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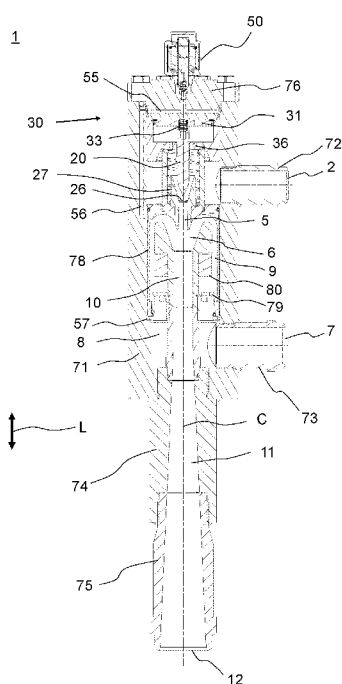


Fig. 1

(57) Abstract: The present invention relates to an ejector (1; 100), e.g. for a refrigerant circuit, with a primary inlet (2), a secondary inlet (7), an outlet (12), a nozzle (5), and a mixing portion (6, 10). The ejector (1; 100) comprises an actuating mechanism (30) moving a needle (20) between an opened position and a closed position. The actuation mechanism (30) comprises a piston (31) in a cylinder (35), wherein a first cylinder chamber (37) is in fluid communication with the primary inlet (2) and a second cylinder chamber (38) is in fluid communication with the first cylinder chamber (37). The second cylinder chamber (38) is in fluid communication with the secondary inlet (7) and/or the outlet (12) via a drain passage (39, 53, 54, 55, 56, 57) when a pilot valve (50) arranged in the drain passage (39, 53, 54, 55, 56, 57) is in an open state. For ensuring smooth opening and closing, the fluid communication of the second cylinder chamber (38) with the first cylinder chamber (37) is provided by an equalization passage (32), wherein a flow cross-section of the equalization passage (32) is larger than a flow cross-section of the drain passage (39, 53, 54, 55, 56, 57).

## **Ejector having an actuation mechanism with a pilot valve and an equalization passage between two cylinder chambers**

The present invention relates to an ejector, e.g. for a refrigeration circuit with circulated refrigerant, with a primary (fluid) inlet, a secondary (fluid) inlet, a (fluid) outlet, a nozzle, and a mixing portion for mixing fluid supplied with a high pressure at the primary inlet and fluid sucked from the secondary inlet. The invention further relates to an ejector assembly with at least two ejectors.

Typically, fluid is supplied by the refrigeration circuit with the high pressure to the primary inlet. Further, the refrigeration circuit supplies fluid to the secondary inlet with a secondary pressure that is less than the high pressure. The nozzle jets the fluid received at the primary inlet into the mixing portion. Thereby, a flow velocity is increased. Fluid received at the secondary inlet is additionally sucked into the mixing portion. As a result, the fluid received at the primary inlet mixes with the fluid received at the secondary inlet in the mixing portion. Thereafter, the combined fluid flow leaves the ejector through the outlet. A diffuser is arranged between the mixing portion and the outlet. In some applications, a flow of fluid through the nozzle can be prevented. By this, the ejector is closed.

Examples of ejectors are known from WO 2018/159320 A1, US 7,841,193 B2, JP 4 134 918 B2, and EP 1 923 575 A2.

US 2004/0040340 A1 discloses an ejector including a high-pressure refrigerant inlet port, a low-pressure refrigerant inlet port, a nozzle, a mixing portion, and a diffuser. A pilot valve controls a throttle opening degree of the nozzle in accordance with a difference between a pressure of a refrigerant in a first pressurized compartment and a pressure of a middle pressure refrigerant in a second pressurized compartment. The pressure of the refrigerant in the first pressurized compartment is the same as a pressure of the refrigerant in the high-pressure

refrigerant inlet part. An orifice is provided in the pilot valve. A passage opening on a side of the high-pressure inlet port and the second pressurized compartment communicate with each other through the orifice. A control valve is in fluid connection with the second pressurized compartment and controls an opening area of a low-pressure refrigerant passage extending between the control valve and the low-pressure refrigerant inlet port.

Fast opening or closing of an ejector can cause fast pressure variations in the refrigeration circuit employing the ejector, e.g. pressure peaks. This can lead to damages of components of the refrigeration circuit. Furthermore, this can lead to instability in the controlling of the refrigeration system.

One approach is to control opening and closing of the ejector with a stepper motor. However, stepper motors are particularly expensive and not perfectly suitable for all applications.

Hence, it is an object of the invention to ensure smooth opening and closing of an ejector in a cost-effective and reliable manner.

The problem mentioned above is solved by an ejector, e.g. for a refrigeration circuit with circulated refrigerant.

The ejector comprises:

a primary (fluid) inlet; a secondary (fluid) inlet; and a (fluid) outlet;

a nozzle for jetting fluid supplied at the primary inlet into a mixing portion for sucking fluid supplied at the secondary inlet into the mixing portion;

a needle and a needle seat, wherein the needle seat is arranged downstream of the primary inlet and upstream of the nozzle (and the outlet); and

an actuating mechanism for moving the needle between an opened position, in which the needle is lifted from the needle seat for allowing fluid flow past the

needle seat, and a closed position, in which the needle abuts the needle seat and blocks fluid flow past the needle seat, wherein the actuating mechanism comprises:

5 a cylinder with a piston connected to the needle, wherein a first cylinder chamber is maximized when the needle is in its opened position and a second cylinder chamber is maximized when the needle is in its closed position, wherein the first cylinder chamber is in fluid communication with the primary inlet via a chamber inlet, and wherein the second cylinder chamber is in fluid communication with the first cylinder chamber, and

10 a drain passage with a pilot valve, wherein the second cylinder chamber is in fluid communication with the secondary inlet and/or the outlet via the drain passage when the pilot valve is in an open state.

The fluid communication of the second cylinder chamber with the first cylinder chamber is provided by an equalization passage.

15 A flow cross-section of the equalization passage may be larger than a flow cross-section of the drain passage.

20 The present invention ensures smooth opening and closing of the ejector. Pressure peaks due to fast opening and/or closing are reliably avoided. The implementation is cost-effective. For example, no expensive stepper motor is needed in order to ensure smooth opening and closing.

25 In addition, as the needle is connected to the piston, the risk is reduced that the needle moves with excessive speed and/or flutters due to external pressure fluctuations, e.g. to fluctuations of a primary pressure applied to the primary inlet by an external refrigeration circuit.

Fluid from the primary inlet can enter the first cylinder chamber via the chamber inlet. This allows filling up the first cylinder chamber while the (volume of) the first cylinder chamber increases.

- 5     The drain passage is configured for discharging fluid from the second cylinder chamber when the pilot valve is open. This allows decreasing the (volume of) the second cylinder chamber (by displacement of the piston in the cylinder).

10     The equalization passage allows that fluid flows from the first cylinder chamber to the second cylinder chamber. In order to bring the needle from the opened position to the closed position, the pilot valve is closed. When the pilot valve is closed, no fluid is discharged from the second cylinder chamber. The piston is displaced in order to maximize (the volume of) the second cylinder chamber. In more detail, the second cylinder chamber is filled up by the fluid from the first cylinder chamber  
15     entering the second cylinder chamber through the equalization passage while the (volume of) the second cylinder chamber increases. At the same time, the (volume) of the first cylinder chamber is decreased.

20     As noted above, if the needle is in the opened position, this allows fluid flow past the needle seat. In more details, this allows that fluid flows from the primary inlet into the nozzle and further into the mixing portion. Fluid flow from the primary inlet into the nozzle is prevented when the needle is in its closed position. Correspondingly, no fluid is sucked from the secondary inlet into the mixing portion. Accordingly, the ejector is in a closed state then.

25

According to one aspect, the drain passage is blocked (closed) when the solenoid valve is in a closed state.

30     The chamber inlet, the equalization passage, and the drain passage may be completely integrated in the ejector. They are not constituted by fluid connections

provided by an environment or any outer element. In particular, they are not constituted by any fluid connections of a refrigeration circuit employing the ejector that are not part of the ejector as such.

5 According to an aspect, the actuating mechanism is for moving the needle along a longitudinal direction between the opened position and the closed position. The cylinder may extend parallel to the longitudinal axis and the piston may be configured to reciprocate parallel to the longitudinal axis in the cylinder for either maximizing (the volume of) the first cylinder chamber (such that the needle is in the  
10 opened position) or maximizing (the volume of) the second cylinder chamber (such that the needle is in the closed position).

The longitudinal direction may be parallel to a central axis. The cylinder, the piston, the needle, the needle seat, the nozzle, and/or the mixing portion may extend  
15 at least substantially along the central axis. A diffuser portion may be formed downstream of the mixing portion. The diffuser portion may extend along the central axis. In one embodiment, the (whole) ejector extends substantially along the central axis.

20 A piston area is a cross-section area of the piston. The piston area may be defined within a plane perpendicular to the longitudinal direction.

In one embodiment, the piston area is at least 1000 times a flow cross-section of the equalization passage. Especially, the piston area may be at least 1600 times  
25 the flow cross-section of the equalization passage.

If the piston area is increased, a displacement of the piston by a certain distance corresponds to larger volume change of the second cylinder chamber. This helps to limit the piston's velocity.

During the transition from the opened position to the closed position of the needle, fluid flows from the first cylinder chamber through the equalization passage to the second cylinder chamber. For given circumstances, the flow cross-section of the equalization passage limits, by its flow resistance, a flow rate (e.g. measured in ml/s) between the first cylinder chamber to the second cylinder chamber. The total volume change of the second cylinder chamber during opening increases with increasing piston diameter. By increasing the piston area while the flow cross-section of the equalization passage and the stroke of the piston remain the same, a closing time is extended. The piston's velocity during closing is slower. In more detail, the piston's velocity reaches a substantially constant value shortly after transition from the opened position to the closed position has started. This value may be related to the flow rate divided by the piston area.

Additionally or alternatively, the piston area may be at least 1200 times a flow cross-section of the drain passage, especially at least 1920 times.

For given circumstances, the flow cross-section of the drain passage limits a fluid discharge rate (e.g. measured in ml/s), with which fluid can be discharged from the second cylinder chamber via the drain passage when the pilot valve is open. During transition from the closed position to the opened position, a net flow rate for the second cylinder chamber may be (at least substantially) determined by the fluid discharge rate and the flow rate of fluid entering through the equalization passage. The piston's velocity may reach a substantially constant value shortly after transition from the closed position to the second position has started. This value may be related to the net flow rate divided by the piston area. If the piston area and hence the total volume change of the second cylinder chamber required for opening are increased, the opening time is extended.

Naturally, if the piston area increases with respect to the flow cross-section of the equalization passage while the flow cross-section of the drain passage remains

the same, the piston area increases with respect to the drain passage as well. Vice versa, if the piston area increases with respect to the flow cross-section of the drain passage while the flow cross-section of the equalization passage remains the same, the piston area increases with respect to the equalization passage as well.

According to one aspect, a needle seat area, which is a cross-section area of the needle seat where the needle engages the needle seat in the closed position, is in the range from 1,005 to 1,4 times a flow cross-section of the nozzle. The cross-section area of the needle seat is particularly small. Accordingly, the effects of pressure changes at a needle tip when then the needle is arriving at the needle seat and starting to lift off from the needle seat are minimized. This facilitates smooth and controlled opening and closing of the ejector.

According to a further aspect, the ejector may comprise a housing. This ensures protection of the components inside the housing.

The housing may include a main sleeve. An interior of the main sleeve may extend along the central axis. The housing may further include a top cover. The top cover can be fixed to an end of the main sleeve in the longitudinal direction at a side opposite to the outlet. The top cover may be removably fixed to the main sleeve. This facilitates maintenance.

According to another aspect, the pilot valve is a solenoid valve. Solenoid valves are particularly inexpensive, reliable, and easy to control. It is not necessary to control an exact opening degree of the pilot valve. The present invention ensures smooth opening and closing also in the case that the pilot valve can be switched only between an open state and a closed state. No additional intermediate states of the pilot valve are needed in order to keep the movement speed of the needle below a pre-determined threshold.

In one embodiment, the piston area corresponds to at least 20 times the needle seat area. Hence, the effects of pressure changes when then the needle is arriving at the needle seat and starting to lift off from the needle seat can be at least substantially neglected compared to the effects of the fluid flows into and out of the first cylinder chamber and the second cylinder chamber.

According to one aspect, a stroke of the needle between the closed position and the opened position correspond to at least  $2 \cdot (A_{\text{noz}}/\pi)^{0.5}$ , where  $A_{\text{noz}}$  is the flow cross-section of the nozzle. When the needle is in its opened position, it is sufficiently retracted to ensure low flow resistance against fluid flow from the primary inlet to the nozzle. This is beneficial for efficiency.

According to another aspect, the ejector comprises a check valve function for preventing fluid flow from the outlet to the secondary inlet. Hence, elements of a refrigeration circuit employing the ejector cannot be damaged by such a back flow.

The first cylinder chamber may be a piston-rod side cylinder chamber. The second cylinder chamber may be the cylinder chamber in the same cylinder at the other side of the piston.

According to one aspect, the needle may be formed integrally with the piston. The needle may be a piston rod at the same time. This is a particularly reliable, cost-effective, and lightweight implementation. It may include at least one hole extending thorough the piston.

In one embodiment, the equalization passage is formed (completely) in the piston. This allows fast and cost-efficient production.

According to another aspect, the flow cross-section of the equalization passage may be in the range from 1,2 to 2,5 times the flow cross-section of the drain passage when the pilot valve is in its open state. This ensure that a flow resistance of the drain passage is higher than a flow resistance of the equalization passage.

5 Only a slight pressure drop from the first cylinder chamber to the second cylinder portion occurs even during the needle's transition from the closed position to the opened position. The movement velocity of the piston and the needle can be precisely controlled and kept low. This further facilitates smooth opening of the ejector.

10 The flow cross-section of the drain passage can be determined by the flow cross-section of the pilot valve. The pilot valve can be designed to be as small as possible. This reduces the costs. Accordingly, the flow cross-section of the equalization passage may be in the range from 1,2 to 2,5 times a flow cross-section of the pilot valve when the pilot valve is in its open state.

15 In one embodiment, a flow cross-section of the chamber inlet is larger than the flow cross-section of the equalization passage. For example, the flow cross-section of the chamber inlet may be at least 5 times, especially at least 10 times, the flow cross-section of the equalization passage. The amount of fluid leaving the first cylinder chamber through the equalization passage, especially if the pilot valve is open, can be easily replaced. This ensures that the pressure in first cylinder chamber is at least substantially maintained when the pilot valve is open and even during the transition from the closed state to the open state, i.e. while the (volume of) the first cylinder chamber is increasing.

20 According to one aspect, the needle seat is at least axially fixed with respect to the housing. This facilitates precise opening and closing of the ejector.

The nozzle may be arranged in an interior of the housing. It may be at least axially fixed with respect to the housing. The nozzle may comprise a throat portion and a divergent nozzle portion. The throat portion may define the flow cross-section of the nozzle. The divergent nozzle portion may be arranged downstream of the throat portion. It may be of a conical shape, wherein an inner diameter increases towards a downstream end of the nozzle. The downstream end of the nozzle may protrude towards the mixing portion.

In one embodiment, a nozzle inlet is formed directly upstream of the nozzle, wherein the nozzle inlet tapers toward the nozzle, wherein the needle seat is located in the nozzle inlet, and wherein a length of the nozzle inlet may correspond to at least 1,8 times the stroke of the needle between the closed position and the opened position. This ensures proper flow from the fluid supplied at the primary inlet into the nozzle and hence low flow resistance when the ejector is in the open state.

The nozzle inlet and the nozzle can be formed in a one-piece component, e.g. in a nozzle insert. The nozzle insert may be mounted to an insert assembly holder that is mounted in the housing, e.g. in an interior of the main sleeve. The nozzle insert may be fixed to the housing. However, it may be removably fixed to the housing in order to facilitate maintenance.

According to one aspect, the ejector can comprise a resilient member acting against minimizing (the volume of) the second cylinder chamber by the piston. For example, the resilient member urges the piston towards maximizing (the volume of) the second cylinder chamber. In other words, the resilient member may urge the needle towards its closed position. The resilient member may engage directly with the piston and/or directly with the needle. For example, the resilient member may be provided between an end wall of the cylinder at the side of the second cylinder chamber and the piston. The resilient member facilitates the transition of

the needle from its opened position to its closed position. The resilient member may include a coil spring.

5 In one embodiment, the ejector is configured such that the opening time of the needle is at least 0,5 s, e.g. at least 1 s. The long opening time prevents fast pressure variations and hence reduces a risk of damages in a refrigeration circuit employing the ejector.

10 Additionally or alternatively, the ejector is configured such that the closing time of the needle is at least 1 s, e.g. at least 2 s. The long closing time prevents fast pressure variations and hence reduces a risk of damages in a refrigeration circuit employing the ejector.

15 In one embodiment, the ejector is configured such that the needle moves, during the transition from its closed position to its opened position (in normal operation), with a substantially constant velocity over a displacement length corresponding to at least 70 % of the stroke. This ensures controlled and smooth opening and reduces the risk of damages in any refrigeration circuit employing the ejector.

20 Additionally or alternatively, the ejector is configured such that the needle moves, during the transition from its opened position to its closed position (in normal operation), with a substantially constant velocity over a displacement length corresponding to at least 70 % of the stroke. This ensures controlled and smooth closing and reduces the risk of damages in any refrigeration circuit employing the  
25 ejector.

Substantially constant velocity may mean that the velocity changes by 15 % at the maximum during the respective movement phase.

According to another aspect, the flow cross-section of the nozzle is at least 50 mm<sup>2</sup>. Hence, the ejector exhibits a high capacity.

In one embodiment, the cylinder is formed by a cylinder insert and the top cover.

5 The cylinder insert may be inserted in an interior of the main sleeve. The cylinder insert may be removably mounted in the main sleeve. This facilitates maintenance.

According to another aspect, the ejector may comprise an elastic member, for  
10 example a spring, especially a coil spring.

The elastic member may bias the cylinder insert against the top cover. The second cylinder chamber may be arranged at the side of the top cover. This ensures proper sealing between those elements. This ensures that the pressure propaga-  
15 tion to the second cylinder chamber is determined by the pressure propagation from the first cylinder chamber to the second cylinder chamber via the equalization passage. A risk of substantial leakage and pressure propagation from the primary inlet to the second cylinder chamber that bypasses the equalization pas-  
20 sage is reduced. An annular end face of the cylinder insert for abutting on the top cover may be ground flat.

The elastic member may be squeezed between the cylinder insert and a member that is at least axially fixed with respect to the housing. For example, the elastic member may be squeezed between the cylinder insert and the insert assembly  
25 holder.

In one embodiment, the ejector comprises a filter between the primary inlet and the needle seat. The filter may be arranged circumferentially about the needle and the needle seat. It may be supported by the elastic member.

According to another aspect, the needle is made of a first material and the needle seat is made of a second material, wherein a hardness of the second material is higher than a hardness of the first material. For example, the hardness of the second material may correspond to at least 1,4 times the hardness of the second material. In one embodiment, the nozzle insert (which includes the needle seat) is made of the second material.

In one embodiment, a needle tip portion of the needle includes an intermediate section with reduced tapering, e.g. a cylindrical intermediate section. The cylindrical intermediate portion causes a "dead zone" at opening, especially at an initial stage of opening: When the needle is not moved away from abutment with the needle seat by at least a certain distance, there is no fluid flow out of the nozzle. In other words, a substantial fluid flow out of the nozzle requires that the needle is moved away from abutment with the needle seat by at least the certain distance. This reduces a sensitivity of the ejector for pressure and/or flow pulsations of the fluid, in particular at the primary inlet. Without the dead zone, even small pulsations of the fluid may lift the needle and this can result in unintended pulsating fluid flow out of the nozzle.

The problem mentioned above is further solved by an ejector assembly comprising at least two ejectors according to any one of the described embodiments and modifications.

The ejectors may be arranged in parallel.

In one embodiment, a flow cross-section of a second one of the at least two ejectors is different from a flow cross-section of a first one of the at least two ejectors. For example, the flow cross-section of the second one can be at least 1,2 times the flow cross-section of the first one. By closing both the first one and the second

one, opening only the first one, opening only the second one, or opening both the first one and the second one, four different flow rates can be set.

5 If it is referred to a flow cross-section of an element (like a passage, a channel, or the like, e.g. the nozzle), this may mean a minimum cross-section of the respective element along an intended flow direction through the element.

Additional features, advantages and possible applications of the invention result from the following description of exemplary embodiments and the drawings. All  
10 the features described and/or illustrated graphically here form the subject matter of the invention, either alone or in any desired combination, regardless of how they are combined in the claims or in their references back to preceding claims.

Fig. 1 shows an embodiment of an ejector according to the present invention in  
15 an open state in a cross-sectional view on a plane extending along a central axis of the ejector;

Fig. 2 is an enlarged upper section of Fig. 1;

20 Fig. 3 shows the upper part of the ejector of Fig. 2 in a cross-sectional view on a plane, which extends along the central axis of the ejector as well but is perpendicular to the plane shown in Fig. 1 and Fig. 2;

Fig. 4 shows an enlarged section of Fig. 1 around a needle seat and a nozzle,  
25

Fig. 5 shows a second embodiment of an ejector according to the present invention in an open state in a cross-sectional view on a plane extending along a central axis of the ejector: and

30 Fig. 6 is a magnified section of Fig. 5 around a needle tip.

An embodiment of an ejector 1 according to the present invention is shown in Fig. 1. The ejector 1 comprises a primary (fluid) inlet 2, a secondary (fluid) inlet 7, and an (fluid) outlet 12. The primary inlet 2 may be also referred to as high pressure inlet 2. The ejector 1 extends along a central axis C. A longitudinal direction L is parallel to the central axis C.

If the ejector 1 is in an open state as shown in Figs. 1 to 4, fluid can flow from the first inlet 2 through a nozzle 5, a mixing portion (which includes a convergent mixing portion 6 and a cylindrical mixing portion 10), and a diffuser portion 11 to the fluid outlet 12. In addition, fluid is drawn from the secondary inlet 7 into the mixing portion 6. In other words, the fluid drawn from the secondary inlet 7 joins the fluid from the primary inlet 2 in the convergent mixing portion 6. This results in mixing of the fluid from the primary inlet 2 and the fluid drawn from the secondary inlet 7 in the convergent mixing portion 6 and the cylindrical mixing portion 10 that follows downstream of the convergent mixing portion 6.

The ejector 1 includes a needle valve mechanism with a needle 20 and a needle seat 26.

If the needle 20 is in a closed position (not shown), it abuts the needle seat 26 and blocks the fluid connection between the primary inlet 1 and the nozzle 5. This prevents that fluid from the primary inlet 1 can enter into the nozzle 5 and flow further into the convergent mixing portion 6. This corresponds to a closed state of ejector 1.

If the needle 20 is in an opened position as shown in Figs. 1 to 4, the needle 20 is lifted from the needle seat 26 by a needle stroke S (see Fig. 4). This allows fluid flow from the primary inlet 2 into the nozzle 5. The stroke S is the displacement of the needle 20 along the longitudinal direction L between its opened position

and its closed position. The stroke S may be at least 10 mm, for example in the range from 12 mm to 30 mm.

In this exemplary embodiment, a housing 70 of the ejector 1 includes a main sleeve 71, an upstream-side top cover 76, a first diffuser tube 74, and a second diffuser tube 75. The first diffuser tube 74 and the second diffuser tube 75 form at least a downstream part of the diffuser portion 11. The housing 70 further includes a primary (fluid) inlet connector 72, which is fixed to the main sleeve 71 and forms the primary inlet 2, and a secondary (fluid) inlet connector 73, which is fixed to the main sleeve 71 and forms the secondary inlet 7.

The ejector 1 further comprises an actuating mechanism 30 for moving the needle 20 along the longitudinal direction L between the opened position and the closed position.

The actuating mechanism 30 comprises a pilot valve 50 and a piston 31. The piston 31 is arranged in a cylinder 35 and can be axially displaced within the cylinder 35 (i.e. along the central axis C). The needle 20 is mechanically connected to the piston 31 such that the axial movement of the piston 31 in the cylinder 35 is transferred to movement of the needle 20 along the longitudinal direction L. Accordingly, the needle 20 can be moved from its opened position to its closed position and vice versa by corresponding axial movements of the piston 31. In this embodiment, the needle 20, the piston 31, and the cylinder 35 are all arranged coaxially along the central axis C and the needle 20 is at least axially fixed to the piston 31. In more detail, the needle 20 and the piston 31 can be formed integrally (in one piece) as shown in Figs. 1 to 3. In other words, the needle 20 (in particular a needle stem 25) also constitutes a piston rod for the piston 31.

The cylinder 35 can be formed by a cylinder insert 77 and the top cover 76 as shown in Figs. 1 to 3. The cylinder insert 77 is arranged in an interior of the main

sleeve 71 and directly abuts the top cover 76. The cylinder insert 77 guides the piston 31 and its piston rod (which is the needle 20 in this embodiment).

5 The piston 31 is configured to form a first cylinder chamber 37 and a second cylinder chamber 38 within the cylinder 35. It can divide an interior of the cylinder 35 into the first cylinder chamber 37 and the second cylinder chamber 38 (along the longitudinal direction L).

10 A volume of the first cylinder chamber 37 is maximized (maximal) when the needle 20 is in its opened position. It is minimized when the needle 20 is in its closed position. It may decrease (at least substantially) to a minimum volume (small residual volume) when the needle 20 is in its closed position (not shown, corresponds to a lowermost possible position of the piston 31 in Figs. 1 to 3).

15 A volume of the second cylinder chamber 38 is maximized (maximal) if the needle 20 is in its closed position. It is minimized when the needle 20 is in its opened position (correspond to an uppermost possible position of the piston 31 as shown in Figs. 1 to 3). It may decrease (at least substantially) to zero when the needle 20 is in its opened position. However, in the exemplary embodiment, an annular end wall 40, which is provided on a surface of the piston 31 facing the second cylinder chamber 38, causes that a residual volume of the second cylinder chamber 38 remains even if the needle 20 is in its opened position. This ensures that the equalization passage 32 is not closed when the needle 20 is in the opened position.

25 At a side of the cylinder insert 77 in the longitudinal direction L that faces away from the top cover 76, a primary (fluid) inlet chamber 3 is formed. The primary inlet connector 72 opens into the primary inlet chamber 3.

The first cylinder chamber 37 is in fluid communication with the primary inlet 2 via a chamber inlet 36. In this embodiment, the chamber inlet 36 is a fluid connection provided between the primary inlet chamber 3 and an end of the cylinder 35 in the longitudinal direction L at the side of the needle 20 (an end of the cylinder 35 at the side of the first cylinder chamber 37, i.e. a lower end of the cylinder 35 in Figs. 1 to 3). The chamber inlet 36 may be formed in the cylinder insert 77, for example as at least one bore extending along the longitudinal direction L. In the embodiment shown in Figs. 1 and 2, four or six of such bores are formed in the cylinder insert 77. Two of them can be seen in Figs. 1 and 2.

Further, the other end of the cylinder 35 in the longitudinal direction L (an end of the cylinder 35 at the side of the second cylinder chamber 38, i.e. an upper end of the cylinder 35 in Figs. 1 to 3) is in fluid communication with the secondary inlet 7 via a drain passage. The pilot valve 50 is arranged in the drain passage. When the pilot valve 50 is in its closed state, it blocks (closes) the drain passage. When the pilot valve 50 is in its open state, the drain passage is open and the second cylinder chamber 38 is in fluid communication with the secondary inlet 7. In other words, the drain passage is formed between the second cylinder chamber 38 on the one hand and, on the other hand, the secondary inlet 7 and/or a space that is in (direct) fluid communication with the secondary inlet 7. In this embodiment, the drain passage is formed between the second cylinder chamber 38 and a secondary (fluid) inlet chamber 8, which is in direct fluid communication with the secondary inlet 7.

In a modification (not shown), the second cylinder chamber 38 is in fluid communication with the outlet 12 via the drain passage when the pilot valve 50 is in an open state. In other words, the drain passage with the solenoid valve 50 is formed between the second cylinder chamber 38 and the fluid outlet 12 and/or a space that is in fluid communication with the fluid outlet 12 in this case. Of course, it is also possible to provide a drain passage with two branches, one branch for fluid

communication of the second cylinder chamber 38 with the secondary inlet 7 and another branch for fluid communication of the second cylinder chamber 38 with the fluid outlet 12. A blocking means, e.g. a check valve, can be employed to prevent fluid flow from the secondary inlet 7 to the fluid outlet 12 via the drain passage.

As shown in Fig. 1, the drain passage may be formed completely within the ejector 1. It is integrated in the ejector 1 as such.

Turning now to Fig. 3, the drain passage includes a fluid connection 39 between the upper end of the cylinder 35 (the second cylinder chamber 38) and an upstream side of the pilot valve 50. Said fluid connection 39 may be also referred to as the chamber outlet 39. As can be seen in Fig. 3, the chamber outlet 39 may be formed by at least one channel, for example two channels, within the top cover 76.

Further, a downstream side of the pilot valve 50 is in fluid communication with the secondary inlet 7. This can be seen in Figs. 1 and 2, where the plane of the depicted cross-section is perpendicular to the one shown in Fig. 3. In the present embodiment, the drain passage includes a first fluid passage 54 formed in the top cover 76, a second fluid passage 55 that is also formed in the top cover 76, a fluid passage 56 formed in the main sleeve 71, and a fluid passage 57 formed between the main sleeve 71 and an insert assembly holder 78. The fluid passage 57 is a substantially annular gap between the main sleeve 71 and the insert assembly holder 78. The drain passage opens into the secondary inlet chamber 8. The secondary inlet connector 73 also opens into the secondary inlet chamber 8. Hence, the downstream side of the pilot valve 50 is in fluid communication with the secondary inlet 7, and the second cylinder chamber 38 is in fluid communication with the secondary inlet 7 when the pilot valve 50 is in its open state.

In addition, the second cylinder chamber 38 is in fluid communication with the first cylinder chamber 37. The fluid communication is provided by an equalization passage 32. In this embodiment, the equalization passage 32 includes longitudinal bore through the piston 31. The equalization passage 32 may be formed completely within the ejector 1. It is integrated in the ejector 1 as such.

The pilot valve 50 includes a valve seat 51, a valve member 52, and an actuator 53. The actuator 53 is configured to switch the pilot valve 50 between an open state and a closed state thereof. In this embodiment, the pilot valve 50 is a solenoid valve. Hence, the actuator 53 is a solenoid actuator. The pilot valve 50 is a part of the ejector 1. In particular, the valve seat 51 may be integrally formed with the housing 70 or an insert fixed to the housing. In the exemplary embodiment, the valve seat 51 is mounted within the top cover 76.

In the following, the operation will be described. It is assumed that the needle 20 is in its opened position and that the pilot valve 50 is in its open state at the beginning. In other words, the ejector 1 is in its open state at the beginning.

In normal operation, fluid is supplied at the primary inlet 2 with a high primary pressure. Consequently, high-pressure fluid from the primary inlet 2 flows through the chamber inlet 36 into the first cylinder chamber 37. A (minimum) flow cross-section  $A_{pci}$  of the chamber inlet 36 is larger than a (minimum) flow cross-section  $A_{eq}$  of the equalization passage 32. For example, the flow cross-section  $A_{pci}$  of the chamber inlet 36 may be at least 5 times, especially at least 10 times, the flow cross-section  $A_{eq}$  of the equalization passage 32. In the exemplary embodiment shown in Fig. 1, the flow cross-section  $A_{pci}$  of the chamber inlet 36 is the sum of the cross-sectional areas of the bores constituting the chamber inlet 36, which are formed in the cylinder insert 77.

Due to the chamber inlet 36, the fluid pressure in the first cylinder chamber 37 at least substantially corresponds to the primary pressure at the primary inlet 2. The fluid pressure in the first cylinder chamber 37 forces the piston 31 (along the longitudinal direction L) towards the top cover 76 and hence the needle 20 towards its opened position, against a resilient force provided by a resilient member 33. In the depicted embodiment, the resilient member 33 is a coil spring.

In normal operation, fluid is supplied at the secondary inlet 7 with a secondary pressure. The secondary pressure is less than the primary pressure at the primary inlet 2 but higher than an outlet pressure at the fluid outlet 12. In other words, there is a pressure drop from the primary pressure to the secondary pressure. This pressure drop is used for jetting the fluid from the primary inlet chamber 3 through the nozzle 5 into the convergent mixing portion 6 when the needle 20 is in its opened position. The fluid jetted out of the nozzle 5 has a high velocity. The ejection through the nozzle 5 results in a pressure drop from the primary inlet chamber 3 to the convergent mixing portion 6. Further, when the needle 20 is in its opened position such that fluid from provided at the primary inlet 2 is jetted out of the nozzle 5, fluid provided at the secondary inlet 7 is sucked from the secondary inlet chamber 8 through a secondary fluid passageway 9 into the convergent mixing portion 6. The fluid from the primary inlet 2, which is ejected by the nozzle 5, and the fluid sucked from the secondary inlet chamber 8 mix in the convergent mixing portion 6 and the cylindrical mixing portion 10.

As noted above, it is assumed that the pilot valve 50 is in its open state at the beginning. A small fluid flow from the first cylinder chamber 37 to the second cylinder chamber 38 via the equalization passage 32 occurs. Furthermore, fluid flows from the second cylinder chamber 38 to the secondary inlet chamber 8 via the drain passage because the pilot valve 50 is in its open state. Hence, there is a small pressure drop from the first cylinder chamber 37 to the second cylinder chamber 38 which is sufficient for keeping the needle 20 in the opened position.

The pressure drop is sufficiently high for holding the piston 31 in abutment with the top cover 76 against the restoring force of the resilient element 33.

The flow cross-section  $A_{eq}$  of the equalization passage 32 is comparatively small. It may be less than  $10 \text{ mm}^2$ , e.g. in the range from  $0,5 \text{ mm}^2$  to  $4 \text{ mm}^2$ . Additionally or alternatively, a value corresponding to the square of a length  $L_{eq}$  of the equalization passage 32 (along a flow direction therethrough) may be at least 15 times, for example at least 25 times, the flow cross-section  $A_{eq}$  of the equalization passage 32 ( $L_{eq}^2 \geq 15 \cdot A_{eq}$ ). The equalization passage 32 exhibits considerable flow resistance.

If the equalization passage 32 has a cylindrical shape, its flow cross-section  $A_{eq}$  is  $\pi \cdot (D_{eq}/2)^2$ , wherein  $D_{eq}$  is a diameter of the equalization passage 32.

In general, the flow cross-section  $A_{eq}$  of the equalization passage 32 can be larger or the same as a (minimum) flow cross-section  $A_{dp}$  of the drain passage (when the pilot valve 50 is in its open state).

When the ejector 1 is in the open state, an intermediate pressure occurs in the second cylinder chamber 38. The intermediate pressure is lower than the pressure in the first cylinder chamber 37 (which may at least substantially correspond to the primary pressure). The intermediate pressure is larger than the secondary pressure. The exact value of the intermediate pressure depends, inter alia, on the flow resistance and hence on the flow cross-section  $A_{eq}$  of the equalization passage 32 as well as on a flow resistance and hence on the flow cross-section  $A_{dp}$  of the drain passage and on a ratio  $A_{eq}/A_{dp}$ .

If the flow cross-section  $A_{eq}$  of the equalization passage 32 is considerably smaller than the flow cross-section  $A_{dp}$  of the drain passage ( $A_{eq}/A_{dp} \ll 1$ ), the flow resistance of the drain passage is considerably smaller than the flow resistance of

the equalization passage 32. When the pilot valve 50 is open, fluid can be discharged from the second cylinder chamber 38 into the secondary inlet chamber 8 through the drain passage in an almost unobstructed manner. The intermediate pressure in the second cylinder chamber 38 will become almost as low as the secondary pressure if the pilot valve 50 is in its open state.

However, according to one aspect of the present disclosure, the flow cross-section  $A_{eq}$  of the equalization passage 32 may be larger than the flow cross-section  $A_{dp}$  of the drain passage ( $A_{eq}/A_{dp} > 1$ ). Especially, the flow cross-section  $A_{eq}$  of the equalization passage 32 may be in the range from 1,2 to 2,5 times the flow cross-section  $A_{dp}$  of the drain passage ( $1,2 \cdot A_{dp} \leq A_{eq} \leq 2,5 \cdot A_{dp}$ ). The flow resistance of the equalization passage 32 is smaller than the flow resistance of the drain passage. However, the pressure-drop from first cylinder chamber 37 to the second cylinder chamber 38 is smaller in that case. Nevertheless, the intermediate pressure in the second cylinder chamber 38 is less than pressure in the first cylinder chamber 37 when the pilot valve 50 is in its open state. In other words, there is nevertheless the small pressure drop. The small pressure drop remains due to the flow resistance exhibited by the equalization passage 32 and due to ongoing discharge of fluid out of the second cylinder chamber 38. For example, the ejector 1 may be configured such that a pressure drop from the first cylinder chamber 37 to the second cylinder chamber 38 (i.e. a pressure drop along the equalization passage 32) is less than 10 bar, especially less than 3 bar, in normal operation if the pilot valve 50 after the pilot valve 50 is open for at least 0,2 s. This ensures a smooth transition from the closed position of the needle 20 to its opened position (and hence a smooth transition from the closed state of the ejector 1 to the open state of the ejector 1) even if the actuating mechanism is controlled by a solenoid valve.

Accordingly, the ejector 1 may be configured such that an opening time of the needle 20 is at least 0,5 s in normal operation, especially at least 1 s. The opening

time may be a time needed for the movement of the needle 20 from its closed position to its opened position in normal operation.

5 The (minimum) flow cross-section  $A_{dp}$  of the drain passage may correspond to a flow cross-section  $A_{pv}$  of the pilot valve 50 when the pilot valve 50 is in its open state.

Starting from the situation that the needle 20 is in its opened position and that the pilot valve 50 is open, as long as the pilot valve 50 remains opened, the intermediate pressure is less than the pressure in the first cylinder chamber 37. The needle 20 is kept in its opened position while the pilot valve 50 remains open. The ejector 1 is configured such that, in this situation, the force on the piston 31 resulting from the pressure difference between the intermediate pressure in the second cylinder chamber 38 and the pressure in the first cylinder chamber 37 is sufficient to (at least substantially) overcome the resilient force of the spring 33.

Now it is assumed that the pilot valve 50 is closed in this situation. No more fluid can be drained from the second cylinder chamber 38 to the secondary inlet chamber 8. As the equalization passage 32 remains open, the pressure in the second cylinder chamber 38 increases towards the pressure in the first cylinder chamber 37 (which may at least substantially correspond to the primary pressure). In addition, the resilient member 33 urges the piston 31 away from the top cover 76. The piston 31 start to move along the longitudinal direction L towards the needle seat 26. Accordingly, the needle 20 starts to move along the longitudinal direction L towards the needle seat 26 (i.e. towards its closed position).

The flow cross-section  $A_{eq}$  of the equalization passage 32 is small compared to a piston area  $A_P$  of the piston 31. The piston area  $A_P$  may correspond to at least 1000 times, e.g. to at least 1600 times, especially to at least 2100 times, the flow

cross-section  $A_{eq}$  of the equalization passage 32. This limits a movement speed of the piston 31.

This ensures a smooth transition from the opened position of the needle 20 to its closed position (and hence a smooth transition from the open state of the ejector 1 to the closed state of the ejector 1) even if the actuating mechanism is controlled by a solenoid valve that can only be switched between the open state and the closed state and does not provide a possibility to adjust any opening degree in-between.

The ejector 1 may be configured such that a closing time of the needle 20 is at least 1 s in normal operation, especially at least 2 s. The closing time may be a time needed for the movement of the needle 20 from its opened position to its closed position in normal operation.

For example, the piston area  $A_P$  can be in the range from 2000 mm<sup>2</sup> to 10000 mm<sup>2</sup>.

If the piston 31 has a rotationally symmetric basic shape, its flow cross-section  $A_P$  is  $\pi \cdot (D_P/2)^2$ , wherein  $D_P$  is a diameter of the piston 31.

At the end of the transition from the open state of the ejector 1 to its closed state, the needle 20 abuts the needle seat 26. The fluid connection from the primary inlet chamber 3 to the nozzle 5 (and hence from the primary inlet 2 to the nozzle 5) is blocked. No more fluid is ejected by the nozzle 5. Accordingly, no further fluid is sucked from the secondary inlet 7 into the convergent mixing portion 6.

In order to bring the ejector 1 from its closed state to its open state again, the pilot valve 50 is opened again. Fluid is discharged from the second cylinder chamber 38 to the secondary inlet chamber 8 and the pressure in the second cylinder

chamber 38 decreases towards the intermediate pressure mentioned above. Due to the pressure drop from the first cylinder chamber 37 and the second cylinder chamber 38, the piston 31 starts to move along the longitudinal direction L such that the needle 20 is retracted from the needle seat 26 towards the opened position.

A cross-sectional area  $A_{nsz}$  of the needle seat 26 (a needle seat area  $A_{ns}$ ) is only a bit larger than a (minimum) flow-cross section  $A_{noz}$  of the nozzle 5. In particular, the needle seat area  $A_{nsz}$  may be in the range from 1,005 to 1,4 times the flow-cross section  $A_{noz}$  of the nozzle 5. This allows for the needle 20 having a small diameter. Hence, a flow resistance for fluid flowing from the primary inlet 2 to the nozzle 5 if the needle 20 is in its opened position is particularly low. Furthermore, the comparatively small needle seat area  $A_{nsz}$  ensures smooth and precise beginning of the transition from the closed position of the needle 20 to its opened position.

Typically, an increased initial force is required for starting the transition from the closed position to the opening position (i.e. from retracting the needle 20 from the closed position, particularly from abutment with the needle seat 26). The force needed for further retraction of the needle 20 may decline. The initial force depends, inter alia, on a size of a contact area between the needle 20 and the needle seat 26. The initial force must be provided by the actuating mechanism 30. It is beneficial that the needle seat area  $A_{nsz}$  is as close as possible to the flow-cross section  $A_{noz}$  of the nozzle 5. This reduces the required initial force. As a consequence, a smaller and less expensive actuating mechanism 30 can be used.

Furthermore, the small needle seat area  $A_{ns}$  reduces the risk of unintentional lift-off of the needle 20 from the needle seat 26 in the case of pressure peaks applied from the secondary inlet 7 and our the outlet 12.

If the nozzle 5 is formed rotationally symmetric, its flow cross-section  $A_{noz}$  is  $\pi \cdot (D_{noz}/2)^2$ , wherein  $D_{noz}$  is a minimum inner diameter of the nozzle 5. If the needle seat 26 has a circle-shape, the needle seat area  $A_{nsz}$  is the area encircled by the needle seat 26 and corresponds to  $\pi \cdot (D_{ns}/2)^2$ , wherein  $D_{ns}$  is a diameter of the needle seat 26.

The flow cross-section  $A_{noz}$  can be at least 50 mm<sup>2</sup>. This corresponds to a diameter of 8,0 mm if the nozzle 5 is formed rotationally symmetric. For example, the flow cross-section  $A_{noz}$  of the nozzle 5 can be in the range from 70 mm<sup>2</sup> to 150 mm<sup>2</sup>.

Fig. 4 shows that, in this exemplary embodiment, an end portion of the needle 20 at the side of the needle seat 26 includes, seen along the longitudinal direction L, a needle tip 21, a first conical needle portion 22, and a second conical needle portion 24. A taper angle of the first conical needle portion 22 is larger than a taper angle of the second conical needle portion 24. Hence, an annular edge 23 is formed at the border between the first conical needle portion 22 to the second conical needle portion 24. (Only) the annular edge 23 abuts onto the needle seat 26 when the needle 20 is in its closed position.

The needle 20 can be made of Aluminum or an aluminum alloy.

In the depicted embodiment, the flow resistance of the drain passage is larger than the flow resistance of the equalization passage 32. This helps to ensure slow and controlled opening of the ejector 1. Especially, the flow cross-section  $A_{pv}$  of the pilot valve 50 may be smaller than the flow cross-section  $A_{eq}$  of the equalization passage 32. Additionally or alternatively, the flow cross-section  $A_{pv}$  of the pilot valve 50 (in its open state) may be less than 1,8 mm<sup>2</sup>.

The piston area  $A_P$  of the piston 31 may be larger than a squared value of a stroke of the piston rod. In this example, the stroke of the piston rod is the same as the stroke  $S$  of the needle 20. For example, the piston area  $A_P$  may correspond to at least 8 times, especially at least 11 times, the squared value of the stroke  $S$  ( $A_P \geq 8 \cdot S^2$ , especially  $A_P \geq 11 \cdot S^2$ ). Hence, the axial displacement of the piston 31 by the stroke  $S$  corresponds to a large change of the volumes of the first cylinder chamber 37 and the second cylinder chamber 38. This helps to ensure slow movement of the piston 31 and hence the needle 20 during transitions between the opened position and the closed position. Moreover, a pronounced synergistic effect can be obtained by combining this aspect with the aspect explained above, according to which the flow cross-section  $A_{eq}$  of the equalization passage 32 may be small compared to the piston area  $A_P$  of the piston 31.

Additionally or alternatively, the piston area  $A_P$  of the piston 31 may be large compared to the needle seat area  $A_{ns}$ . This reduces the influence of the additional lifting force on the opening and results in smoother opening.

The nozzle 5 is formed directly downstream of a nozzle inlet 4. The nozzle inlet 4 extends the longitudinal direction  $L$  and tapers towards the nozzle 5. In more detail, it may extend along the central axis  $C$  as in the figures.

An annular, line-shaped portion of the nozzle inlet 4, onto which the annular edge 23 abuts when the needle 20 is in its closed position, constitutes the needle seat 26.

The nozzle inlet 4 is configured to guide the fluid supplied at the primary inlet 2 into the nozzle 5. More precisely, it guides the fluid supplied at the primary inlet 2 from the primary inlet chamber 3 into the nozzle 5 (when the needle 20 is in its opened position).

The nozzle inlet 4 can be a conical nozzle inlet. A taper angle of the nozzle inlet 4 is smaller than the taper angle of the first conical needle portion 22 but larger than the taper angle of the second conical needle portion 24 (e.g., see Fig. 4).

5 In this exemplary embodiment, the needle seat 26 and the nozzle 5 are formed in the same component, namely in a nozzle insert 27. The nozzle insert 27 is a one-piece component. It is mounted in the insert assembly holder 78. The nozzle insert 27 includes the upstream nozzle inlet 4 and the nozzle 5. The nozzle insert 27 can be made of a material having a higher hardness than a material of the needle 20.

For example, the nozzle insert 27 can be made of iron.

15 According to another aspect, a length  $W$  of the nozzle inlet 4 is larger than the stroke  $S$ . For example, the length of the nozzle inlet 4 may correspond to at least 1,8 times the stroke  $S$ . This ensures that the end portion of the needle 20 still protrudes into the nozzle inlet 4 even if the needle 20 is in its opened position. Accordingly, the needle 20 helps, in its opened position, to guide the fluid from the primary inlet chamber 3 smoothly into the nozzle inlet 4 and further into the nozzle 5 and to reduce turbulences.

20 A distance  $Z$  between the nozzle 5 and the needle seat 26 along the longitudinal direction  $L$  (and according to a local flow direction) is small. It may be less than  $0,8 \cdot (A_{noz}/\pi)^{0,5}$ . In other words, the needle seat 26 may be formed directly upstream of the nozzle 5. This facilitates to keep the needle seat area  $A_{nsz}$  small and to reduce the flow resistance.

25 Additionally or alternatively, the stroke  $S$  may correspond to at least  $2 \cdot (A_{noz}/\pi)^{0,5}$ , which corresponds to the  $D_{noz}$  if the nozzle is of rotationally symmetric shape. Especially, the stroke  $S$  may correspond to at least  $2,8 \cdot (A_{noz}/\pi)^{0,5}$ . As a

consequence, the end portion of the needle 20 does not impair fluid flow through the nozzle 5 or the needle seat 20 in its opened position.

The ejector 1 may be configured such that the flow cross-section  $A_{noz}$  of the nozzle 5 constitutes a minimum flow cross-section between the primary inlet 2 and the convergent mixing portion 6 when the needle 20 is in its opened position.

In the exemplary embodiment, the needle 20 never protrudes downstream of the nozzle 5. In other words, the needle 20 never protrudes into the convergent mixing portion 6.

As an additional feature, the depicted embodiment of the ejector 1 provides a check valve functionality for preventing fluid flow from the outlet 12 to the secondary inlet 7. The ejector 1 provides a check member 80 for closing a fluid connection between the mixing portion (in more detail, the convergent mixing portion 6) and the secondary inlet chamber 8. If the ejector 1 is in its closed state, the check member 80 abuts on a check valve seat 79 and blocks fluid flow from the outlet 12 to the secondary inlet 7. If the ejector 1 is in its open state, fluid is sucked from the secondary inlet 7 through the secondary inlet chamber 3 and the secondary fluid passageway 9 into the convergent mixing portion 6. Thereby, the check member 80 is displaced along the longitudinal direction L and lifts off from the check valve seat 79.

An annular end face of the cylinder insert 77 and a corresponding abutment area on the top cover 76 are grounded flat. An elastic member 90 (which is a coil spring in this embodiment) biases the cylinder insert 77 against the top cover. Hence, no significant fluid leakage or pressure propagation can occur directly from the primary inlet chamber 3 to the second cylinder chamber 38. The elastic member 90 is arranged in the primary inlet chamber 3 and coaxially to the needle 20. It is squeezed between the top cover 76 and the insert assembly holder 78.

Optionally, a filter 91 is provided between the primary inlet 2 and the nozzle inlet 4. In the exemplary embodiment, the filter 91 is provided in the primary inlet chamber 3 around the elastic member 90, wherein the elastic member supports (backs up) the filter 91.

The top cover 76 is removably fixed to the main sleeve 71 by screws. If the top cover 76 is detached, the cylinder insert 76 can be taken out of the main sleeve 71 for maintenance.

Naturally, the depicted embodiment is only an exemplary one and the elements can be implemented in other manners and geometries. For example, the end portion of the needle 20 may be formed with another shape (e.g. convexly tapered), the needle seat 26 and the nozzle 5 can be formed two by separate elements, and the like.

Fig. 5 shows an ejector 100 according to a second embodiment of the present invention. The ejector 100 is in general of the same structure than the ejector 1. Hence, only the relevant differences from the ejector 1 are explained in the following and the same reference signs are used for corresponding elements.

The ejector 100 shown in Fig. 5 differs from the ejector 1 of Figs. 1 in that the needle 20 has a modified needle tip 121. Fig. 6 is a magnified section of Fig. 5 around the needle tip 121.

In this embodiment, the needle tip 121 includes an intermediate cylindrical portion 123. In more detail, the needle tip 121 comprises a first tapered portion 122, the cylindrical intermediate portion 123, and a second tapered portion 124. The first tapered portion 122 constitutes a downstream-side end of the needle tip 121 (in the longitudinal direction L). The second tapered portion 124 is adjacent to the

needle stem 25. Seen along the longitudinal direction L, the intermediate portion 123 is arranged between the first tapered portion 122 and the second tapered portion 124. The needle stem 25 and the needle tip 121 may be formed integrally. Due to the cylindrical intermediate portion 123, a substantial fluid flow out of the nozzle 5 occurs only if the needle 20 is moved away from abutment with the needle seat 26 by at least a certain distance, the latter being larger than zero. In other words, there is a "dead zone", in which no or at least no substantial fluid flow through the nozzle 5 occurs when the needle 20 is not in abutment with the needle seat 26 but displaced away by less than the certain distance. This reduces a sensitivity of the ejector 100 for pressure and/or flow pulsations of the fluid at the primary inlet 2.

Fig. 5 also shows a spring-elastic member 81 biasing the check member 80.

**List of reference signs:**

|    |         |                                                          |
|----|---------|----------------------------------------------------------|
|    | 1       | ejector                                                  |
|    | 2       | primary inlet                                            |
|    | 3       | primary inlet chamber                                    |
| 5  | 4       | nozzle inlet                                             |
|    | 5       | nozzle                                                   |
|    | 6       | (convergent) mixing portion                              |
|    | 7       | secondary inlet                                          |
|    | 8       | secondary inlet chamber                                  |
| 10 | 9       | secondary fluid passageway                               |
|    | 10      | (cylindrical) mixing portion                             |
|    | 11      | diffuser portion                                         |
|    | 12      | outlet                                                   |
|    | 20      | needle                                                   |
| 15 | 21, 121 | needle tip                                               |
|    | 22      | first conical needle portion                             |
|    | 23      | annular edge                                             |
|    | 24      | second conical needle portion                            |
|    | 25      | needle stem                                              |
| 20 | 26      | needle seat                                              |
|    | 27      | nozzle insert                                            |
|    | 30      | actuating mechanism                                      |
|    | 31      | piston                                                   |
|    | 32      | equalization passage                                     |
| 25 | 33      | resilient member                                         |
|    | 35      | cylinder                                                 |
|    | 36      | chamber inlet                                            |
|    | 37      | first cylinder chamber                                   |
|    | 38      | second cylinder chamber                                  |
| 30 | 39      | fluid connection (chamber outlet, part of drain passage) |

|    |           |                                              |
|----|-----------|----------------------------------------------|
|    | 40        | annular end wall                             |
|    | 50        | pilot valve                                  |
|    | 51        | valve seat                                   |
|    | 52        | valve member                                 |
| 5  | 53        | actuator                                     |
|    | 54        | first fluid passage (part of drain passage)  |
|    | 55        | second fluid passage (part of drain passage) |
|    | 56, 57    | fluid passage (part of drain passage)        |
|    | 70        | housing                                      |
| 10 | 71        | main sleeve                                  |
|    | 72        | primary inlet connector                      |
|    | 73        | secondary inlet connector                    |
|    | 74        | first diffuser tube                          |
|    | 75        | second diffuser tube76                       |
| 15 | 76        | top cover                                    |
|    | 77        | cylinder insert                              |
|    | 78        | insert assembly holder                       |
|    | 79        | check valve seat                             |
|    | 80        | check member                                 |
| 20 | 81        | elastic member                               |
|    | 90        | elastic member                               |
|    | 91        | filter                                       |
|    | 122       | first tapered section                        |
|    | 123       | intermediate section                         |
| 25 | 124       | second tapered section                       |
|    | C         | central axis                                 |
|    | $D_{noz}$ | diameter (of the nozzle 5)                   |
|    | $D_{ns}$  | diameter (of the needle seat 26)             |
|    | $D_p$     | diameter (of the piston 31)                  |
| 30 | L         | longitudinal direction                       |

**Claims:**

1. Ejector (1; 100) comprising

a primary inlet (2); a secondary inlet (7); and an outlet (12);

5 a nozzle (5) for jetting fluid supplied at the primary inlet (2) into a mixing portion (6, 10) for sucking fluid supplied at the secondary inlet (7) into the mixing portion (6, 10);

a needle (20) and a needle seat (26), wherein the needle seat (26) is arranged downstream of the primary inlet (2) and upstream of the nozzle (5); and

10 an actuating mechanism (30) for moving the needle (20) between an opened position, in which the needle (20) is lifted from the needle seat (26) for allowing fluid flow past the needle seat (26), and a closed position, in which the needle (20) abuts the needle seat (26) and blocks fluid flow past the needle seat (26), wherein the actuating mechanism (30) comprises:

15 a cylinder (35) with a piston (31) connected to the needle (20), wherein a first cylinder chamber (37) is maximized when the needle (20) is in its opened position and a second cylinder chamber (38) is maximized when the needle (20) is in its closed position, wherein the first cylinder chamber (37) is in fluid communication with the primary inlet (2) via a chamber inlet (36), and wherein the second cylinder chamber (38) is in fluid communication with the first cylinder chamber (37), and  
20 a drain passage (39, 53, 54, 55, 56, 57) with a pilot valve (50), wherein the second cylinder chamber (38) is in fluid communication with the secondary inlet (7) and/or the outlet (12) via the drain passage (39, 53, 54, 55, 56, 57) when the pilot valve (50) is in an open state,

25

characterized in that the fluid communication of the second cylinder chamber (38) with the first cylinder chamber (37) is provided by an equalization passage (32), wherein a flow cross-section of the equalization passage (32) is larger than a flow cross-section of the drain passage (39, 53, 54, 55, 56, 57).

30

2. Ejector (1; 100) according to claim 1, characterized in that a piston area, which is a cross-section area of the piston, is at least 1000 times the flow cross-section of the equalization passage (32).

5 3. Ejector (1; 100) according to any one of the preceding claims, characterized in that a needle seat area, which is a cross-section area of the needle seat (26) where the needle (20) engages the needle seat (26) in the closed position, is in the range from 1,005 to 1,4 times a flow cross-section of the nozzle (26).

10 4. Ejector (1; 100) according to any one of the preceding claims, characterized in that the pilot valve (50) is a solenoid valve.

5. Ejector (1; 100) according to any one of the preceding claims, characterized in that the piston area corresponds to at least 20 times the needle seat area.  
15

6. Ejector (1; 100) according to any one of the preceding claims, characterized in that a stroke (S) of the needle (20) between the closed position and the opened position correspond to at least  $2 \cdot (A_{noz}/\pi)^{0,5}$ , where  $A_{noz}$  is the flow cross-section of the nozzle (5).  
20

7. Ejector (1; 100) according to any one of the preceding claims, characterized in that the ejector (1; 100) includes a check valve (79, 80) for preventing fluid flow from the outlet (12) to the secondary inlet (7).

25 8. Ejector (1; 100) according to any one of the preceding claims, characterized in that the equalization passage (32) is formed in the piston (31).

9. Ejector (1; 100) according to any one of the preceding claims, characterized in that the flow cross-section of the equalization passage (32) is in the range

from 1,2 to 2,5 times the flow cross-section of the drain passage (39, 53, 54, 55, 56, 57) when the pilot valve (50) is in an open state.

10. Ejector (1; 100) according to any one of the preceding claims, characterized in that a nozzle inlet (4) is formed directly upstream of the nozzle (5), wherein the nozzle inlet (4) tapers toward the nozzle (5), wherein the needle seat (26) is located in the nozzle inlet (4), and wherein a length (W) of the nozzle inlet (4) corresponds to at least 1,8 times the stroke (S) of the needle (20) between the closed position and the opened position.

11. Ejector (1; 100) according to any one of the preceding claims, characterized in that the ejector (1; 100) comprises a resilient member (33) acting against minimizing the second cylinder chamber (38) by the piston (31).

12. Ejector (1; 100) according to any one of the preceding claims, characterized in that the ejector (1; 100) is configured such that an opening time of the needle (20) is at least 0,5 s and/or that a closing time of the needle (20) is at least 1 s.

13. Ejector (1; 100) according to any one of the preceding claims, characterized in that the flow cross-section of the nozzle (5) is at least 50 mm<sup>2</sup>.

14. Ejector (1; 100) according to any one of the preceding claims, characterized in that the cylinder (35) is formed by a cylinder insert (77) and a top cover (76), wherein an elastic member (81) biases the cylinder insert (77) in abutment against the top cover (76).

15. Ejector assembly comprising at least two ejectors (1; 100) according to any one of the claims 1 to 14.

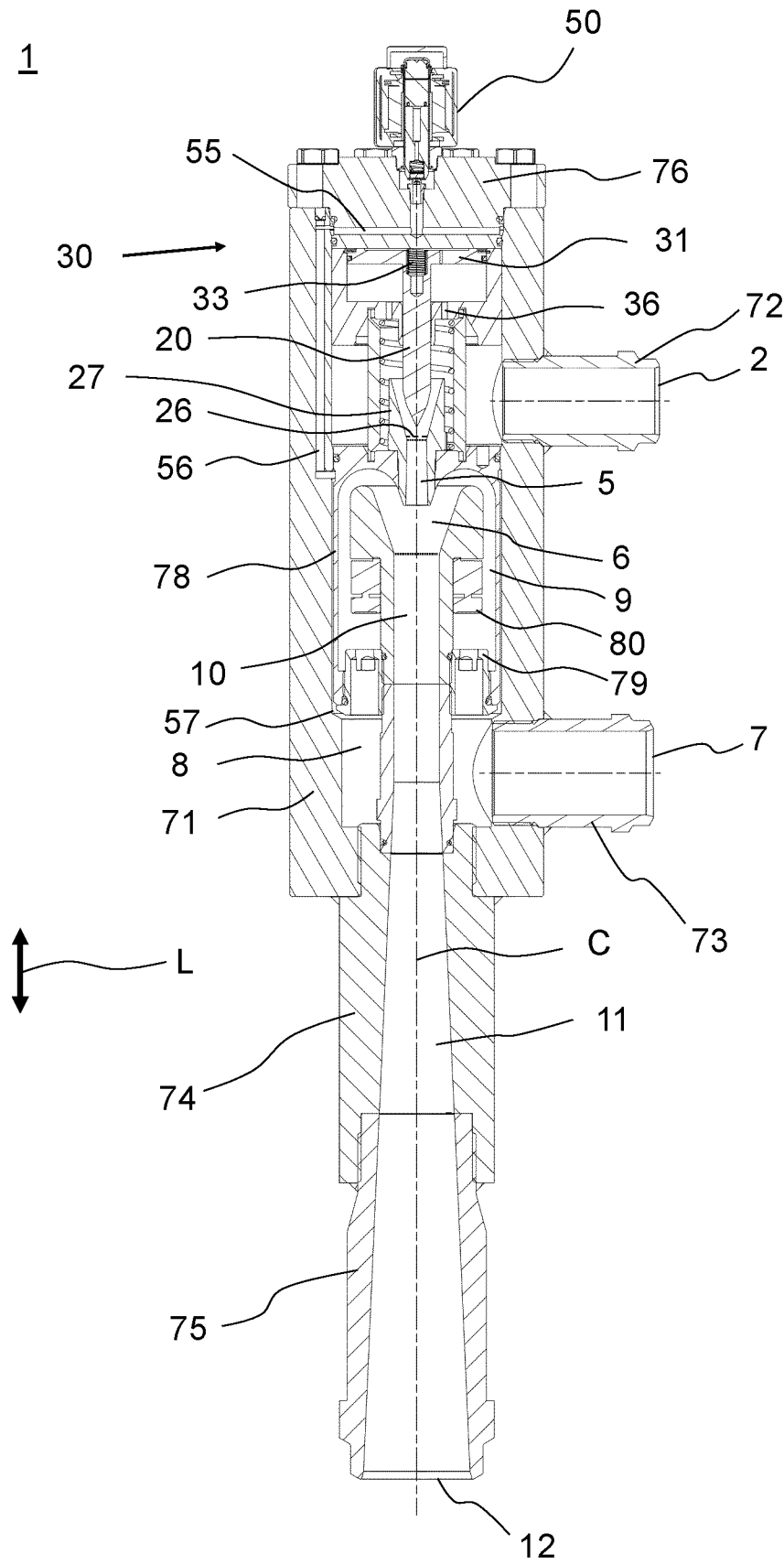
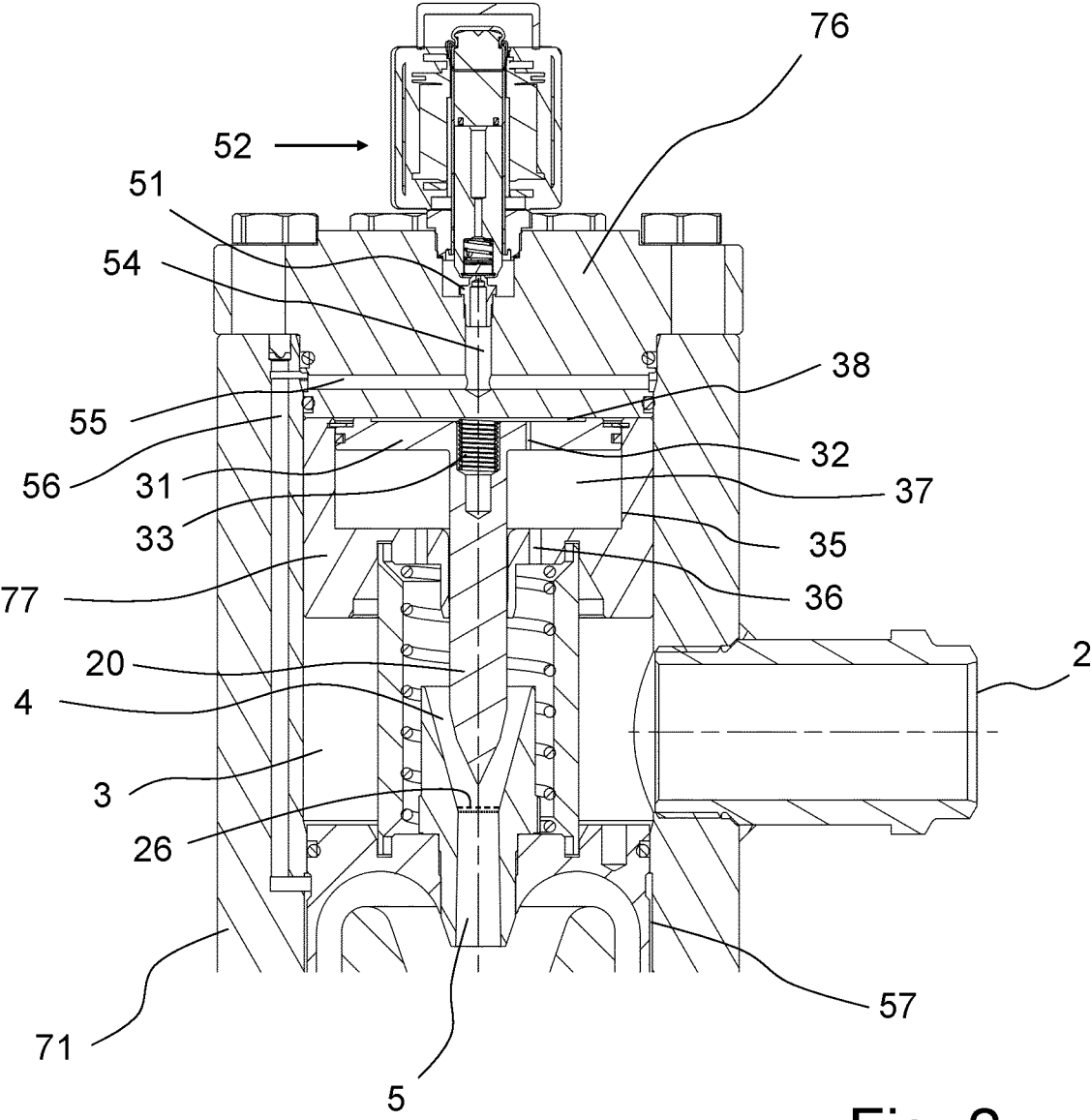


Fig. 1



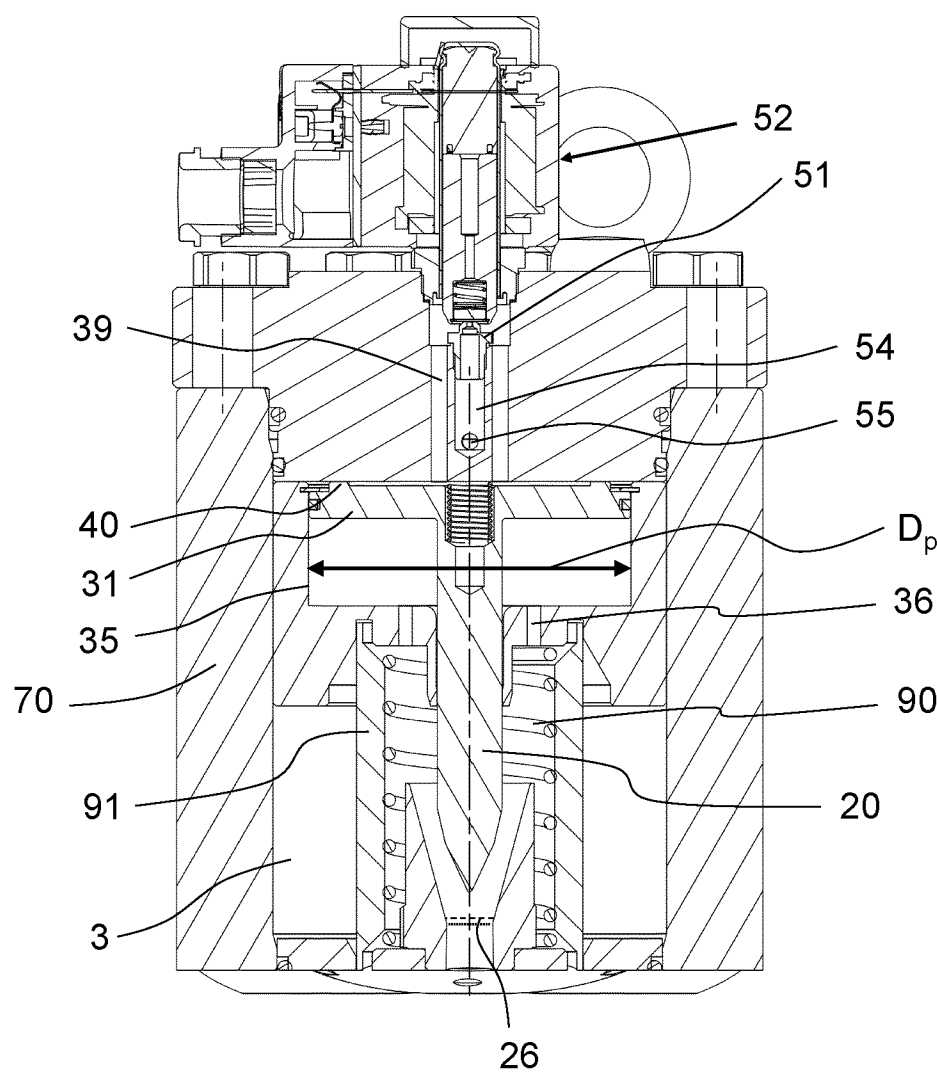


Fig. 3

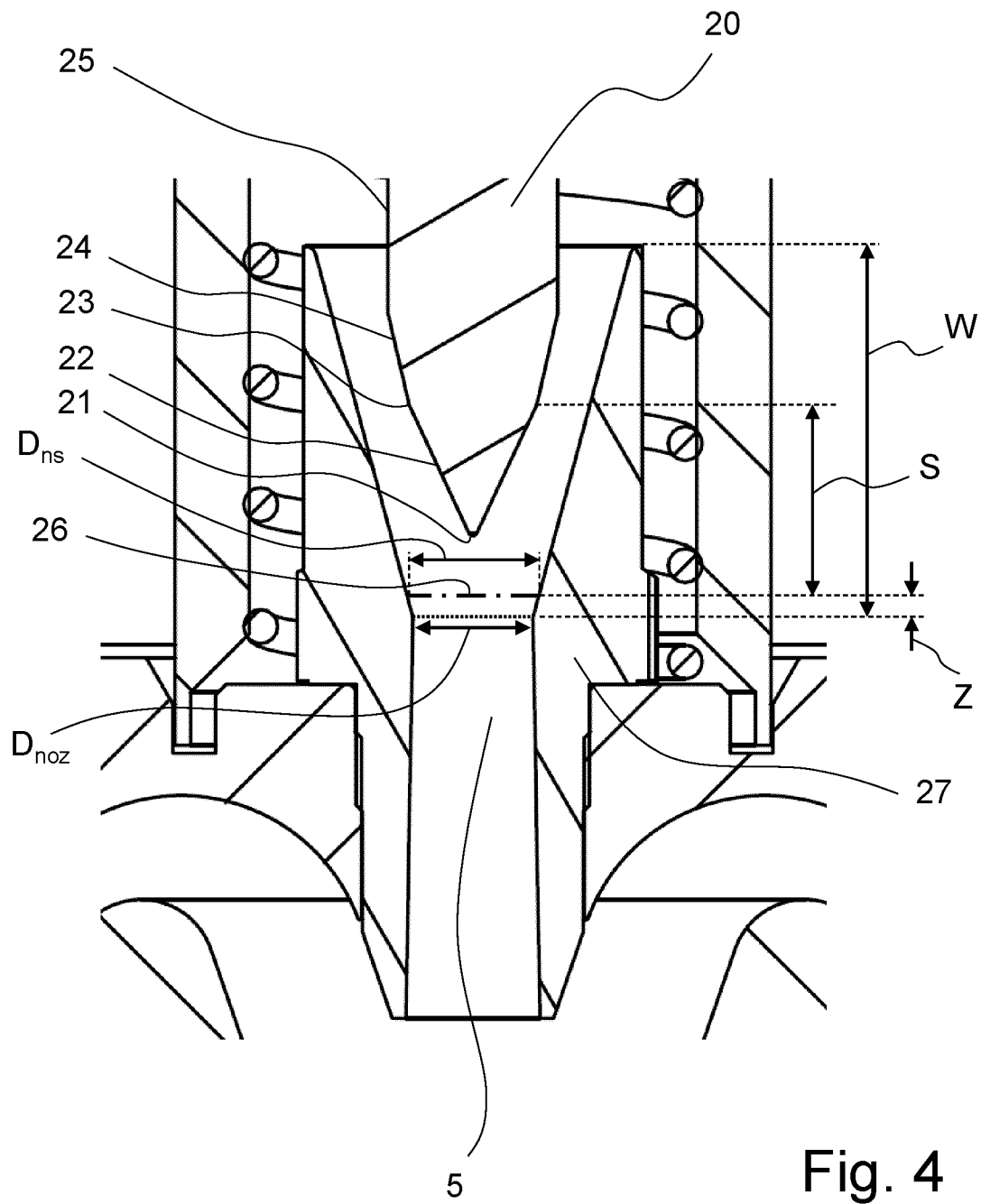


Fig. 4

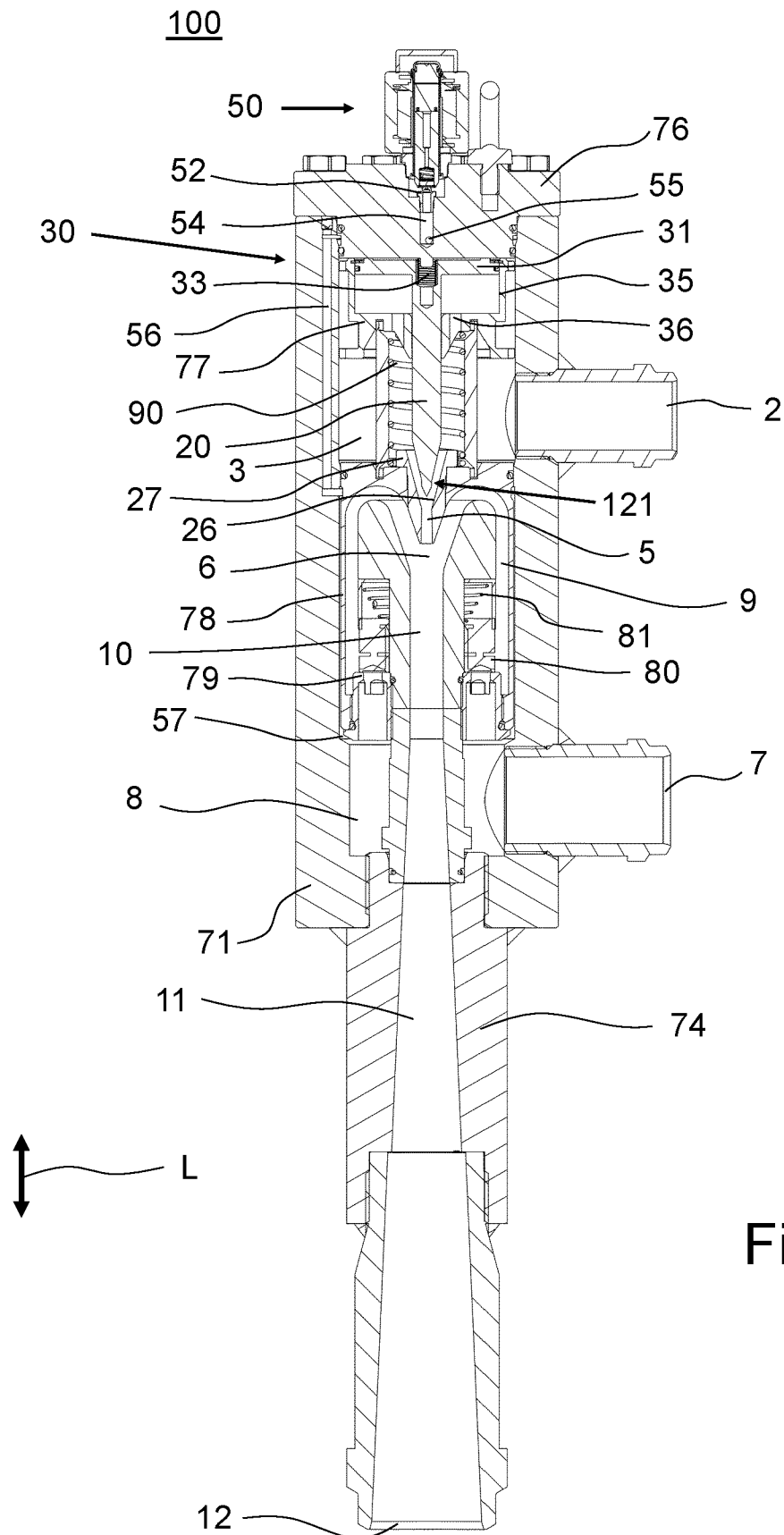


Fig. 5

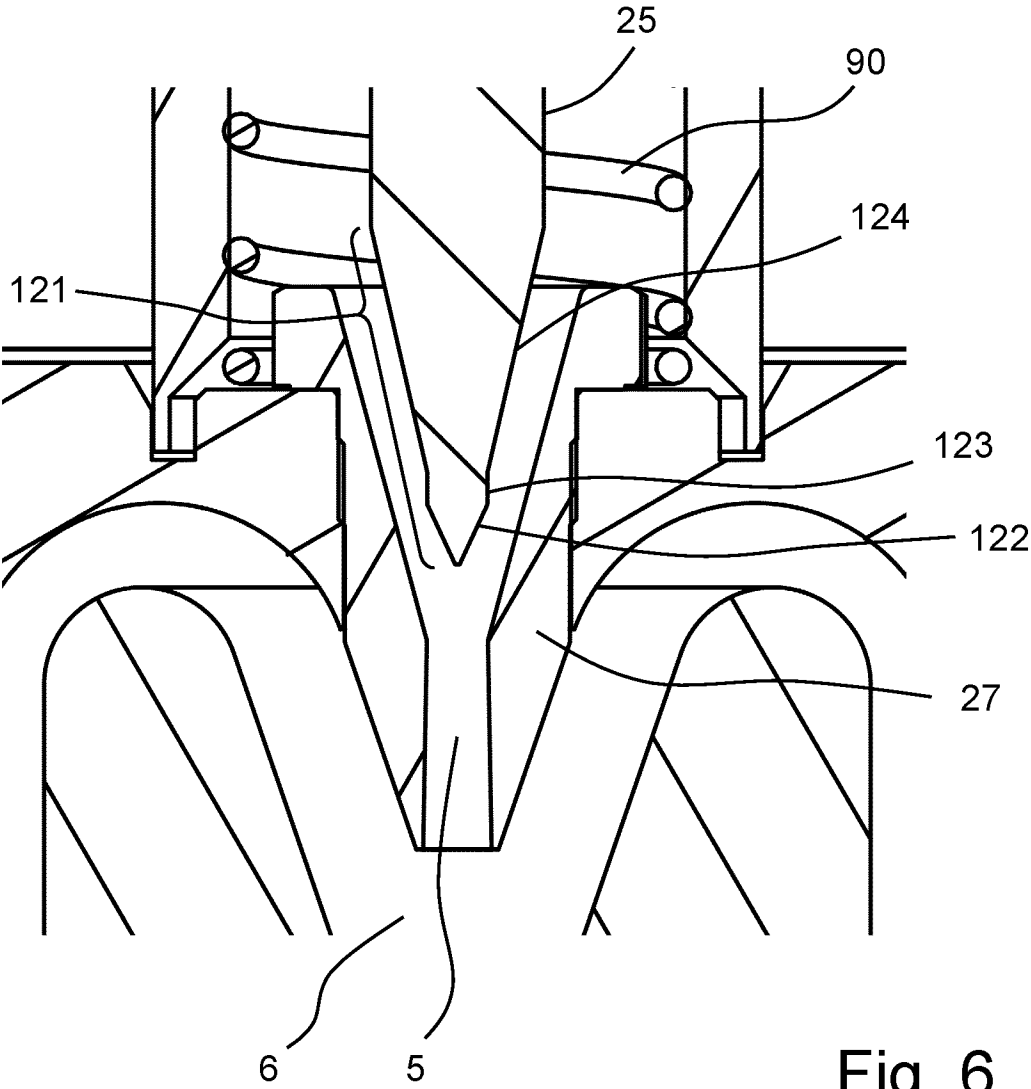


Fig. 6

## INTERNATIONAL SEARCH REPORT

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PCT/EP2023/072386

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br><b>INV. F25B41/00</b><br><b>ADD.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                       |                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                       |                                                    |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br><b>F25B</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                       |                                                    |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                       |                                                    |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br><b>EPO-Internal, WPI Data</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                       |                                                    |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                       |                                                    |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Citation of document, with indication, where appropriate, of the relevant passages                                                    | Relevant to claim No.                              |
| <b>X</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>US 2004/040340 A1 (TAKEUCHI M; TOMATSU Y; YAMANAKA Y) 4 March 2004 (2004-03-04) paragraphs [0033], [0034], [0035]; figures 1,2</b> | <b>1-15</b>                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -----                                                                                                                                 |                                                    |
| <b>A</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>EP 1 722 107 A1 (TOYOTA MOTOR CO LTD [JP]) 15 November 2006 (2006-11-15) the whole document</b>                                    | <b>1-15</b>                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -----                                                                                                                                 |                                                    |
| <b>A</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>DE 11 2015 003818 T5 (DENSO CORP [JP]) 4 May 2017 (2017-05-04) figure 2</b>                                                        | <b>1-15</b>                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -----                                                                                                                                 |                                                    |
| <b>A</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>US 1 421 843 A (SCHMIDT HENRY F) 4 July 1922 (1922-07-04) figure 3</b>                                                             | <b>11</b>                                          |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -----                                                                                                                                 |                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -/--                                                                                                                                  |                                                    |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                       |                                                    |
| * Special categories of cited documents :<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |                                                                                                                                       |                                                    |
| Date of the actual completion of the international search                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                       | Date of mailing of the international search report |
| <b>31 October 2023</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                       | <b>09/11/2023</b>                                  |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                       | Authorized officer<br><br><b>Ritter, Christoph</b> |

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/072386

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                      |                       |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                   | Relevant to claim No. |
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Information on patent family members

International application No

PCT/EP2023/072386

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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