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(54) VALVE ASSEMBLY AND FLUID INJECTION VALVE

(57) A valve assembly (3) for a fluid injection valve (1) is disclosed. It comprises a valve needle (11) and an armature (23). The armature (23) comprises a recess (33) at an upper side (27), the recess (33) having a first circumferential surface (231) and a first bottom surface (233). A second circumferential surface (341) of the armature (23) defines a central bore (34) which extends from the first bottom surface (233) to a lower side (41) of the armature (23), opposite of the upper side (27). The valve needle (11) comprises a retaining element (24) fixed to a shaft (13) of the valve needle (11), the retaining element (24) having a first external circumferential surface (241) and a second bottom surface (243) and the shaft having a second external circumferential surface (131). At least a portion of the retaining element (24) is

arranged in the recess (33) so that the first bottom surface (233) opposes the second bottom surface (243) and the shaft (13) extends through the central bore (34). The recess (33) and the retaining element (24) are dimensioned such that a radial gap (G1) is established between the first circumferential surface (231) and the first external circumferential surface (241) for establishing a fluid leakage path from the upper side (27) to the first bottom surface (233). The shaft (13) and the central bore (34) are dimensioned such that a radial gap (G2) is established between the second circumferential surface (231) and the second external circumferential surface (241) for establishing a fluid leakage path from the lower side (41) to the first bottom surface (233).

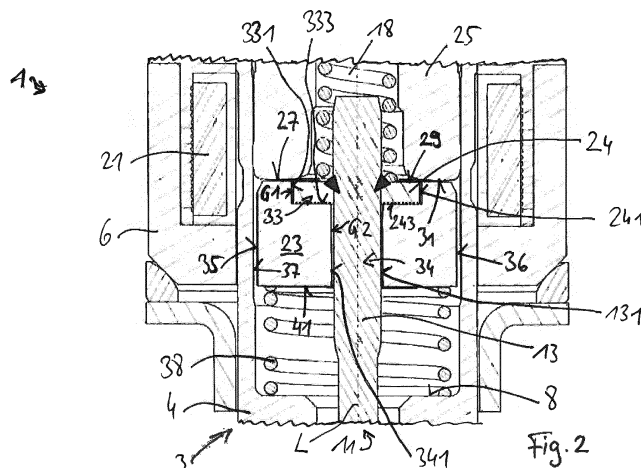


Fig. 2

Description

[0001] The present invention relates to a valve assembly for a fluid injection valve and to a fluid injection valve, e.g. a fuel injection valve of a vehicle. It particularly relates to solenoid injection valves.

[0002] Fuel injection valves are required to deliver fuel very accurately to fulfill legislative emission regulations such as the EURO 6 C regulation. The amount of fuel injected during one injection event and the spray distribution, such as cone shape and droplet size, need to be accurately controlled to comply with these requirements.

[0003] One problem that may occur in controlling the injection characteristics of injection valves is an uncontrolled re-opening of the valve at the end of an injection event. This may be caused by the valve needle rebounding from the valve seat, e.g. due to the momentum transfer when the valve needle hits the valve seat. The uncontrolled reopening generates an undesired additional injection which may additionally have a poor atomization of the fluid.

[0004] Such needle rebound can be reduced in solenoid injection valve by decoupling the magnetic armature from the valve needle to reduce the effective mass for the momentum transfer when the valve needle hits the valve seat. However, in such valves, the armature continues moving when the movement of the valve needle is stopped by the valve seat. The kinetic energy of the armature has to be dissipated so that the injection valve can come to rest in its closed configuration. This requires damping of the armature movement relative to the valve needle.

[0005] It is an object of the present disclosure to provide a valve assembly for an injection valve and an injection valve enabling an improved and/or cost-effective damping of the armature movement.

[0006] This object is achieved by means of a valve assembly according to the independent claim. Advantageous embodiments and developments of the valve assembly and the injection valve are specified in the dependent claims, the following description and the drawings.

[0007] According to a first aspect of the present disclosure, a valve assembly for a fluid injection valve is specified.

[0008] The valve assembly comprises a valve needle. Further, it comprises an armature of an electro-magnetic actuator assembly. The armature is axially displaceable relative to the valve needle along a longitudinal axis. In other words, the armature can slide along the valve needle in reciprocating fashion in direction along the longitudinal axis.

[0009] The armature may expediently be operable to actuate the valve needle. In particular, the armature is configured for axially displacing the valve needle away from a closing position, in particular against the bias of a calibration spring of the valve assembly, the calibration spring being preloaded to bias the valve needle towards

the closing position. The armature is preferably mechanically coupled to the valve needle in such fashion that it takes the valve needle with it when it moves towards a stationary pole piece of the actuator assembly.

[0010] The armature has an upper side and a lower side, opposite of the upper side. The upper and lower sides represent in particular opposite axial ends of the armature. The armature comprises a recess at the upper side. The recess has a circumferential side surface and a bottom surface. The circumferential side surface and the bottom surface of the recess are herein also denoted as "first circumferential surface" and "first bottom surface". Further, the armature comprises a circumferential surface which defines a central bore through the armature. The circumferential surface which defines the central bore is herein also denoted as "second circumferential side surface". The central bore extends from the first bottom surface to the lower side of the armature. The bottom surface of the recess in particular is perforated by an aperture of the central bore. It is in particular an annular surface which extends circumferentially around the central bore.

[0011] The valve needle comprises a shaft and a retaining element. The retaining element is fixed to the shaft. This is understood in the present context to comprise also embodiments in which the retaining element is in one piece with the shaft. In an expedient embodiment, the valve needle further comprises a sealing element such as a sealing ball. The sealing element may expediently be fixed to an axial end of the shaft remote from the retaining element. The armature is in particular operable to engage in form-fit contact with the retaining element for axially displacing the valve needle away from the closing position.

[0012] The retaining element has an external circumferential surface and a bottom surface. The external circumferential surface and the bottom surface of the retaining element are herein also denoted as "first external circumferential surface" and "second bottom surface". The shaft has an external circumferential surface, also denoted herein as "second external circumferential surface".

[0013] At least a portion of the retaining element is arranged in the recess so that the first bottom surface opposes the second bottom surface. In particular, the form-fit contact of the armature with the retaining element for axially displacing the valve needle away from the closing position is established between the bottom surfaces of the retaining element and the recess. The recess and the retaining element are dimensioned such that a radial gap is established between the first circumferential surface and the first external circumferential surface for establishing a fluid leakage path from the upper side to the first bottom surface.

[0014] The shaft extends through the central bore. The shaft and the central bore are dimensioned such that a radial gap is established between the second circumferential surface and the second external circumferential

surface for establishing a fluid leakage path from the lower side to the first bottom surface.

[0015] A "fluid leakage path" is understood in the present context to provide a fluid path which is in particular dimensioned that its contribution to the fluid flow is insignificant. In particular, the valve assembly comprises at least one main fluid path in parallel to the above described fluid leakage paths. The hydraulic diameter of the main fluid path is preferably at least ten times as large, for example at least 20 times as large, as the hydraulic diameter of each of the fluid leakage paths. Preferably, the radial gaps establishing the fluid leakage paths are larger than required due to manufacturing tolerances of the armature, the retaining element and the shaft. In one embodiment, each of the radial gaps has a gap width of 10 μm or more, for example of 50 μm or more. Expediently, the gap width may have a value of 200 μm or less, in particular of 150 μm or less.

[0016] With advantage, due to the flow resistance through the fluid leakage paths, a large hydraulic damping is achievable when the bottom surface of the recess and the retaining element move axially away from one another or approach one another. The amount of the hydraulic damping force may in particular be dominated by the flow resistance of the fluid leakage paths. Therefore, the damping effect may advantageously be particularly insensitive with respect to the distance between the bottom surfaces and/or with respect to manufacturing tolerances such as the planarity of the bottom surfaces.

[0017] With advantage, additional components - such as a disc element fixed to the shaft of the valve needle or fixed into a valve body of the valve assembly on the lower side of the armature, remote from the retaining element - can be omitted. This makes the valve assembly particularly cost-efficient - e.g. due to reduced number of components and simpler manufacturing of the armature-needle assembly. It may also be advantageous for the fluid flow through the valve assembly. In particular, the risk that throttling elements impede the fluid flow may be particularly small in this way.

[0018] The hydraulic damping force is advantageously generated between surfaces which are not involved in stopping the armature at the end of its opening transient. Surfaces which are involved in stopping the armature at the end of the opening transient often experience large mechanical stress and are subject to wear. This requires costly hard-coatings to guarantee the tolerances which are required for achieving the damping effect. Such hard-coatings on the damping surface may be avoidable in the subject valve assembly.

[0019] In one embodiment, the first bottom surface and the second bottom surface are coplanar. Preferably they have an annular overlapping area. The bottom surfaces of the recess are preferably unperforated. The annular overlapping area then extends in particular from the inner circumferential surface to the first external circumferential surface. In this way, a particularly large hydraulic damping force is achievable.

[0020] In an expedient embodiment, the valve assembly further comprises an armature return spring which is preloaded and biases the first bottom surface in form-fit contact with the second bottom surface. This may enable the armature to actuate the valve needle particularly quickly without delay until the armature can take the valve needle with it on its travel by means of form-fit contact between the bottom surfaces of retaining element and the recess.

[0021] In one embodiment, the axial extension of the second circumferential surface is at least twice as large as the axial extension of the first circumferential surface. In this way, the leakage path from the bottom surface of the recess to the lower side of the armature is at least twice as large as the leakage path from the upper side of the armature to the bottom surface of the recess. This may be advantageous for achieving suitable leak rates - in particular similar leak rates - through the fluid leakage paths in the presence of a pressure gradient along the armature.

[0022] In one embodiment, the valve assembly comprises a valve body, in particular sharing the central longitudinal axis with the valve needle. The valve body comprises a cavity with a fluid inlet portion and a fluid outlet portion. The valve needle is received in the cavity.

[0023] The valve needle is axially moveable relative to the valve body. The valve needle prevents a fluid flow through the fluid outlet portion in the closing position and releases the fluid flow through the fluid outlet portion in further positions. In particular, the valve needle is axially displaceable relative to the valve body away from the closing position for releasing the fluid flow. The armature may expediently be arranged in the cavity of the valve body. It is axially displaceable in reciprocating fashion relative to the valve body.

[0024] The valve assembly may expediently comprise a calibration spring which biases the valve needle towards closing position, i.e. in axial direction towards the fluid outlet portion in the case of an inward opening valve assembly. One axial end of the calibration spring may be seated against the retaining element.

[0025] In one embodiment, the armature return spring is seated against the armature and against a step of the valve body at its opposite axial ends. Preferably, absent the armature return spring, axial displaceability of the armature with respect to the valve body and the valve needle in direction away from the retaining element is limited by said step, and only by said step. This may enable a particularly unimpaired fluid flow through the cavity below the armature. In particular, apart from the shaft of the valve needle and the armature return spring, no other elements of the valve assembly - which could impair the fluid flow - may be arranged in the cavity in the region between the armature and the step.

[0026] In one embodiment, at least one guiding surface is provided on an outer surface of the armature. This means in particular that the outer surface of the armature has a section which represents the guiding surface. The

guiding surface interacts with an inner surface of the valve body to guide the axial movement of the armature. In particular, the guiding surface is in sliding mechanical contact with the inner surface of the valve body. The "outer surface" of the armature is in particular understood in the present context to be an external surface of the armature, in particular an external circumferential surface of the armature. In particular, the outer surface delimits the armature laterally in radial outward direction. Thus, the outer surface is in particular the surface of the armature opposing the inner surface of the valve body. The inner surface of the valve body in particular defines the cavity.

[0027] A plurality of flow passages are formed in the outer surface of the armature. The flow passages may expediently extend axially along the armature at its periphery, i.e. at the external surface opposing the inner surface of the valve body. In particular, the outer surface has recessed further sections. The recessed further sections may expediently be spaced apart from the inner surface of the valve body to define the flow passages.

[0028] In a preferred embodiment, the armature has a plurality of guiding surfaces which are spaced apart from one another in circumferential direction. In particular, the guiding surfaces are separated from one another in circumferential direction by the flow passages.

[0029] With advantage, the armature is guided by the guiding surface on the outer surface of the armature and not by valve needle or by an armature retainer which is fixed to the valve needle. The flow passages at the periphery of the armature can be manufactured particularly simply and cost-efficiently. The guiding surfaces on the outer surface of the armature are manufacturable with particular small tolerances, allowing a particularly precise axial guidance of the armature.

[0030] The upper side of the armature has in particular a top surface of the armature which is facing in axial direction towards the pole piece. Preferably, the top surface is a planar surface which extends radially from the outer circumferential contour of the upper armature retainer to the outer surface of the armature. This is possible, because guidance of the valve needle is not effected by way of the upper armature retainer. A radial flow path with particularly small turbulences is achievable in this way.

[0031] According to one embodiment, the flow passages provided in the outer surface are flattened surface sections extending in axial direction from the upper side of the armature to a lower side of the armature. The lower side in particular comprises a lower surface of the armature, facing towards the fluid outlet portion in case of an inward opening valve. The lower side is in particular facing away from the pole piece. This embodiment has the advantage, that the flow passages can be very easily formed during manufacture of the armature by flattening the cylindrical surface of the armature in some places by a suitable process.

[0032] According to one embodiment, the armature is

solid and in particular does not comprise fuel passages on the inside. In particular, the top surface of the armature, extending radially outward from the retaining element to the outer surface of the armature is unperforated.

5 That the armature does not comprise fuel passages on the inside means in particular that the armature has one, and only one, axial opening which is defined by the recess and the central bore.

[0033] The injection valve has the advantage, that it enables a no-hard-stop-concept and therefore eliminates the necessity of a hardening coating on the pole piece and the upper side of the armature. This is due to the fact that the only flow path is built by the flow passages on the outer surface of the armature. Apart from the small amount through the leakage paths which is in particular negligible for the flow rate through the valve assembly, fluid does not flow in passages inside the armature, for no such passages on the inside are provided. As a consequence, during an opening phase of the injection valve, there is a pressure gradient across the upper side of the armature, suspending the armature in a stable position and building up a sufficient hydraulic force to stop the armature from contacting the pole piece. Thus, fluid can pass between the lower side of the pole piece and the upper side of the armature. In this way, a stable suspended stop position for the armature is achievable. The spring rate of the calibration spring is in particular adapted to the magnetic force of the actuator assembly in such fashion that the spring force of the calibration spring alone is smaller than the magnetic force on the armature during operation of the actuator assembly. Such a comparatively small spring rate may be advantageous for the dynamic behavior of the valve assembly. Due to the valve assembly having only flow paths along the passages on the outside of the armature, the spring force of the calibration spring is supplemented by the hydraulic force generated by the pressure drop along the radial flow path along the upper side of the armature. This leads to suspension of the armature in the maximum opening position of the valve assembly at a distance from the pole piece.

[0034] In this way, a monotonous and preferably linear dependence of the amount of fuel which is dispensed by the valve assembly during one injection event on the valve opening time is achievable. The valve opening time is in particular the amount of time for which a coil of the actuator assembly is energized during one injection event for generating a magnetic force on the armature to actuate the valve needle. Conventional valve assembly usually exhibit an S-shaped "wiggle" and a change of slope in the region of valve opening times at the transition from a ballistic operation mode to an operation mode where the armature hits the pole piece during the injection event. In this context a "ballistic operation mode" is an operation mode for injecting small amounts of fluid in which the coil is energized for such a short time that the valve needle does not reach its fully open position before it starts returning to the closing position.

[0035] An anti-friction coating may be provided on the

at least one guiding surface on the outer surface of the armature. The anti-friction coating may in particular comprise tungsten carbon carbide (WCC) or diamond-like carbon (DLC). The coating has the advantage, that it reduces noise, wear and facilitates guidance of the valve needle.

[0036] According to a further aspect of the present disclosure, a fluid injection valve with the valve assembly according to at least one of the above embodiments is provided. The injection valve may in particular be a fuel injection valve of a vehicle. Preferably, the valve assembly if the fluid injection valve has a solid armature which is free of internal flow channels as described above.

[0037] Further advantages, advantageous embodiments and developments of the valve assembly for an injection valve and the fluid injection valve will become apparent from the exemplary embodiments which are described below in association with the schematic figures.

Figure 1 shows a longitudinal section of an injection valve according to one embodiment of the invention,

Figure 2 shows a detail of figure 1,

Figure 3 shows the valve assembly of figure 2 with dimensions of the valve assembly being indicated, and

Figure 4 shows a cross section of the valve assembly according to the embodiment shown in figures 1, 2 and 3.

[0038] In the exemplary embodiments and figures, identical, similar or similarly acting constituent parts are provided with the same reference symbols. In some figures, individual reference symbols may be omitted to improve the clarity of the figures.

[0039] The fluid injection valve 1 shown in figure 1 is in particular suitable for dosing fuel to a combustion engine, preferably for dosing fuel directly into a combustion chamber of the engine.

[0040] The injection valve 1 comprises a valve assembly 3. A detailed longitudinal section view of the valve assembly 3 is shown in figures 2 and 3. Some reference symbols are only shown in Fig. 2 and others are only shown in Fig. 3 to improve the clarity of the figures. Figure 4 shows a cross-sectional view of the valve assembly 3.

[0041] The valve assembly 3 comprises a valve body 4 with a central longitudinal axis L. A housing 6 is partially arranged around the valve body 4.

[0042] The valve body 4 is hollow so as to define a cavity 9. The cavity 9 has a fluid outlet portion 7. The fluid outlet portion 7 communicates with a fluid inlet portion 5 which is provided in the valve body 4. The fluid inlet portion 5 and the fluid outlet portion 7 are in particular positioned at opposite axial ends of the valve body 4. The

cavity 9 takes in a valve needle 11. The valve needle 11 comprises a needle shaft 13 and a sealing ball 12 welded to the tip of the needle shaft 13. The valve needle 11 further comprises a retaining element 24. The retaining element 24 is positioned adjacent to an axial end of the needle shaft 13 remote from the sealing ball 12 and is fixedly coupled to the needle shaft 13 by a welded joint (roughly indicated by the triangles in Fig. 2).

[0043] In a closing position of the valve needle 11, its sealing element 12 sealingly rests on a valve seat comprised by a seat element 14 having at least one injection nozzle. The fluid outlet portion 7 is arranged near the seat element 14. The seat element 14 closes the fluid outlet portion 7 of the valve body 4. In the closing position of the valve needle 11, a fluid flow through the at least one injection nozzle is prevented. The injection nozzle may be, for example, an injection hole. However, it may also be of some other type suitable for dosing fluid.

[0044] A preloaded calibration spring 18 exerts a force on the valve needle 11, biasing the valve needle 11 towards the closing position. One axial end of the calibration spring 18 is seated against the retaining element 24 for transferring the spring force of the calibration spring 18 to the valve needle 11. The other axial end of the calibration spring 18 is positionally fixed relative to the valve body 4.

[0045] The injection valve 1 is provided with an electromagnetic actuator assembly 19 to actuate the valve needle 11. Portions of the actuator assembly 19 are shown in Fig. 2 but are omitted in Fig. 3.

[0046] The electro-magnetic actuator assembly 19 comprises a solenoid 21, i.e. an electromagnetic coil, which is preferably arranged inside the housing 6 and surrounds the valve body 4. Furthermore, the electro-magnetic actuator assembly 19 comprises an armature 23 and a pole piece 25. The housing 6, parts of the valve body 4, the pole piece 25 and the armature 23 form a magnetic circuit.

[0047] The pole piece 25 is fixed to the valve body 4, in particular inside the cavity 9, in the present embodiment. It can also be in one piece with the valve body 4. The armature 23 is arranged in the cavity 9 of the valve body 4. It is axially displaceable in reciprocating fashion relative to the valve body 4. In this way, the pole piece 25 and the armature 23 represent a stationary core and a movable core, respectively, of the actuator assembly 19. A substantially planar, radially extending upper side 27 of the armature 23 is facing towards a lower side 31 of the pole piece 25. A lower side 41 of the armature 23, remote from the upper side 27, faces away from the pole piece 25 and in the present embodiment towards the fluid outlet portion 7.

[0048] The armature 23 has a central axial opening through which the valve needle 11 extends. The central axial opening is formed by a recess 33 which extends into the armature 23 from the upper side 27 and by a central bore 34 which extends from the lower side 41 of the armature 23 to the recess 33.

[0049] The recess 33 has a circumferential surface 231 - i.e. a first internal circumferential surface of the armature 23 - and a bottom surface 233. The bottom surface 233 is arranged opposite of the opening of the recess at the upper side 27 and preferably coplanar with the upper side 27. The circumferential surface 231 is in particular a cylindrical surface.

[0050] The central bore 34 is defined by a circumferential surface 341 which is a second internal circumferential surface of the armature 23. The second internal circumferential surface 341 is preferably also a cylindrical surface. At its opposite axial ends, the central bore 34 opens out into the bottom surface 233 of the recess 33 and into the lower side 41 of the armature 23.

[0051] The retaining element 24 has a - preferably cylindrical - external circumferential surface 241 and a bottom surface 243. The retaining element 24 is embedded into the recess 33 of the armature 23 so that the upper side 27 of the armature 23 and an upper side 29 of the upper retaining element 24 are coplanar and the bottom surface 243, 233 of the retaining element 24 and the recess 33 of the armature 23 face towards each other. The shaft 13 of the valve needle 11 projects on both sides from the retaining element 24 and extends through the central bore 34 in direction towards the lower side 41 of the armature 23 where it protrudes from the central bore 34 towards the fluid outlet portion 7.

[0052] The armature 23 is axially movable relative to the valve needle 11, i.e. it may slide on the needle 11. Axial displaceability of the armature 23 relative to the valve needle 11 in direction towards the pole piece 25 is limited by the retaining element 24. Specifically, the bottom surfaces 243, 233 of the retaining element 24 and of the recess 33 of the armature are coplanar and have an annular overlapping area 32 so that they are engageable in form-fit connection with one another for limiting the axial displaceability of the armature 23 relative to the valve needle 11 in direction towards the pole piece 25. In the present embodiment, the annular overlapping area 32 extends in radial direction from the external circumferential surface 131 of the needle shaft 13 to the external circumferential surface 241 of the retaining element 24.

[0053] Between the external circumferential surface 241 of the retaining element 24 and the circumferential surface 231 of the recess 33, a first radial gap G1 is established. The first radial gap G1 has a gap width of $(D1 - D0)/2$, where D1 is the diameter of the circumferential surface 231 of the recess 33 and D0 is the diameter of the external circumferential surface 241 of the retaining element 24.

[0054] A second radial gap G2 is established between the circumferential surface 341 of the central bore 34 and external circumferential surface 131 of the needle shaft 13. The second radial gap G2 has a gap width of $(D4 - D3)/2$, where D4 is the diameter of the circumferential surface 341 of the central bore 34 and D3 is the diameter of the external circumferential surface 131 of the needle shaft 13 in the region where it axially overlaps the central

bore 34.

[0055] The first radial gap G1 defines a first fluid leakage path which extends from the upper side 27 of the armature to the bottom surface 233 of the recess 33. The second radial gap G2 defines a second fluid leakage path which extends from the lower side 41 of the armature to the bottom surface 233 of the recess 33. The length of the second fluid leakage path G2 is between 3 and 4 times as large as the length of the first fluid leakage path G1, the limits being included, in this and other embodiments. The lengths of the first and second fluid leakage paths are in particular defined by the lengths of the circumferential surfaces 231, 341 of the recess 33 and of the central bore 34, respectively.

[0056] At least a part of the outer surface 35 of the armature 23 serves as a guiding surface 36 interacting with an inner surface 37 of the valve body 4.

[0057] Figure 4 shows a cross section of parts of the valve assembly 3 along a plane including the upper retaining element 24. Along the outer surface 35 of the armature 23, a number of flow passages 39 are formed by flattened sections of the outer surface 35, extending from the upper side 27 of the armature 23 to the lower side 41 of the armature 23. Along those flow passages 39, fluid can flow from the fluid inlet portion 5 towards the fluid outlet portion 7, when the injection valve 1 is open.

[0058] When the actuator assembly is de-energized in a closed configuration of the valve assembly 3, the bottom surface 233 of the recess 33 of the armature 23 is in form-fit engagement with the bottom surface 243 of the retaining element 24 due to an armature return spring which biases the armature 23 in axial direction towards the upper armature retainer 24. When the solenoid 21 is energized, the armature 23 experiences a magnetic force and slides upwards - i.e. in axial direction towards the pole piece 25. Due to the form-fit connection with the retaining element 24, it takes the valve needle 11 with it in axial direction away from the fluid outlet portion 7, thereby compressing the calibration spring 18. Consequently, the valve needle 11 moves in axial direction out of the closing position of the valve 1.

[0059] Fuel starts to flow from a central opening of the pole piece 25 in radial outward direction along the upper armature retainer 24 and the upper surface 27 of the armature 23 and, because there are no passages formed on the inside of the armature 23, to the outer surface 35 of the armature 23. There, the fuel flows further along the passages 39 in the outer surface 35 of the armature 23 and towards the fluid outlet portion 7. It has to be noted that fluid cannot flow through the first and second fluid leakage paths through the armature 23 from its upper side 27 to its lower side 41 due to the form-fit connection in the overlapping area 32 of the bottom surfaces 233, 241 of the recess 33 of the armature 23 and of the retaining element 24 which blocks fluid flow from the first to the second fluid leakage path.

[0060] As the armature 23 approaches the pole piece 25, the residual gap between the upper side 27 of the

armature 23 and the lower side 31 of the pole piece 25 decreases. The decreasing hydraulic diameter of the residual gap effects an increasing pressure difference between the upper side 27 and the lower side 41 of the armature 23. The pressure difference generates a hydraulic force on the armature 23 in axial direction away from the pole piece 25. The magnetic force of the actuator assembly 19 and the spring force of the calibration spring 18 are adapted to the hydraulic force which is generated under normal operating conditions of the injection valve 1 that the spring force and the hydraulic force exceed the magnetic force before the residual gap is completely closed.

[0061] Therefore, the armature 23 stops moving upwards before contact with the pole piece 25 is made. Thus, in a maximum opening position of the valve 1, in which the needle 11 has travelled furthest upwards away from the fluid outlet portion 7, a residual gap is still present between the upper side 27 of the armature 23 and the lower side 31 of the pole piece 25. The residual gap stays open because of the hydraulic force the fuel exerts on the upper side 27 of the armature 23 and the upper side 29 of the upper armature retainer 24. Consequently, there is no hard stop for the armature 23 in the maximum opening position.

[0062] In fact, the armature 23 is suspended in the maximum opening position by an equilibrium of forces in a stable position. In the maximum opening position, a magnetic force acting in a direction away from the fluid outlet portion 7 is balanced by the sum of a hydraulic force and a spring force exerted by the calibration spring 18 both acting in a direction towards the fluid outlet portion 7.

[0063] When the solenoid 21 is de-energized, the calibration spring 18 is able to force the valve needle 11 to move in axial direction into its closing position. The valve needle 11 takes the armature 23 with it by means of the form-fit connection between the bottom surfaces 243, 233 of the retaining element 24 and the recess 33 of the armature 23.

[0064] When the sealing element 12 hits the seat element 14, movement of the valve needle 11 relative to the valve body 4 is stopped while the armature travels further in direction away from the pole piece 25 relative to the valve body 4 and the valve needle 11.

[0065] Thus, an axial gap opens between the bottom surfaces 241, 231 of the retaining element 24 and the recess 33 of the armature 23.

[0066] In addition to the bias of the armature return spring 38, the filling of said axial gap by fluid flow through the first and second leakage paths, dampens the movement of the armature 23 until the kinetic energy of the armature 23 is dissipated and the armature movement away from the pole piece 25 is stopped.

[0067] Then, the armature return spring 38 forces the bottom surface 233 of the recess 33 of the armature 23 back in contact with the bottom surface 243 of the retaining element 24, thereby decreasing the gap width of the

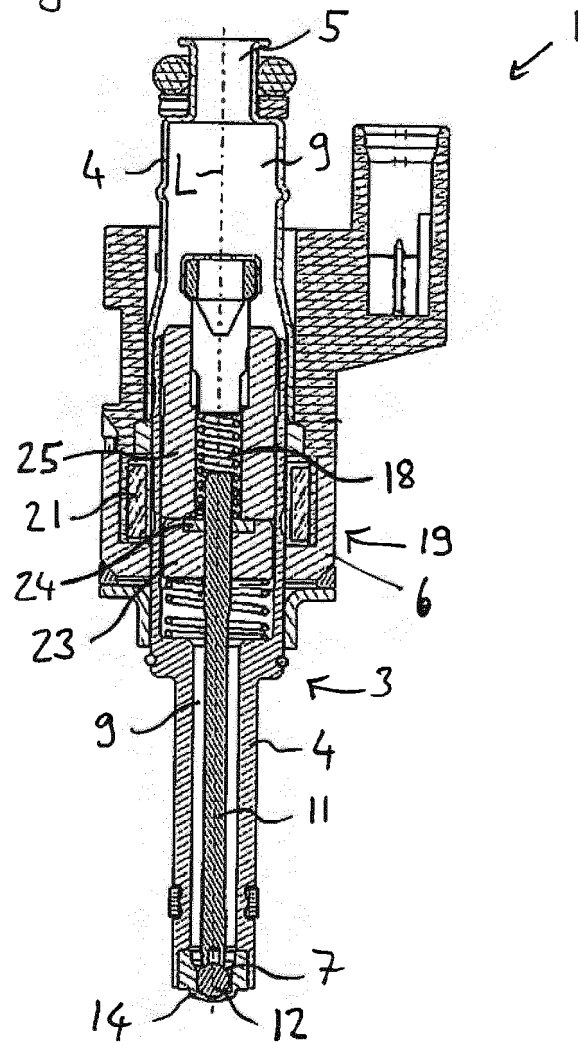
axial gap between the bottom surfaces 243, 233 to zero. Also this movement is damped by the flow resistances of the first and second leakage paths when squeezing fluid out of the axial gap through the first and second leakage paths.

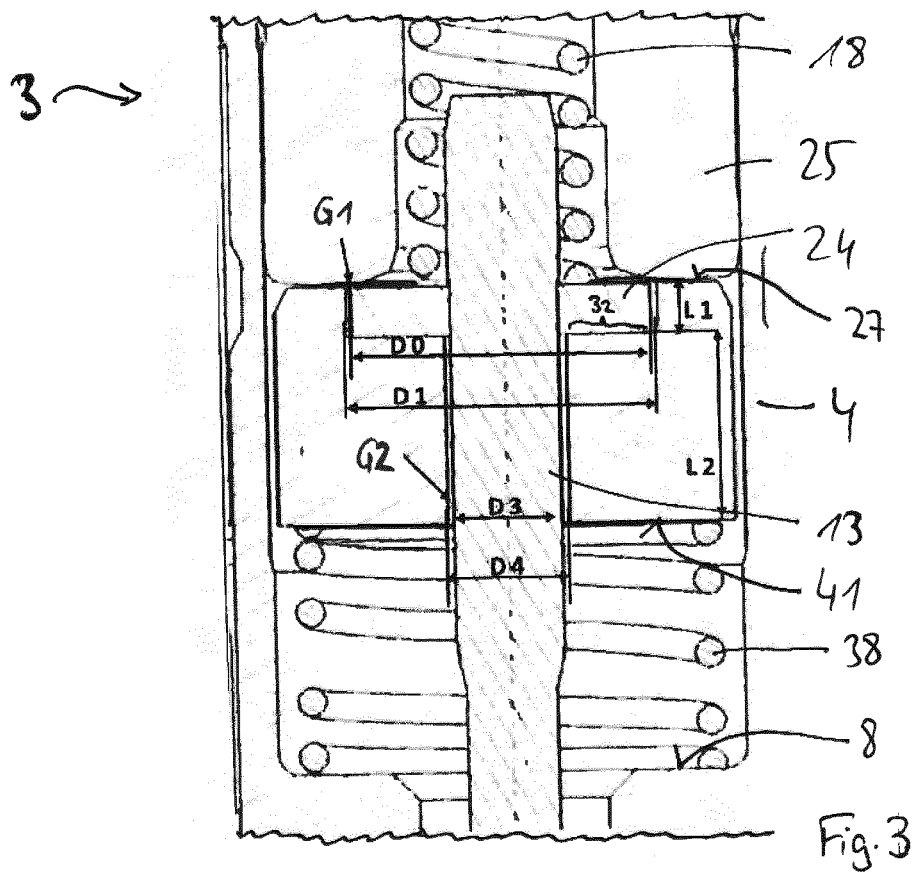
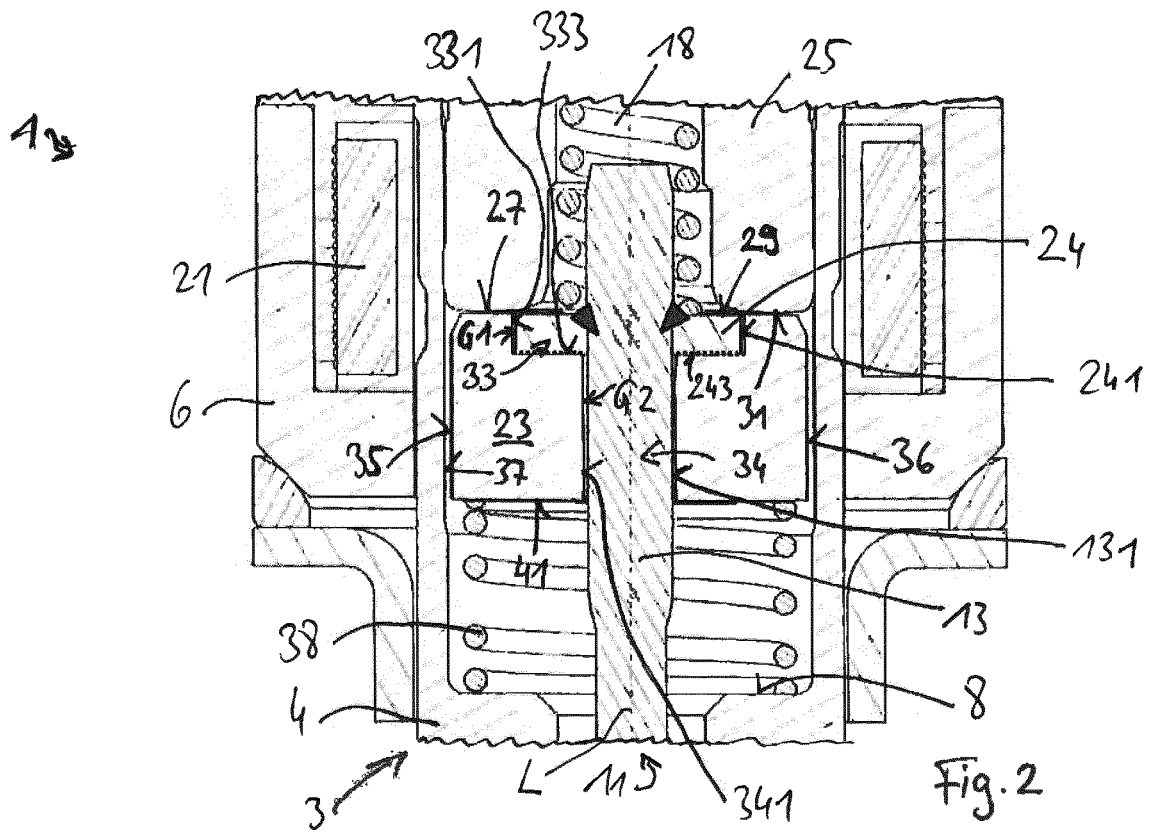
Claims

1. Valve assembly (3) for a fluid injection valve (1), comprising a valve needle (11) and an armature (23) of an electro-magnetic actuator assembly (19), wherein
 - the armature (23) is axially displaceable relative to the valve needle (11) along a longitudinal axis (L),
 - the armature (23) comprises a recess (33) at an upper side (27), the recess (33) having a first circumferential surface (231) and a first bottom surface (233), and a second circumferential surface (341) defining a central bore (34) which extends from the first bottom surface (233) to a lower side (41) of the armature (23), opposite of the upper side (27),
 - the valve needle (11) comprises a retaining element (24) fixed to a shaft (13) of the valve needle (11), the retaining element (24) having a first external circumferential surface (241) and a second bottom surface (243) and the shaft having a second external circumferential surface (131),
 - at least a portion of the retaining element (24) is arranged in the recess (33) so that the first bottom surface (233) opposes the second bottom surface (243) and the shaft (13) extends through the central bore (34),
 - the recess (33) and the retaining element (24) are dimensioned such that a radial gap (G1) is established between the first circumferential surface (231) and the first external circumferential surface (241) for establishing a fluid leakage path from the upper side (27) to the first bottom surface (233), and
 - the shaft (13) and the central bore (34) are dimensioned such that a radial gap (G2) is established between the second circumferential surface (231) and the second external circumferential surface (241) for establishing a fluid leakage path from the lower side (41) to the first bottom surface (233).
2. Valve assembly (3) according to the preceding claim, wherein the first bottom surface (233) and the second bottom surface (243) are coplanar and have an annular overlapping area (32), extending in particular from the inner circumferential surface (341) to the first external circumferential surface (241).

3. Valve assembly (3) according to the one of the preceding claims, further comprising an armature return spring (38) which is preloaded and biases the first bottom surface (333) in form-fit contact with the second bottom surface (243).
4. Valve assembly (3) according to the one of the preceding claims, wherein an upper side (29) of the retaining element (24) is coplanar with an upper side (27) of the armature (23).
5. Valve assembly (3) according to the one of the preceding claims, wherein the axial extension (L2) of the second circumferential surface (341) is at least twice as large as the axial extension (L1) of the first circumferential surface (231).
6. Valve assembly (3) according to one of the preceding claims, further comprising
 - a valve body (4) comprising a cavity (9) with a fluid inlet portion (5) and a fluid outlet portion (7), the valve needle (11) being received in the cavity (9), the valve needle (11) preventing a fluid flow through the fluid outlet portion (7) in a closing position and axially displaceable relative to the valve body (4) away from the closing position for releasing the fluid flow through the fluid outlet portion (7).
7. Valve assembly (3) according to the preceding claim, wherein the armature return spring (38) is seated against the armature (23) and against a step (8) of the valve body (4) at its opposite axial ends and, absent the armature return spring (38), axial displaceability of the armature (23) with respect to the valve body (4) and the valve needle (11) in direction away from the retaining element (24) is limited by said step (8).
8. Valve assembly (3) according to one of the preceding claims 6 and 7, wherein the armature (23) comprises
 - at least one guiding surface (36) on an outer surface (35) of the armature (23), the guiding surface (36) interacting with an inner surface (37) of the valve body (4) to guide the axial movement of the armature (23) and
 - a plurality of flow passages (39) formed in the outer surface (35) of the armature (23).
9. Valve assembly (3) according to the preceding claim comprising a plurality of guiding surfaces (36), wherein the outer surface (35) is an external circumferential surface of the armature (23) having a plurality of sections representing the guiding surfaces (36) and a plurality of further sections representing the flow passages (39), the guiding surfaces (36) being separated from one another in circumferential direction by the flow passages (39).
10. Valve assembly (3) according to one of the preceding claims 8 and 9, wherein the flow passages (39) provided in the outer surface (35) are flattened surface sections extending in axial direction from the upper side (27) of the armature (23) to a lower side (41) of the armature (23).
11. Valve assembly (3) according to one of the preceding claims 8 to 10, wherein an anti-friction coating is provided on the at least one guiding surface (36) on the outer surface (35) of the armature (23).
12. Valve assembly (3) according to one of the preceding claims, wherein the armature (23) is solid and does not comprise fuel passages on the inside.
13. Valve assembly (3) according to one of the preceding claims, further comprising a calibration spring (18) biasing the valve needle (11) towards the closing position
14. Fluid injection valve (1) with a valve assembly (3) according to one of the preceding claims.

Fig. 1





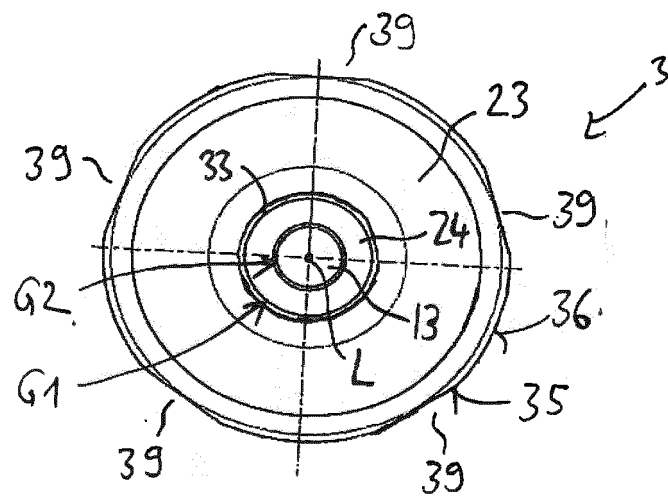


Fig. 4



EUROPEAN SEARCH REPORT

Application Number
EP 17 15 7333

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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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