 with a central longitudinal axis L. The valve body 10 further comprises a cavity 11. The cavity 11 accommodates a valve needle 4 and an armature 5. A pin 50 is arranged along the longitudinal axis L and is fixedly coupled to the armature 5, for example by a press-fit connection and/or a welding connection. Alternatively, the pin 50 can be a part of the armature 5 so that the armature 5 and the pin 50 are a single piece. The pin 50 is partly in contact with an inner side of the valve body 10 and serves as guide for the armature 5. The valve needle 4 as well as the armature 5 together with the pin 50 are movable along an axial direction, i.e. in a direction running parallel to the central longitudinal axis L.

[0016] Due to openings 51 in the armature 5, the cavity 11 is hydraulically coupled to a recess 20 of the fluid inlet tube 2 and a fuel connector. The fuel connector is designed to be connected to a high pressure fuel chamber of an internal combustion engine, in which the fuel is stored under high pressure.

[0017] A main spring 12 is arranged in the cavity 11 between a ring element 13, which is fixedly coupled to the valve needle 4, and a step-like part of the valve body 10. The ring element 13 can also be a part of the valve needle 4. The main spring 12 is arranged and configured to act on the valve needle 4 to move the valve needle 4 along the axial direction into its closing position, i.e. in an upward direction in Figure 1.

[0018] On the free end of the valve body 10 facing away from the inlet tube 2, a fluid outlet portion 14 is formed, which is closed or opened depending on the axial position of the valve needle 4. Outside the closing position of the valve needle 4, there is a gap between the valve body 11 and the valve needle 4 at an axial end of the injection valve 100 facing away from the inlet tube 2, the gap forming a valve nozzle. Furthermore, the valve needle 4 has a groove 40 which is of an annular shape and which allows fluid to flow to the fluid outlet portion 14. The fluid outlet portion 14 is closed or opened depending on the axial position of the valve needle 4.

[0019] At an axial end of the valve needle 4 facing away from the fluid inlet tube 2, the valve needle 4 has a tip 41. Preferably, the tip 41 is conical. The tip 41 cooperates with the valve body 11 to prevent or enable the fluid flow through the fluid outlet portion 14.

[0020] The fluid is led from the fluid inlet tube 2 into the cavity 11, and, in particular, through the openings 51 of the armature 5 to the lower part of the valve needle 4, to be led on through the groove 40 to the fluid outlet portion 14 near the tip 41 of the valve needle 4. The valve needle 4 prevents a fluid flow through the fluid outlet portion 14 in the valve body 11 in a closing position of the valve needle 4.

[0021] The valve assembly 1 is provided with an electro-magnetic actuator unit 3. The electro-magnetic actuator unit 3 comprises a coil 30, which is preferably arranged inside a housing 31, which can be part of the valve body 10. The coil 30 can be electrically connected via a connector 32. Furthermore, the electro-magnetic actuator unit 3 comprises the armature 5. The coil 30 is arranged such as to interact with the armature 5, in particular to move the armature 5 along the axial direction into the direction of the fluid outlet portion 14. Furthermore, the injection valve 100 comprises a calibration spring 6 that is arranged on the side of the armature 5 which faces away from the fluid outlet portion 14 and which interacts with the armature 5.

[0022] Between the housing 31 and the armature 5, the electro-magnetic actuator unit 3 comprises a pole piece 33, which may also be part of the housing 31. In the closing position of the injection valve 100, there is a gap (not shown) between the armature 5 and the pole piece 33.

[0023] If the electro-magnetic actuator unit 3 with the coil 30 is sufficiently energized, the actuator unit 3 exerts an electro-magnetic force on the armature 5. The armature 5 is attracted by the electro-magnetic actuator unit 3 and moves in axial direction towards the fluid outlet portion 14, thereby decreasing the gap between the armature 5 and the pole piece 33. The armature 5 takes along the pin 50, which pushes against an end portion 42 of the valve needle 4 distal from the fluid outlet, portion 14. Due to the mechanical contact between the pin 51 and the end portion 42 of the valve needle 4 the armature 5 and the pin 51 cooperate with the valve needle 4 such that at least part of the lift generated by the coil 30 with respect to the armature 5 is transferred to the valve needle 4, thereby moving the valve needle 5 in an opening position.

[0024] In the case that the actuator unit 3 is de-energized, the main spring 12 can force the valve needle 4 to move along the axial direction into its closing position. It depends on the force balance between the force exerted on the valve needle 4 by the actuator unit 3 and the force exerted on the valve needle 4 by the main spring 12 whether the valve needle 4 moves into its closing position or not. In the case that the valve needle 4 moves into its closing position, the pin 51 and thus the armature 5 may decouple from the valve needle 4 due to their inertia.

[0025] As explained above in the general part, a direct driven outward opening injection valve that uses a mechanical contact between the armature 5 and the valve needle 4, as shown in Figure 1, is very sensitive on parameter changes and difficult to control in stable positions.

[0026] Figure 2 shows a partial view of an injection valve 101 that allows reducing or even avoiding such problems.

[0027] Similar to the injection valve 100, the injection valve 101 is also a direct driven electro-magnetic outward opening injection valve. Except for the differences explained in the following, the injection valve 101 can have the same or similar elements as explained in connection with the injection valve 100, even though not all elements of the injection valve 100 are shown and explained in connection with Figure 2. Consequently, references numbers, which are referred to in the following but not shown in Figure 2, refer to the description of Figure 1.

[0028] As already explained in connection with the injection valve 100, also the injection valve 101 comprises a valve assembly 1 and a fluid inlet tube 2 with a recess 20, the valve assembly 1 and the fluid tube 2 being connected to each other. The valve assembly 1 comprises a valve body 10 with a central longitudinal axis L, wherein the valve body 10 comprises a cavity 11 with a fluid outlet portion 14. A valve needle 4 is arranged in the cavity 11 and movable along the central longitudinal axis L between a closing position and opening positions, so that the valve needle 4 can prevent a fluid flow through the fluid outlet portion 14 in the closing position and release the fluid flow through the fluid outlet portion 14 in opening positions.

[0029] The injection valve 101 further comprises an electro-magnetic actuator unit 3 with an electro-magnetic coil 30 being designed to actuate an armature 5, which is arranged in the cavity 11. The armature 5, which may comprise a pin 50, is axially moveable relative to the valve needle 4 along the longitudinal axis L.

[0030] In contrast to the armature 5 being mechanically coupled to the valve needle 4 as shown in Figure 1, the armature 5 of the injection valve 101 is hydraulically coupled to the valve needle 4 and moves the valve needle 4 to an opening position by exerting a hydraulic force when being actuated by the electro-magnetic actuator unit 3.

[0031] In particular, the armature 5 is hydraulically coupled to the valve needle 4 by a coupling member 8 arranged between the armature 5 and the valve needle 4. The coupling member 8, which is arranged in the cavity 11, may be press-fitted into the valve body 10 or otherwise attached to the valve body 10. The coupling member 8 may even be a part of the valve body 10. The coupling member 8 forms a first chamber 81 with the armature 5. In particular, the pin 50 of the armature 5 can form a piston in the first chamber 81. The coupling member 8 further forms a second chamber 82 with the valve needle 4. In particular, the end portion 42 of the valve needle 4 distal from the fluid outlet portion 14 may form a piston in the second chamber 82. The first chamber 81 and the second chamber 82 are hydraulically coupled by an orifice 80 in the coupling member 8, which forms a constriction between the chambers 81, 82.

[0032] The first and second chamber 81, 82 are filled with a fluid which in the shown embodiment is the fluid to be injected by the injections valve 101 and which may be for example fuel. The first and second chamber 81, 82 are filled with the fluid through gaps 83, 84 which are between the coupling member 8 and the armature 5 and between the coupling member 8 and the valve needle 4, respectively, and which connect the chambers 81, 82 to the cavity 11. Preferably, the gaps 83, 84 are as small as possible to avoid too much leakage but are large enough so that fluid can stream into the chambers 81, 82.

[0033] By actuating the electro-magnetic actuator unit 3, the armature 5 moves towards the valve needle 4 and the pin 50 moves into the first chamber 81, thereby increasing the pressure inside the first chamber 81. Due to the connection between the first and second chamber 81, 82 by means of the orifice 80, also the pressure in the second chamber 82 increases. Caused by this pressure increase, the force on the valve needle 4 increases in the opening direction so that the hydraulic force exerted by the armature 5 on the valve needle 4 moves the valve needle 4 in an opening position.

[0034] The injection valve 101 further comprises a spring 89, which is designed and such arranged in the valve body 11 to act on the armature 5 to move the armature 5 away from the valve needle 4 and the electro-magnetic actuator unit 3. In particular it is operable to move the armature 5 axially away from the pole piece 33. In particular, the spring 89 is configured and such arranged in the valve body 11 to increase the gap 35 between the armature 5 and the electro-magnetic actuator unit 3 when the actuator unit 3 is not operated. The injection valve 101 can furthermore comprise a stopping member (not shown) for stopping the armature 5 in a closing position to which the armature 5 is pressed by the spring 89. As explained in connection with Figure 1, a main spring 12 is designed and such arranged in the cavity 11 to act on the valve needle 4 to move the valve needle 4 along the longitudinal axis L into its closing position and/or to retain the valve needle 4 in its closing position when the actuator unit 3 is not operated.

[0035] While actuating the electro-magnetic actuator unit 3, the orifice 80 acts as a damping orifice so that pressure oscillations inside the chambers 81, 82 and therefore also an oscillating needle displacement are avoided. In this or in other embodiments, a diameter of the first chamber 81 may be at least five times as large, preferably at least ten times as large, particularly preferably at least 15 times as large as a diameter of the orifice 80.

[0036] Due to a proper ratio between the piston areas in the first and second chamber 81, 82 the magnetic force which is needed to open the injection valve 101 is much lower compared to the magnetic force needed in the injection valve 100 shown in Figure 1. For example, the diameter of the pin 50 in the first chamber may have a value of 3/4 or less, preferably of 2/3 or less of the diameter of the end portion 42 of the valve needle 4 in this or in other embodiments. The hydraulic coupling between the armature 5 and the valve needle 4 may have a mechanical advantage of 2 or more, preferably of 3 or more. The mechanical advantage is in particular the ratio of the distance travelled by the armature 5 to the distance travelled by the valve needle 4.

[0037] As a consequence, the initial gap 35 between the armature 5 and the pole piece 33 can be increased in the injection valve 101 compared to the injection valve 100, since the magnetic force is proportional to the reciprocal square of the size of the gap 35. For example, the size of the initial gap 35 may be 200 μm or larger, preferably 300 μm or larger. In other words, the closer the armature comes to the pole piece, the higher the magnetic force becomes, which results in a higher acceleration in the opening direction and which can lead to a contact between the armature 5 and the pole piece 33 in the injection valve 100. As a consequence, the air gap 35 in the injection valve 101 is large enough so that the influence of the gap 35 on the magnetic force is as small as possible and so that the injection valve 101 can be driven completely in a ballistic mode, which means that during the complete opening time the valve needle 4 and in particular also the armature 5 is/are in motion and that no stopper is required. Preferably, the armature 5 is always spaced apart from the pole piece 33 throughout the operation of the injection valve 101.

[0038] In order to demonstrate the capability of the injection valve 101, simulations are shown in connection with Figures 3 to 6. For the simulations, a linear flow-lift characteristic has been assumed and the following parameters have been taken into account:

- initial (maximal) gap 35: 300 μm
- minimal gap 35: 100 μm
- initial volume of first chamber 81: approx. 3 mm^3
- initial volume of second chamber 82: approx. 5 mm^3
- diameter of orifice 80: 0.1 mm
- force of spring 89: 3 N
- force of main spring 12: 160 N
- piston diameter in first chamber 81: 1.8 mm
- piston diameter in second chamber 82: 3 mm
- clearance of gaps 83, 84: 3 μm
- length of gaps 83, 84: approx. 10 mm

[0039] These parameters of the injection valve 101 are suitable also for other embodiments of the injection valve either alone or in combination.

[0040] Figure 3 shows the Ti-map for the injection valve 101 for a fluid pressure of 100 bar. Due to the absence of a stopper and the possibility to completely drive the injection valve 101 in a ballistic mode, the Ti-map shows a linear behavior of the injection quantity IQ depending on the injection time Ti without ripples or other irregularities.

[0041] Figure 4 shows the needle lift NL during a time T for injection times Ti between 0.22 ms and 2.5 ms, whereas in Figure 5 the corresponding armature lift AL is shown. As can be seen in Figure 4, the maximum needle lift is approximately 60 to 70 μm. From both Figures 4 and 5, it becomes apparent that the valve needle 4 and the armature 5 are completely driven in a ballistic mode.

[0042] Figure 6 shows the Ti-map for various pressures between 5 bar and 100 bar. As can be seen, independently from the fluid pressure the Ti-map always shows a linear behavior.

[0043] According to the simulations, at a fluid pressure of 100 bar a force of approximately 56 N is needed at the valve needle 4 in order to open the valve needle 4. The required pressure increase in the chambers 81, 82 is approximately 80 bar, which leads to a required magnetic force for opening of approximately 20 N. However, due to the strong dependency the opening force on the pressure, the peak and hold current of the coil 30 has to be increased with decreasing pressure. For example, for a fluid pressure of 5 bar a force of approximately 158 N is needed at the valve needle 4 in order to open the valve needle 4, which leads to a required pressure increase in the chambers 81, 82 of approximately 220 bar.

[0044] The simulations have also revealed that the needle opening velocity at the first 10 μm needle lift is higher compared to the injector concept shown in Figure 1, whereas the needle opening velocity at higher lifts is lower than the velocity for the injector concept of Figure 1, since in the injection valve 101 the armature is accelerated alone, i.e. without the valve needle, by the coil until the pressure is reached in the chambers 81, 82 to open the needle.

[0045] Figure 7 shows a further embodiment for an injection valve 102, which, in contrast to the injection valve 101 of Figure 2, has the first chamber 81 and the second chamber 82 sealed from the cavity 11 by sealing members 85 between the coupling member 8 and the armature 5 and between the coupling member 8 and the valve needle 4. For example, the sealing members 85 can be O-rings.

[0046] Since the chambers 81, 82 are sealed form the cavity 11, the chambers 81, 82 have to be filled when the injection valve 102 is manufactured. However, constraints regarding the clearances of the gaps 83, 84 and regarding the length of the gaps 83, 84, which influence the functionality and stability of the injection valve 101 of Figure 2, can possibly be avoided by the embodiment shown in Figure 7.

[0047] As described above, it is possible to drive the injection valves 101, 102 only in ballistic mode, which requires a low magnetic force dependency on the lift or gap 35 between the armature 5 and the pole piece 33. Due to the high distance between the pole piece 33 and the armature 5, the absolute magnetic force value decreases. Nevertheless, the required high opening force can be achieved with the hydraulic leverage described above. As it is possible to drive the injection valve described herein only in ballistic mode but directly driven, without a stopper and with low magnetic force, an outward opening injection valve with an electro-magnetic actuator with a linear Ti-map is feasible.

Claims

1. Injection valve (101, 102), comprising
a valve assembly (1) and a fluid inlet tube (2) with a recess (20) connected to the valve assembly (1), the valve assembly (1) comprising a valve body (10) having a central longitudinal axis (L), the valve body (10) comprising a cavity (11) with a fluid outlet portion (14),
a valve needle (4) arranged in the cavity (11) and movable along the central longitudinal axis (L) between a closing position and opening positions, the valve needle (4) preventing a fluid flow through the fluid outlet portion (14) in the closing position and releasing the fluid flow through the fluid outlet portion (14) in opening positions,
an electro-magnetic actuator unit (3) being designed to actuate an armature (5) which is arranged in the cavity (11) and is axially moveable relative to the valve needle (4) along the longitudinal axis (L),
wherein the armature (5) is hydraulically coupled to the valve needle (4) and is operable to move the valve needle (4) to an opening position by exerting a hydraulic force when being actuated by the electro-magnetic actuator unit (3).

2. Injection valve (101, 102) according to claim 1, wherein the armature (5) is hydraulically coupled to the valve needle (4) by a coupling member (8) arranged between the armature (5) and the valve needle (4), wherein the coupling member (8) forms a first chamber (81) with the armature (5) and a second chamber (82) with the valve needle (4), the first chamber (81) and the second chamber (82) being hydraulically coupled by an orifice (80) in the coupling member (8).

3. Injection valve (101, 102) according to claim 2, wherein the armature (5) comprises a pin (50) which forms a piston in the first chamber (81) and wherein an end portion (42) of the valve needle (4) distal from the fluid outlet portion (14) forms a piston in the second chamber (82).

4. Injection valve (101, 102) according to claim 2 or 3, wherein the first chamber (81) and the second chamber (82) are connected to the cavity (11) by gaps (83, 84) between the coupling member (8) and the armature (5) and between the coupling member (8) and the valve needle (4).

5. Injection valve (101, 102) according to claim 2 or 3, wherein the first chamber (81) and the second chamber (82) are sealed from the cavity (11) by sealing members (85) between the coupling member (8) and the armature (5) and between the coupling member (8) and the valve needle (4).

6. Injection valve (101, 102) according to claim 5, wherein the sealing members (85) are O-rings.

7. Injection valve (101, 102) according to any of the preceding claims, wherein a spring (89) is configured and such arranged in the valve body (11) to act on the armature (5) to move the armature (5) away from the valve needle (4).

8. Injection valve (101, 102) according to claim 7, wherein the spring (89) is configured and such arranged in the valve body (11) to increase a gap (35) between the armature (5) and the electro-magnetic actuator unit (3).

9. Injection valve (101, 102) according to any of the preceding claims, wherein a main spring (12) is configured and such arranged in the cavity (11) to act on the valve needle (4) to move the valve needle (4) along the longitudinal axis (L) into its closing position and/or to retain the valve needle (4) in its closing position.

10. Injection valve (101, 102) according to any of the preceding claims, wherein the injection valve (101, 102) is a direct driven electro-magnetic outward opening injection valve.

FIG. 1

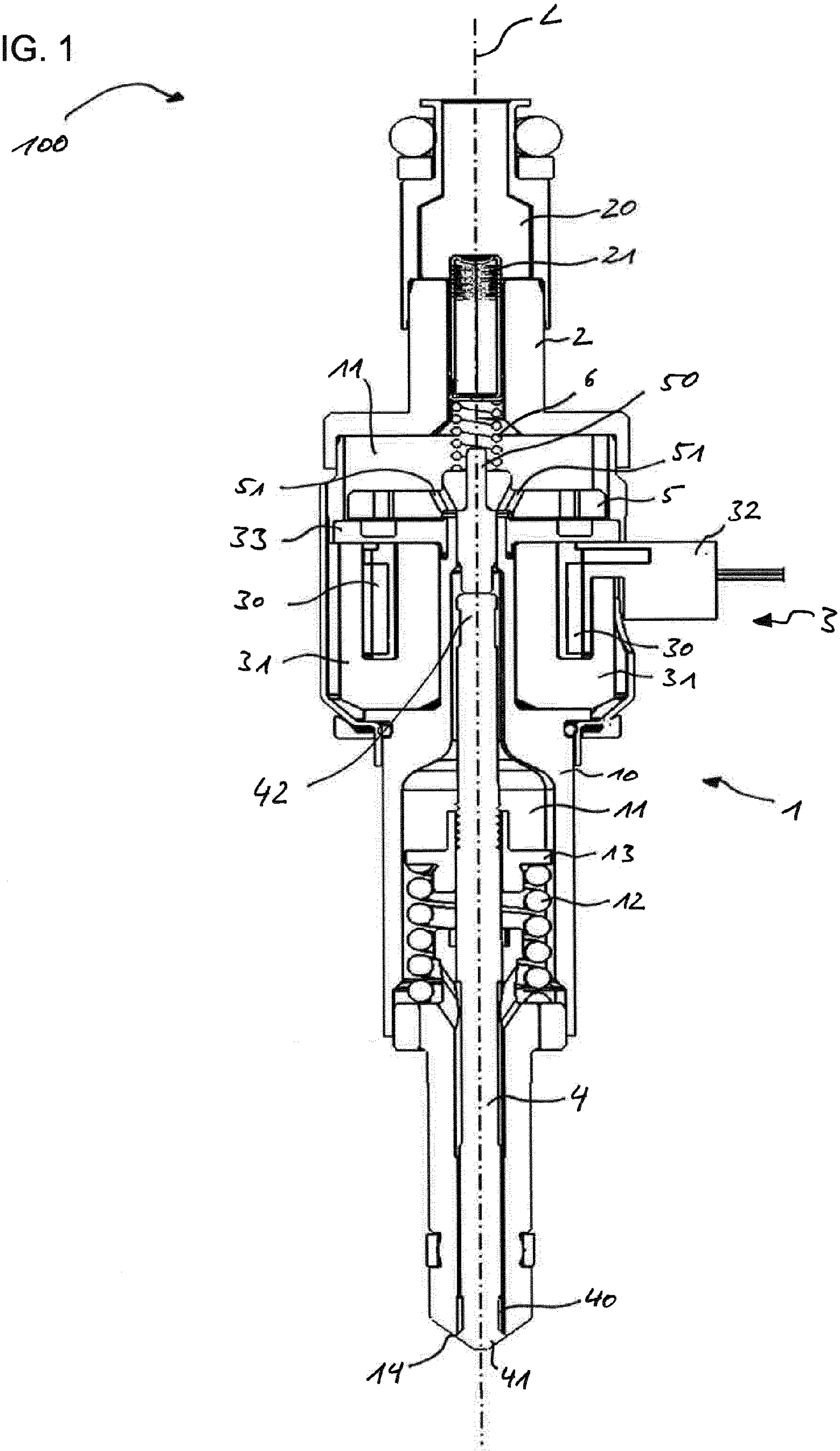

L
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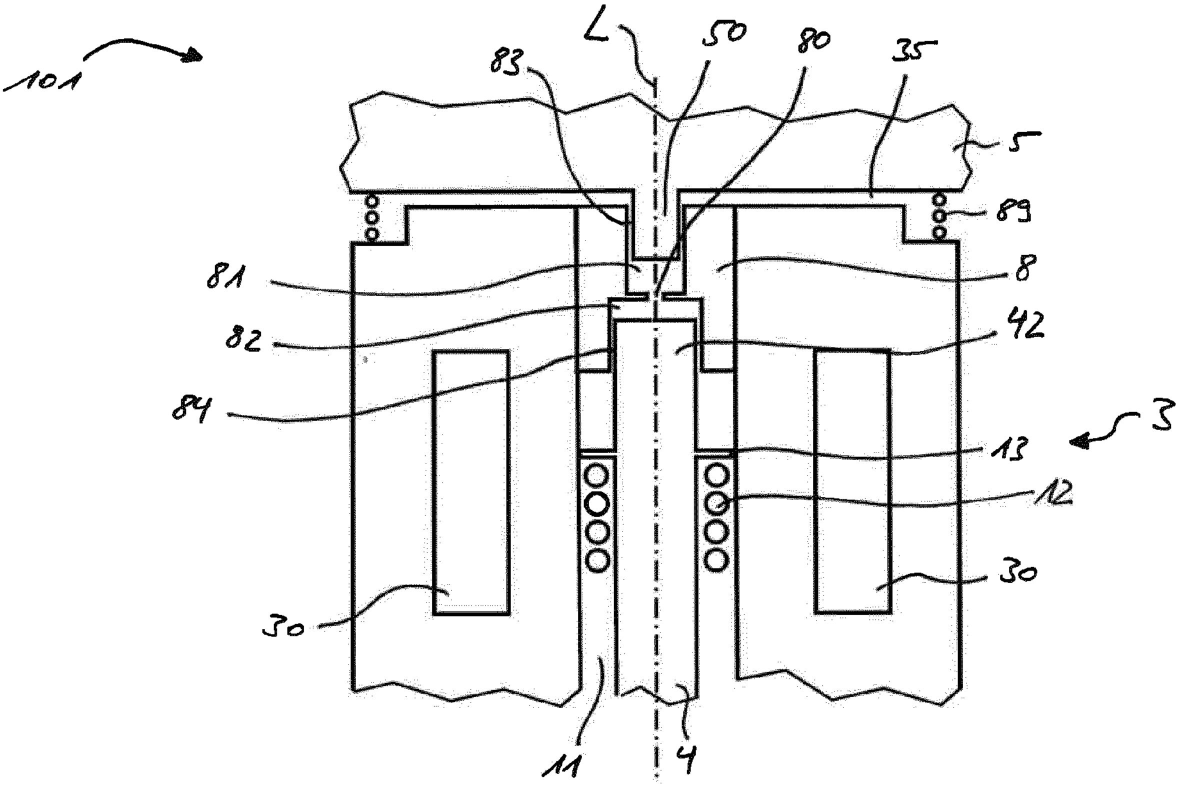
FIG. 2



101
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8
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84
3
13
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11
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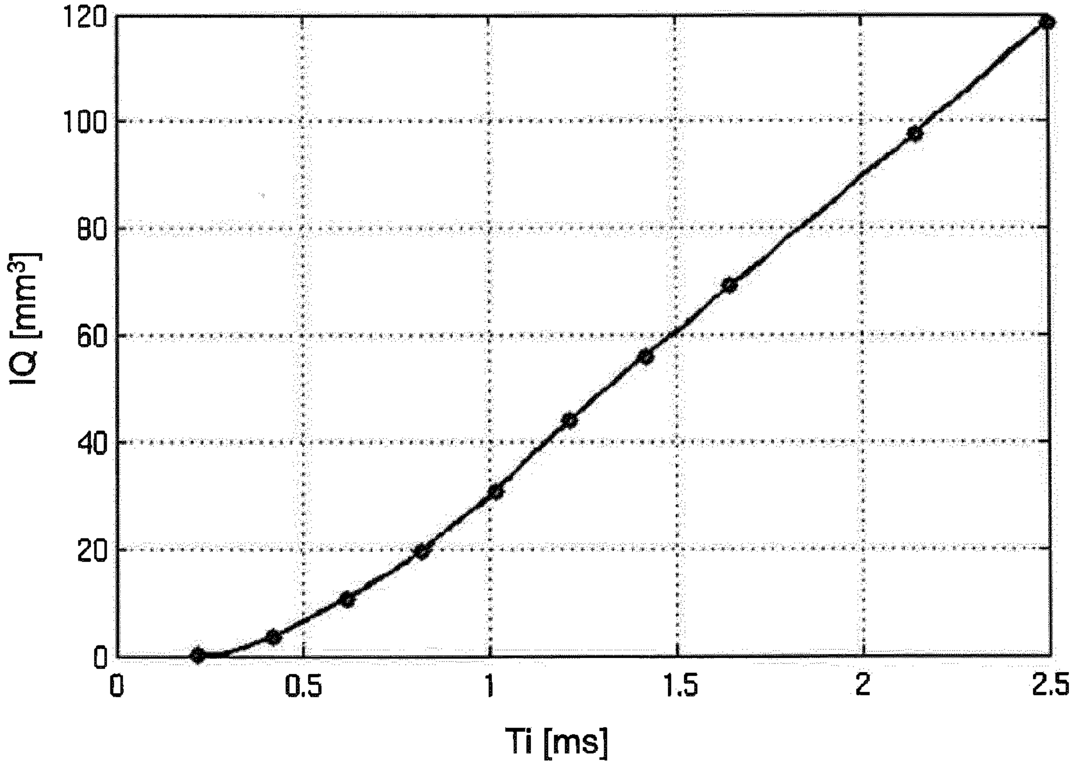
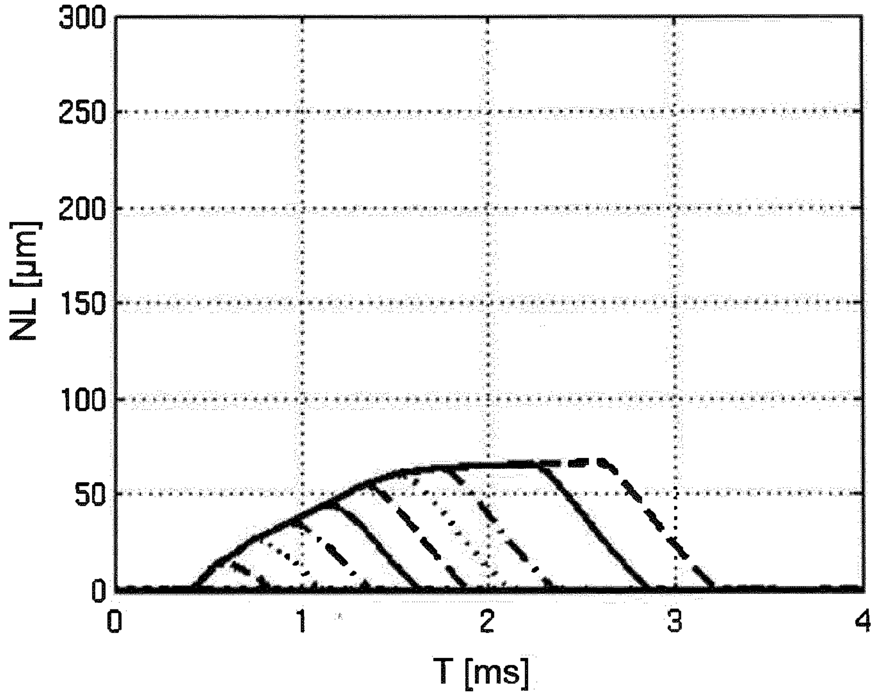
FIG. 3



120
100
80
60
40
20
0
IQ [mm3]
0
0.5
1
1.5
2
2.5
Ti [ms]

FIG. 4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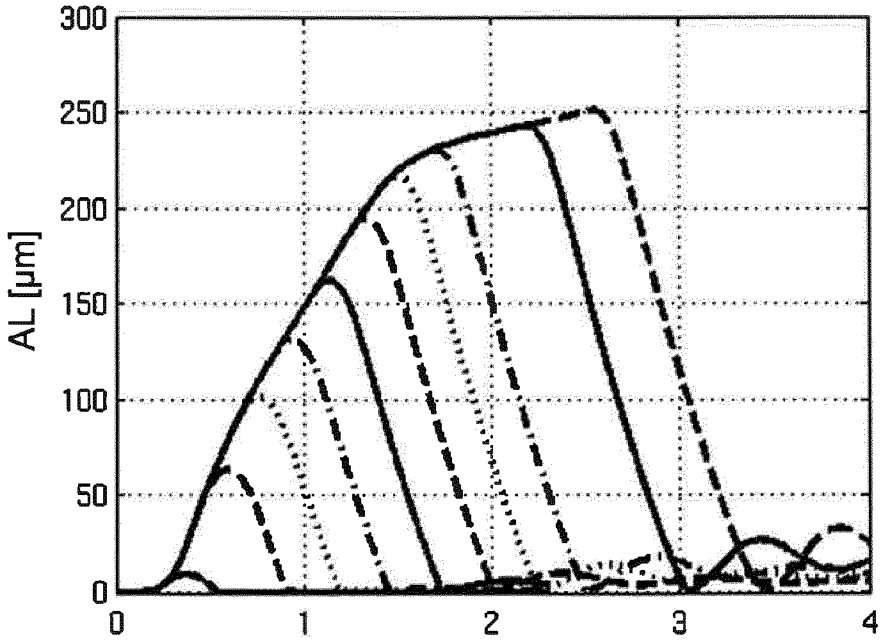
T [ms]

FIG. 5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AL [μm]
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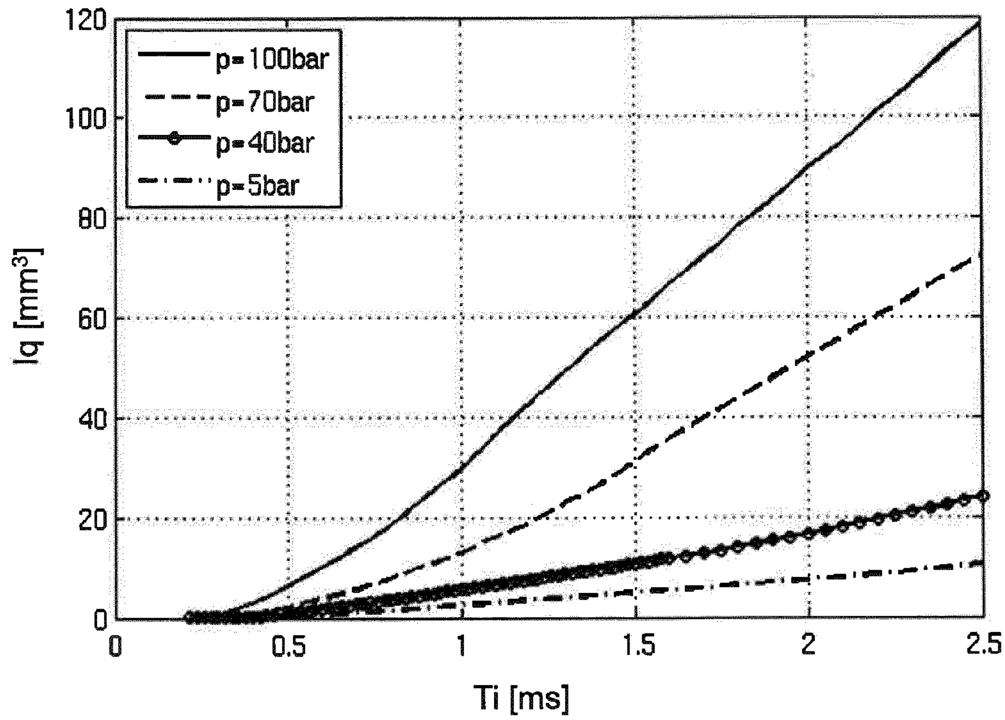
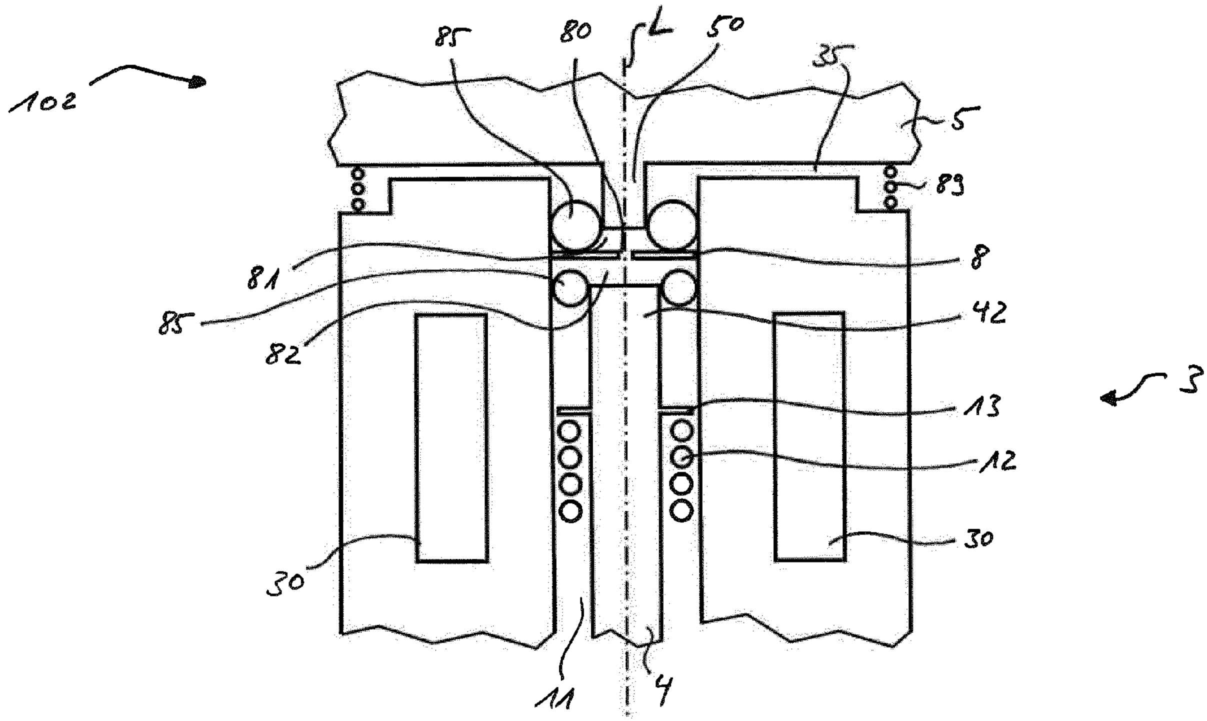
1
2
3
4

FIG. 6



120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
p=100bar
p=70bar
p=40bar
p=5bar
Iq [mm³]
Ti [ms]

FIG. 7



102
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EUROPEAN SEARCH REPORT

Application Number
EP 13 18 8793

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Place of search	Date of completion of the search	Examiner
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X : particularly relevant if taken alone
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