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(54) **FUEL INJECTION SYSTEM, FUEL PUMP AND PLUNGER**

(57) The present invention pertains to a fuel injection system (10) for use in an internal combustion engine comprising an injection nozzle (18) and a fuel pump (14) adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle (18) via a discharge valve of the fuel pump (14). The discharge valve is configured to open at

a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump (14). In a non-injection mode of the fuel injection system (10), the fuel pump (14) is configured to pressurize fuel flowing through the fuel pump (14) to a pressure level higher than the opening pressure of the discharge valve.

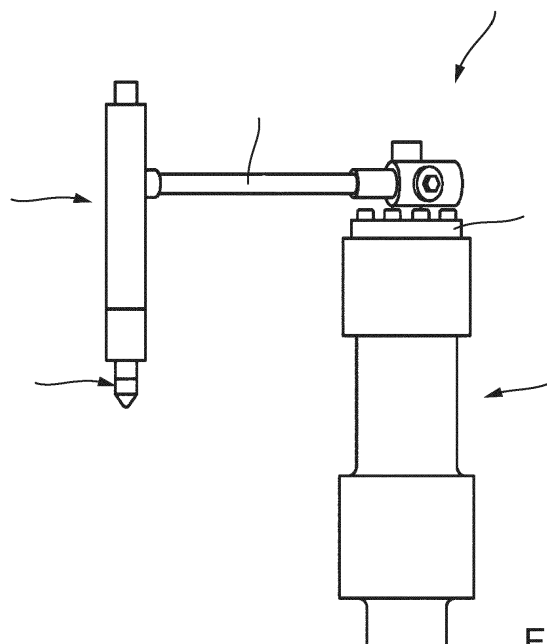


Fig. 1

Description

Technical Field

[0001] The present invention relates to a fuel injection system for use in an internal combustion engine, a fuel pump for use in such a fuel injection system and a plunger for use in such a fuel pump and in such a fuel injection system.

Technological Background

[0002] Internal combustion engines, such as diesel engines, are typically equipped with a fuel injection system for pressurizing and pumping fuel at a high pressure level into cylinders of the internal combustion engine. Fuel injection systems thus normally comprise a high pressure fuel pump for pressurizing fuel and supplying the pressurized fuel to an injection nozzle for injecting the pressurized fuel into the cylinders of the internal combustion engine. Specifically, so called pump-line-nozzle systems are known, for example, in the field of diesel engines, in which a high pressure pump is used for producing high fuel pressure and the pressurized fuel is then transferred through a high pressure injection line to the injection nozzle.

[0003] For large internal combustion engines, such as marine engines or construction machine engines, reciprocating pumps are used as high pressure pumps in fuel injection systems. In general, reciprocating pumps comprise a plunger or piston which is actuated within a pump barrel or cylinder forming a pump chamber so as to, upon reciprocating motion along an axial direction of the pump barrel, pressurize and force a gas or a fluid through the pump. For supplying and discharging fuel to and from the pump barrel, the pump is equipped with a supply valve on a suction side and a discharge valve on the discharge side of the pump which are respectively actuated in dependence on a pressure prevailing in the pump chamber. Such a high pressure fuel pump of a fuel injection system using a plunger is disclosed, for example, in EP 2 339 166 A1 and EP 2 669 504 A1.

[0004] Known high pressure pumps, for example, as disclosed in EP 2 669 504 A1 are configured for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged from the fuel pump. Specifically, for variably adjusting the feed rate, a head portion of the plunger is provided with a feed rate controlling structure configured to set a discharge portion and pressure of a pump stroke in dependence on an angular position of the plunger relative to the pump barrel. In other words, the plunger is configured to be rotatable within the pump barrel so as to adjust a feed rate of the fuel pump.

[0005] Specifically, upon reciprocatingly actuating the plunger within the pump barrel, the pump chamber formed by an end face of the plunger and the pump barrel may continuously increase and decrease. During the in-

crease phase, fuel is supplied to the pump chamber via the fuel port provided at the inner surface of the pump barrel. Then, during the decreasing phase, the fuel may be pressurized and then be released as pressurized fuel to the injection nozzle via the discharge valve. More specifically, in order to pressurize the fuel within the pump chamber during the decreasing phase, the fuel port is at least time-sequentially blocked by virtue of an outer surface of the plunger, i.e. a so called sealing surface of the feed rate controlling structure.

[0006] In this configuration, the amount of pressure and fuel discharged from the pump chamber depends on a blocking time during which the fuel port is blocked by the sealing surface of the feed rate controlling structure in the decreasing phase. Accordingly, a length of axial extension of the sealing surface for covering the fuel port can be varied so as to set a desired amount of pressure and fuel discharged from the fuel pump.

[0007] Known fuel injection systems can be operated in a so called non-injection mode, in which the injection of pressurized fuel into the cylinders of the internal combustion engine is stopped. In the non-injection mode of the fuel injection system, the known fuel pumps are accordingly configured to interrupt a discharge of fuel to the injection nozzle via the discharge valve although the plunger may be reciprocatingly actuated within the pump barrel as it is usually driven by a camshaft of the internal combustion engine. Accordingly, for interrupting the discharge of pressurized fuel from the fuel pump, the plunger may typically be positioned into a so called zero discharge position within the pump barrel, in which a pressure build-up in the pump chamber and thus a discharge of pressurized fuel from the fuel pump is obviated.

[0008] For that reason, the feed rate controlling structure of the plunger is provided with a zero feed groove extending along an axial direction of the plunger. Specifically, for operating the injection fuel system in its non-injection mode, the plunger, upon being rotated within the pump barrel, is positioned in the zero discharge position, in which the zero feed groove is aligned to the fuel port provided on the inner surface of the pump barrel. In this end position of the plunger, the fuel port is not covered by an outer surface of the plunger during the pump stroke such that the fuel present in the pump chamber is not pressurized to a pressure level sufficiently high to open the discharge valve of the fuel pump. In other words, in this position of the plunger, fuel is not discharged from the fuel pump via the discharge valve upon actuating the plunger within the pump barrel.

[0009] Due to recent developments, dual fuel engines are known which are designed to combust two different types of fuels, for example, a liquid fuel such as a diesel fuel and/or a gaseous fuel such as natural gas. In such engines, separate fuel injection systems for each one of the different types of fuels are provided.

[0010] In gas operation of such a dual fuel engine, the injection of liquid fuel into the cylinder is not required. Thus, the liquid fuel injection system is set in a non-in-

jection mode. However, due to operating the liquid fuel injection system in the non-injection mode, i.e. for a longer period of time, a high pressure side downstream of the fuel pump, i.e. the high pressure injection line connected to the injection nozzle, may be subjected to a pressure drop. Then, upon run up of the liquid fuel system, cavitation may occur as the pressure in the high pressure side of the fuel injection system is reduced, thereby causing wear due to cavitation erosion. To maintain the pressure level in the high pressure side of the fuel injection system, the injection nozzle may be provided with a pressure sequence valve or a spring-biased valve. However, even by such a configuration, the high pressure side of the liquid fuel injection system is subjected to a pressure drop, i.e. due to leakage when being operated in the non-injection mode for a longer period of time, thereby causing cavitation erosion and thus shortening the lifetime of respective components of the internal combustion engine.

Summary of the Invention

[0011] Starting from the prior art, it is an objective to provide an improved fuel injection system which decreases the risk of cavitation erosion for an internal combustion system, in particular after being operated in a non-injection mode for a longer period of time. In addition, it is an objective to provide a fuel pump for such a fuel injection system and a plunger for such a fuel pump.

[0012] These objectives are solved by means of a fuel injection system with the features of claim 1, a fuel pump with the features of claim 4 and a plunger with the features of claim 15. Preferred embodiments are set forth in the present specification, the Figures as well as the dependent claims.

[0013] Accordingly, a fuel injection system for use in an internal combustion engine is provided. The fuel injection system comprises an injection nozzle and a fuel pump adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle via a discharge valve of the fuel pump. The discharge valve is configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump. Further, in a non-injection mode of the fuel injection system, the fuel pump is configured to pressurize fuel flowing through the fuel pump to a pressure level higher than the opening pressure of the discharge valve.

[0014] Furthermore, a fuel pump for use in a fuel injection system is provided. The fuel pump may particularly be used in the fuel injection system as described above. Accordingly, technical features which are described in connection with the fuel injection system may also relate and be applied to the proposed fuel pump, and vice versa.

[0015] The proposed fuel pump is adapted for pressurizing fuel flowing through the fuel pump and to variably adjust a feed rate of the pressurized fuel to be discharged from the fuel pump. Further, the fuel pump comprises a

discharge valve configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump, wherein the fuel pump, when being operated in a state of a minimal feed rate, is configured to pressurize fuel flowing through the fuel pump to a pressure level higher than the opening pressure of the discharge valve.

[0016] Furthermore, a plunger for use in a fuel pump is provided. Specifically, the proposed plunger may be used in the fuel pump as described above. Accordingly, technical features which are described in connection with the fuel pump may also relate and be applied to the proposed plunger.

[0017] Thus, a plunger for use in a fuel pump is provided which has an essentially cylindrical base shape for reciprocating movement and rotation within a pump barrel of the fuel pump. For variably adjusting a feed rate of the fuel pump, the plunger is configured to be rotatably movable within the pump barrel between a first end position of a minimum feed rate and a second end position of a maximum feed rate. Further, the plunger is provided with a feed rate controlling structure which, upon reciprocatingly moving the plunger within the pump barrel along an axial direction in its first end position, is configured to time-sequentially block a fuel port provided in the pump barrel so as to pressurize fuel within the pump barrel.

Brief Description of the Drawings

[0018] The present disclosure will be more readily appreciated by reference to the following detailed description when being considered in connection with the accompanying drawings in which:

Figure 1 shows a schematic side view of a fuel injection system for an internal combustion engine;
Figure 2 shows a schematic side view with a partial cross-sectional side view of a fuel pump used in the fuel injection system depicted in Fig. 1;
Figure 3 shows a schematic side view of a plunger of the fuel pump depicted in Fig. 2 according to a first embodiment;
Figure 4 shows a schematic diagram for illustrating a feed rate controlling structure which extends circumferentially around a head portion of the plunger according to the first embodiment; and
Figure 5 shows a schematic diagram for illustrating the feed rate controlling structure which extends circumferentially around the head portion of the plunger according to a second embodiment.

Detailed Description of Preferred Embodiments

[0019] In the following, the invention will be explained in more detail with reference to the accompanying figures. In the Figures, like elements are denoted by identical reference numerals and repeated description there-

of may be omitted in order to avoid redundancies.

[0020] In Fig. 1, a fuel injection system 10 for use in an internal combustion engine is depicted. Specifically, the fuel injection system 10 is intended for pressurizing and spraying a liquid fuel into a cylinder of a dual fuel engine.

[0021] The fuel injection system 10 comprises an injector 12 which is in fluid connection with a high pressure fuel pump 14 via a high pressure pipe 16. In such a system, the fuel pump 14 is configured to pressurize fuel received from a fuel reservoir and to supply the pressurized fuel to an injection nozzle 18 of the injector 12 via the high pressure pipe 16.

[0022] More specifically, the fuel pump 14 is adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle 18 via a discharge valve of the fuel pump 14. The discharge valve is comprised in a valve carrier 20 of the fuel pump 14. The valve carrier 20 is designed to connect the discharge valve with the high pressure pipe 16 to supply pressurized fuel discharged from the fuel pump 14 to the injector 12.

[0023] The discharge valve is configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump 14. Specifically, the discharge valve is moveable between an open and a closed position so as to control flow of pressurized fuel. The discharge valve is biased to the closed position and openable when the fuel pressurized in the fuel pump 14 reaches the predetermined opening pressure. The discharge valve then remains open until a pressure level of the pressurized fuel drops to a pressure level lower than the opening pressure. For example, the discharge valve may be a spring-biased valve.

[0024] The fuel injection system 10 is configured to be operated in a non-injection mode, in which the pressurized fuel from the fuel pump 14 is prevented from being injected into the cylinder of the dual fuel engine through the injection nozzle 18. For example, the shown fuel injection system 10, i.e. for supplying liquid fuel, may be operated in the non-injection mode when the dual fuel engine is driven in gas operation where merely gaseous fuel is injected into its cylinder. This is performed by a gaseous fuel injection system that is provided separately from the liquid fuel injection system 10 depicted in Fig. 1.

[0025] For preventing the pressurized fuel from being injected into the cylinder, the fuel injection system 10 in its non-injection mode is configured to operate the injection nozzle 18 in a closed state. In this way, a flow of pressurized fuel through the injection nozzle 18 is blocked. Specifically, the injection nozzle 18 comprises an injection valve which is movable between an open and closed position to control the flow of pressurized fuel through the injection nozzle 18. The injection valve is biased to its closed position and configured to open at a predetermined further opening pressure. The injection valve then remains open until a pressure level of the pressurized fuel drops to a pressure level lower than the fur-

ther opening pressure. For example, the injection valve may be a pressure sequence valve or a spring-biased valve. Compared to the discharge valve, the further opening pressure of the injection valve is greater than the opening pressure of the discharge valve.

[0026] In the non-injection mode of the fuel injection system 10, the fuel pump 14 is configured to pressurize fuel flowing through the fuel pump 14 to a pressure level higher than the opening pressure of the discharge valve, but lower than the further opening pressure of the injection valve. In this way, the fuel pressurized by the fuel pump 14 in the non-injection mode of the fuel injection system 10 has a pressure level that is sufficiently high to open the discharge valve while the injection valve is maintained in its closed position. By this configuration, the fuel pump 14 enables to pressurize a high pressure side of the fuel injection system 10, i.e. in the injector 12 and the high-pressure pipe 16, or to maintain a pressure level in the high pressure side 12, 16 when the fuel injection system 10 is operated in the non-injection mode. In this way, a pressure drop in the high pressure side 12, 16 and thus the occurrence of cavitation can be effectively prevented even if the fuel injection system 10 is operated frequently and/or for a longer period of time in the non-injection mode.

[0027] The fuel pump is configured such that the feed rate of pressurized fuel discharged from the fuel pump is continuously and/or gradually adjustable between a minimal feed rate and a maximal feed rate. In this context, the minimal and maximal feed rates refer to boundary conditions of the fuel pump 14. Accordingly, the fuel pump 14 is not suitable or intended to be operated at a feed rate that is lower than the minimal feed rate or that is greater than the maximal feed rate. In the non-injection mode of the fuel injection system 10, the fuel pump 14 is operated at minimal feed rate. According to the present disclosure, the state of the minimal feed rate refers to an operational mode or condition of the fuel pump 14, in which the minimal feed rate of the fuel pump 14 is adjusted. In other words, the fuel pump 14 is operated in a state in which the minimal feed rate is adjusted. Accordingly, the fuel pump 14 is configured to pressurize fuel flowing through the fuel pump 14 to a pressure level higher than the opening pressure of the discharge valve when the fuel pump 14 is operated in a state of minimal feed rate, i.e. when the minimal feed rate of the fuel pump 14 is adjusted during operation. The fuel pump 14 is not suitable or intended to be operated at a feed rate that is lower than the minimal feed rate.

[0028] In the following, the fuel pump 14 is further specified with reference to Fig. 2. The fuel pump 14 is a reciprocating pump comprising a pump housing 22 accommodating a pump barrel 24 and a plunger 26. The plunger 26 has an essentially cylindrical base shape and is configured for reciprocating or axial movement and rotation within the pump barrel 24. On a discharge side of the fuel pump 14, the pump housing 22 and the pump barrel 24 are closed by the valve carrier 20. The fuel pump 14

further comprises a pump chamber 28 which is delimited, in a radial direction, by the pump barrel 24 and, at one axial side by the plunger 26 and, at an opposing axial side, by the valve carrier 20. In the valve carrier 20 the discharge valve is comprised which enables a fluid connection between the pump chamber 28 and the high pressure pipe 16.

[0029] In the pump chamber 28, fuel is received, pressurized and then provided as pressurized fuel to the injector 12 via the discharge valve in the valve carrier 22. This is achieved by reciprocating movement of the plunger 26 within the pump barrel 24 along an axial direction 30 of the fuel pump 14 which coincides with a plunger axis, as depicted in Fig. 2. For actuating the plunger 26, the plunger 26 is connected to a camshaft of the dual fuel engine. Thus, the plunger 26 is actuated by the camshaft of the dual fuel engine when the fuel injection system 10 is operated in its non-injection mode.

[0030] During reciprocating movement of the plunger 26, the fuel pump 14 is configured to continuously increase and decrease the pump chamber 28. During the increasing phase, the fuel pump 14 is configured to supply fuel into the pump chamber 28 via a pair of opposing fuel ports 32 extending through a side wall of the pump barrel 24. The fuel ports 32 open into a fuel gallery 34 which is connected to the fuel reservoir. Accordingly, via the fuel ports 32 and the fuel gallery 34 the pump chamber 28 is fluidly connected to the fuel reservoir. Then, during the decreasing phase, the fuel present in the pump chamber 28 is pressurized and thereafter released as pressurized fuel to the injector 12 via the discharge valve.

[0031] In order to pressurize the fuel present in the pump chamber 28 during the decreasing phase, the plunger 26 is provided with a feed rate controlling structure 36 which forms an outer surface of a head portion of the plunger 26, as depicted in Fig. 3. The feed rate controlling structure 36 is configured to time-sequentially block the fuel ports 32 upon reciprocatingly moving the plunger 26 within the pump barrel 24 during operation. In other words, the feed rate controlling structure 36 is configured to block the fuel ports 32 during the decreasing phase of a pump stroke so as to prevent the fuel present in the pump chamber 28 from being discharged via the fuel ports 32 and thus to enable pressurization of the fuel.

[0032] For variably adjusting the feed rate, the pump barrel 24 and the plunger 26 are configured to set a discharge portion and pressure of a pump stroke in dependence on an angular position of the plunger 26 relative to the pump barrel 24. Specifically, the plunger 26 within the pump barrel 24 is rotatable between a first end position of minimal feed rate and a second end position of maximal feed rate. In this context, the term "end position" refers to a position of the plunger 26 within the pump barrel 24, beyond which the plunger 26 cannot be moved. Thus, when the plunger 26 is positioned in its first end position relative to the pump barrel 24, the fuel pump 14 is adjusted to be operated at its minimal feed rate. Ac-

cordingly, when the plunger 26 is positioned in its second end position relative to the pump barrel 24, the fuel pump 14 is adjusted to be operated at its maximal feed rate. When the plunger 26 is positioned in its first end position of minimal feed rate, the feed rate controlling structure 36 is configured to time-sequentially block and release the fuel ports 32 upon reciprocatingly moving the plunger 26 along the axial direction 30 so as to pressurize the fuel present in the pump chamber 28 to the pressure level higher than the opening pressure of the discharge valve.

[0033] Referring to Figs. 3 and 4, the configuration of the feed rate controlling structure 36 is further specified. As can be gathered from Fig. 4, the feed rate controlling structure 36 comprises two identically designed portions 38, 40 on opposed sides of the head portion of the plunger 26. Each of these portions 38, 40 is assigned to one of the opposing fuel ports 32. In other words, each of the portions 38, 40 is configured to interact with one fuel port 32, respectively, during operation. In the following, the configuration of the feed rate controlling structure 36 is specified with regard to one of the portions 38, 40 which respectively applies to the other one of the portions 38, 40.

[0034] The feed rate controlling structure 36 comprises a sealing surface 42 and a recessed surface region 44. The sealing surface 42 is provided with a radial extension that corresponds to an inner radius of the pump barrel 24 so as to provide a sealing between the pump barrel 24 and the plunger 26 and thus to enable a blocking of the fuel ports 32. Accordingly, the sealing surface 42 surrounds the plunger axis 30 at a plunger sealing radius R_{max} and the recessed surface region 44 surrounds the plunger axis at a reduced radius R_{red} .

[0035] The length of an axial extension of the sealing surface 42 is used to control the time during which the fuel ports 32 are blocked and thus during which the pressure is built up during a pump stroke. Accordingly, in order to adjust the amount of fuel pumped during a pump stroke and thus to adjust a feed rate of the fuel pump 14 in dependence on an angular position of the plunger relative to the pump barrel, the sealing surface 42 is provided with a varying length of axial extension along a circumferential direction of the plunger 26.

[0036] More specifically, the sealing surface 42 is provided with a first sealing surface section 46 which is aligned with one of the fuel ports 32 when the plunger 26 is positioned in its first end position of minimal feed rate. Further, the sealing surface 42 is provided with a second sealing surface section 48 arranged adjacent to the first sealing surface section 46 in a circumferential direction around the plunger axis 30, as indicated with dotted lines in Fig. 3 and 4. The first sealing surface section 46 merges into the second sealing surface section 48. The length of axial extension of the first sealing surface section 46 is smaller compared to the second sealing surface section 48. In other words, the first sealing surface section 46 has a smallest length of axial extension of the sealing surface 42. In this way, the fuel pump 14 ensures that,

when the plunger 26 is arranged in its first end position, the lowest possible feed rate, i.e. the minimal feed rate, of the fuel pump 14 is adjusted.

[0037] The first sealing surface section 46 has a length of an axial extension that is substantially 1.25 times greater than a length of an axial extension of the fluid ports 32.

[0038] The feed rate controlling structure 36 further comprises a minimal feed groove 50 which extends along the axial direction 30 from an end face 52 of the plunger to the first sealing surface section 46. Thus, the minimal feed groove 50 is arranged adjacent to the first sealing surface section 46 in the axial direction 30. Specifically, the minimal feed groove 50 is provided in form of an undercut transitioning smoothly into the recessed surface region 44.

[0039] In addition, a circularly extending groove 54 is provided at the head portion of the plunger 26, into which the recessed surface region opens 44. The circularly extending groove 54 is arranged between and adjacent to the sealing surface 42 and a body portion of the plunger 26 having a circumferential sealing surface 56 which surrounds a plunger axis at the plunger sealing radius R_{max} . In this configuration, the first sealing surface section 46, in axial direction 30, is accordingly arranged between and adjacent to the minimal feed groove 50 and the circularly extending groove 54.

[0040] The minimal feed groove 50, the recessed surface region 44 and the circularly extending groove 54 form a pressure release chamber 58. The pressure release chamber 58 is in fluid connection with the pump chamber 28 through the minimal feed groove 50.

[0041] Further, the feed rate controlling structure 36 is provided with an interface surface 60 which connects, in a radial direction, the recessed surface region 44 with the sealing surface 42. In the region of the first sealing surface section 46, the interface surface 60 extends parallel to a circumferential direction. In the region of the second sealing surface section 48, the interface surface 60 extends as a helix around the plunger axis 30 beginning at the minimal feed groove 50.

[0042] Fig. 5 shows yet another embodiment of the plunger 26 which differs from the plunger depicted in Figs. 3 and 4 in that, in the region of the second sealing surface section 48, the interface surface 60 extends partially as a helix around the plunger axis 30. More specifically, in the region of the second sealing surface 48, the interface surface 60 is provided with a first and a second helix section 62, 64 of different helix angles which are interlinked via a plane section 66 extending parallel to the circumferential direction of the plunger 26, i.e. with a helix angle of 0° . The first helix section 62 is provided adjacent to the minimal feed groove 50 and has a helix angle of substantially 30° and the second helix section 64 has helix angle of substantially 45° . Between the second helix section 64 and a further minimal feed groove 50, i.e. that is assigned to another portion of the feed rate controlling surface 36, the interface surface 60 comprises a further plane section 68 extending parallel to the circumferential

direction of the plunger 26.

[0043] It will be obvious for a person skilled in the art that these embodiments and items only depict examples of a plurality of possibilities. Hence, the embodiments shown here should not be understood to form a limitation of these features and configurations. Any possible combination and configuration of the described features can be chosen according to the scope of the invention.

[0044] This is in particular the case with respect to the following optional features which may be combined with some or all embodiments, items and/or features mentioned before in any technically feasible combination.

[0045] A fuel injection system for use in an internal combustion engine may be provided. The fuel injection system may comprise an injection nozzle and a fuel pump adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle via a discharge valve of the fuel pump. The discharge valve may be configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump. Further, in a non-injection mode of the fuel injection system, the fuel pump may be configured to pressurize fuel flowing through the fuel pump to a pressure level higher than the opening pressure of the discharge valve.

[0046] It has been found that, in the non-injection mode of the fuel injection system, a high pressure side of the fuel injection system downstream of the fuel pump is typically subjected to a pressure drop, in particular due to leakage when being operated in the non-injection mode for a longer period of time. This pressure drop, however, makes the injection system prone to wear caused by cavitation erosion.

[0047] Therefore, a fuel injection with a fuel pump may be proposed which may enable to pressurize the high pressure side or maintain a pressure level in the high pressure side of the fuel injection system when being operated in the non-injection mode. Specifically, this is achieved as the fuel pump, in the non-injection mode of the fuel injection system, may be configured to pressurize fuel flowing through the fuel pump to a pressure level sufficiently high to open the discharge valve. In this way, pressurized fuel may be discharged from the fuel pump into the high pressure side of the fuel injection system via the discharge valve during the non-injection mode. A pressure drop in the high pressure side of the fuel injection system and thus the occurrence of cavitation can be effectively prevented even if the fuel injection system is operated frequently and/or for a longer period of time in the non-injection mode. As a result, the proposed fuel injection system may be less prone to wear caused by cavitation erosion.

[0048] The proposed fuel injection system may be used in internal combustion engines, during normal operation of which the fuel injection system undergoes many starts and stops or is subjected to long idle times. Such an internal combustion engine may be a multi fuel engine designed to combust different types of fuels. For

example, the internal combustion engine may be a dual fuel engine which can be operated either by gaseous or liquid fuel. The dual fuel engine may comprise separate fuel injection systems for the gaseous and the liquid fuel for each cylinder. In such a configuration, the proposed fuel injection system may be a liquid fuel injection system. Accordingly, in gas operation of the dual fuel engine, the liquid fuel injection system is typically configured to interrupt a supply of pressurized fuel, i.e. pressurized liquid fuel, into the cylinder. In the present disclosure, such an operational mode of the fuel injection system is referred to as a "non-injection mode". In other words, in the non-injection mode, the fuel injection system is configured to stop injecting fuel into a cylinder of the internal combustion engine via the injection nozzle of the injection fuel system.

[0049] The fuel injection system may be equipped with the injection nozzle which forms a part of the high pressure side of the fuel injection system. The injection nozzle may be configured to spray pressurized fuel into a cylinder of the internal combustion engine. For being supplied with pressurized fuel, the injection nozzle may be connected to the discharge valve of the fuel pump via a high pressure pipe which may also form a part of the high pressure side of the fuel injection system.

[0050] For stopping the injection of pressurized fuel from the injection nozzle into the cylinder of the internal combustion engine, the fuel injection system in its non-injection mode may be configured to operate the injection nozzle in a closed state. In this state, the injection nozzle may be configured to prevent the pressurized fuel from being discharged from the injection nozzle. In other words, a flow of pressurized fuel through the injection nozzle is stopped in the closed state.

[0051] In this configuration, the fuel injection system in its non-injection mode may be configured to gradually discharge pressurized fuel into the pressure pipe and/or pressurize fuel present in the high pressure pipe while the injection nozzle is set in its closed state. In this way, compared to known fuel injection systems, a pressure prevailing in the high pressure side of the fuel injection system may be maintained at a constant high pressure level even if the fuel injection system is operated for a longer period of time in its non-injection mode.

[0052] Specifically, for adjusting the flow through the injection nozzle, an injection valve may be comprised in the injection nozzle. The injection valve may be provided, for example, in form of a pressure sequence valve or a spring-biased valve, and may be configured to open at a predetermined further opening pressure. In other words, the injection valve may be configured to block a flow of pressurized fuel through the injection nozzle if a pressure prevailing in the pressurized fuel upstream of the injection valve is less than the predetermined further opening pressure of the injection valve. Accordingly, if the pressure prevailing in the pressurized fuel upstream of the injection valve is equal to or exceeds the predetermined further opening pressure of the injection valve,

the injection valve may open such that a flow through the injection nozzle is released. In this context, the terms "downstream" and "upstream" refer to a flow direction of the fuel through the fuel injection system.

[0053] Accordingly, the fuel pump may be configured to pressurize the fuel discharged from the discharge valve to a pressure level lower than the further opening pressure of the injection valve when the injection system is operated in the non-injection mode. The opening pressure of the discharge valve may be lower than the further opening pressure of the injection valve. In other words, in the non-injection mode of the fuel injection system, the fuel pump may be configured to pressurize fuel flowing through the fuel pump to a pressure level which is greater than the opening pressure of the discharge valve and lower than the further opening pressure of injection valve.

[0054] In this way, the fuel pressurized by the fuel pump may have a pressure level that is sufficiently high to open the discharge valve while the injection valve is maintained in its closed position. In other words, the fuel injection system in its non-injection mode may enable to maintain a high pressure level in the high pressure side of the fuel injection system, i.e. the high pressure pipe between the discharge valve and the injection valve, while the injection nozzle is maintained in its closed state.

[0055] Furthermore, a fuel pump for use in a fuel injection system may be provided. The fuel pump may particularly be used in the fuel injection system as described above. Accordingly, technical features which are described in connection with the fuel injection system may also relate and be applied to the proposed fuel pump, and vice versa.

[0056] The proposed fuel pump may be adapted for pressurizing fuel flowing through the fuel pump and to variably adjust a feed rate of the pressurized fuel to be discharged from the fuel pump. Further, the fuel pump may comprise a discharge valve configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump, wherein the fuel pump, when being operated in a state of a minimal feed rate, may be configured to pressurize fuel flowing through the fuel pump to a pressure level higher than the opening pressure of the discharge valve.

[0057] Compared to known fuel pumps of a fuel injection system, the proposed fuel pump may ensure that, even in an operational state of a minimal feed rate of the fuel pump, fuel flowing through the fuel pump is pressurized to a pressure level sufficiently high to open the discharge valve and thus to discharge fuel, i.e. to a high pressure side of the fuel injection system, via the discharge valve. In this way, the fuel pump, when being employed in the fuel injection system as described above, may contribute to effectively prevent the occurrence of cavitation and thus of cavitation erosion.

[0058] According to the present disclosure, the state of the minimal feed rate refers to an operational mode or condition of the fuel pump, in which the minimal feed rate of the fuel pump is adjusted. The fuel pump may be con-

figured such that its feed rate may be continuously or gradually adjusted between the minimal feed rate and a maximal feed rate. In this context, the minimal and maximal feed rates refer to boundary conditions of the fuel pump. Accordingly, the fuel pump is not suitable or intended to be operated at a feed rate that is lower than the minimal feed rate or that is greater than the maximal feed rate.

[0059] Again, the fuel pump, even when being operated in the state of minimal feed rate, may be configured to pressurize fuel flowing through the fuel pump to a pressure level sufficiently high to open the discharge valve. In this way, the proposed fuel pump may ensure that, in each operational mode of the fuel pump, fuel is pressurized to a pressure level sufficiently high to be discharged from the discharge valve. Thus, the proposed fuel pump may be provided with an optimized design for being used in the fuel injection system with improved wear characteristics as described above.

[0060] The discharge valve may be moveable between an open and a closed position so as to control flow of pressurized fuel therethrough. The discharge valve may be biased to the closed position and openable when the fuel pressurized in the fuel pump reaches the predetermined opening pressure. The discharge valve then may remain open until a pressure level of the pressurized fuel drops to a pressure level lower than the opening pressure. For example, the discharge valve may be a spring-biased valve.

[0061] The discharge valve may be connectable to an injection nozzle of the fuel injection system, in particular via a high pressure pipe. In this configuration, the fuel pump, when being operated in its state of minimal feed rate, may be configured to pressurize the fuel discharged from the discharge valve to a pressure level lower than a further opening pressure, upon which an injection valve of the injection nozzle opens.

[0062] The fuel pump may be a reciprocating pump and may comprise a pump barrel and a plunger for reciprocating movement and rotation within the pump barrel. The fuel pump may further comprise a pump chamber which may be delimited, in a radial direction, by the pump barrel and, at one axial side by the plunger and, at an opposing axial side, by a valve carrier comprising the discharge valve. For reciprocatingly driving the plunger within the pump barrel along the axial direction, the plunger may be connected with a camshaft of the internal combustion engine. Upon reciprocatingly moving the plunger, the pump chamber may continuously increase and decrease. During the increasing phase, fuel may enter the pump chamber via at least one fuel port provided at an inner surface of the pump barrel and being connected to a fuel reservoir. During the decreasing phase, the fuel port may be blocked by an outer surface of the plunger so as to pressurize the fuel present in the pump chamber and then to release the pressurized fuel via the discharge valve.

[0063] The basic structure of a reciprocating pump is

well known to a person skilled in the art and is thus not further specified. Rather, characteristics of the fuel pump interlinked with the present invention are addressed in the following.

[0064] For variably adjusting the feed rate, the plunger and the pump barrel may be configured to set a discharge portion and pressure of a pump stroke in dependence on an angular position of the plunger relative to the pump barrel. Specifically, the plunger, relative to the pump barrel, may be rotatable between a first end position of minimal feed rate and a second end position of maximal feed rate. In this context, the term "end position" refers to a position of the plunger within the pump barrel, beyond which the plunger cannot be moved.

[0065] When the plunger is positioned in its first end position relative to the pump barrel, the minimal feed rate of the fuel pump may be adjusted. In other words, when the plunger has its first position relative to the pump barrel and is reciprocatingly driven within the pump barrel, the fuel pump may be operated in the state of minimal feed rate. Accordingly, when the plunger is positioned in its second end position relative to the pump barrel, the maximal feed rate of the fuel pump may be adjusted.

[0066] Further, the plunger may be adapted to gradually and/or continuously increase a feed rate of the fuel pump upon being rotated within the pump barrel from the first end position to the second end position. For setting the discharge portion and pressure of a pump stroke and thus to adjust the feed rate of the fuel pump, the plunger may be provided with a feed rate controlling structure. The feed rate controlling structure may form a part of the outer surface of the plunger and is configured to interact with the fuel port provided at the inner surface of the pump barrel. The feed rate controlling structure may be configured to time-sequentially block and release the fuel port during reciprocating movement of the plunger so as to control the supply of fuel to and the discharge of pressurized fuel from the fuel pump.

[0067] More specifically, the feed rate controlling structure may be configured such that, when the plunger is positioned in its first end position of minimal feed rate, the feed rate controlling structure time-sequentially blocks the fuel port upon reciprocatingly moving the plunger within the pump barrel along the axial direction. In this way, fuel present in the pump chamber may be pressurized and then the pressurized fuel may be discharged via the discharge valve. By this configuration, the plunger may enable that the fuel pump, when being operated in the state of minimal feed rate, is configured to pressurize fuel flowing through the fuel pump to a pressure level sufficiently high to open the discharge valve and thus to discharge fuel to the injection nozzle connected to the discharge valve.

[0068] Particularly, the feed rate controlling structure may constitute an outer surface of a plunger's head portion and may comprise a sealing surface and a recessed surface region. The sealing surface may be provided with a radial extension that corresponds to an inner radius of

the pump barrel so as to provide a sealing between the pump barrel and the plunger and thus to enable a blocking of the fuel port provided on the inner surface of the pump barrel. Accordingly, the sealing surface may at least partially surround a plunger axis at a plunger sealing radius and the recessed surface region may at least partially surround the plunger axis at a reduced radius compared to the plunger sealing radius. The plunger axis may coincide to the axial direction.

[0069] In general, the length of an axial extension of the sealing surface may be used to control the time during which the fuel port provided at the inner surface of the pump barrel is blocked and thus during which the pressure is built up during a pump stroke. Accordingly, in order to adjust the amount of fuel pumped during a pump stroke and thus to adjust a feed rate of the fuel pump in dependence on an angular position of the plunger relative to the pump barrel, the sealing surface may be provided with a varying length of axial extension, i.e. along a circumferential direction of the plunger. In this way, the length of axial extension of respective sections of the sealing surface may be indicative of a feed rate of the fuel pump, when being aligned with the fuel port during operation of the fuel pump.

[0070] For example, the sealing surface may be provided with a first sealing surface section which is aligned with the fuel port when the plunger is positioned in its first end position of minimal feed rate. In other words, upon reciprocating movement of the plunger, the first sealing surface may time-sequentially block and release the fuel port during a pump stroke. Thus, for providing the minimal feed rate of the fuel pump, the length of axial extension of the sealing surface in the first sealing surface section may be smaller compared to other, i.e. residual sections of the sealing surface. In other words, the first sealing surface section may have a smallest length of axial extension of the sealing surface. For example, the first sealing surface section may have a length of an axial extension that is substantially 1.1 to 1.5 times, in particular 1.25 times, greater than a length of an axial extension of the fluid port.

[0071] The feed rate controlling structure may further comprise a minimal feed groove which may extend along the axial direction, in particular from the end face of the plunger and preferably to the sealing surface, in particular the first sealing surface section. Alternatively or additionally, the minimal feed groove and the sealing surface, in particular the first sealing surface section, may be arranged on the plunger head in axial direction, in particular adjacent to one another. Further, the minimal feed groove may be provided in form of an undercut transitioning smoothly into the recessed surface region.

[0072] In a further development, the plunger may be provided with a circularly extending groove, into which the recessed surface region opens. The circularly extending groove may be arranged between the sealing surface and a body portion of the plunger having a circumferential sealing surface. Specifically, the circularly

extending groove may be arranged adjacent to the sealing surface and the body portion of the plunger. The circumferential sealing surface of the body portion of the plunger may have a radial extension with regard to the plunger axis that corresponds to the inner radius of the pump barrel so as to provide a sealing between the plunger and the pump barrel. The first sealing surface section, in axial direction, may be arranged between, in particular adjacent to, the minimal feed groove and the circularly extending groove.

[0073] The minimal feed groove, the recessed surface region and the circularly extending groove may form a pressure release chamber. The pressure release chamber may be in fluid connection with the pump chamber through the minimal feed groove. Further, the pressure release chamber may be configured to provide a fluid connection between the pump chamber and the fuel port during a pump stroke, i.e. after the fuel in the pump chamber has been pressurized and discharged from the fuel pump.

[0074] The sealing surface may further comprise a second sealing surface section that is arranged adjacent to the first sealing surface section in a circumferential direction of the plunger. The second sealing surface section may be provided with a length of axial extension that is greater compared the length of the first sealing surface section. Specifically, the sealing surface may be provided such that the first sealing surface section merges into the second sealing surface section.

[0075] Further, the feed rate controlling structure may be provided with an interface surface which connects, in a radial direction, the recessed surface region with the sealing surface. In the region of the first sealing surface section, the interface surface may extend parallel to a circumferential direction. In the region of the second sealing surface section, the interface surface may extend at least partially as a helix around the plunger axis, in particular beginning at the minimal feed groove.

[0076] Furthermore, a plunger for use in a fuel pump may be provided. Specifically, the proposed plunger may be used in the fuel pump as described above. Accordingly, technical features which are described in connection with the fuel pump may also relate and be applied to the proposed plunger.

[0077] Thus, a plunger for use in a fuel pump may be provided which may have an essentially cylindrical base shape for reciprocating movement and rotation within a pump barrel of the fuel pump. For variably adjusting a feed rate of the fuel pump, the plunger may be configured to be rotatably movable within the pump barrel between a first end position of a minimum feed rate and a second end position of a maximum feed rate. Further, the plunger may be provided with a feed rate controlling structure which, upon reciprocatingly moving the plunger within the pump barrel along an axial direction in its first end position, may be configured to time-sequentially block a fuel port provided in the pump barrel so as to pressurize fuel within the pump barrel.

Industrial Applicability

[0078] With reference to the Figures and in operation, a fuel injection system 10 for use in an internal combustion engine is suggested. The fuel injection system 10 comprises an injection nozzle 18 and a fuel pump 14 adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle 18 via a discharge valve of the fuel pump 14. The discharge valve is configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump 14. Further, in a non-injection mode of the fuel injection system 10, the fuel pump 14 is configured to pressurize fuel flowing through the fuel pump 14 to a pressure level higher than the opening pressure of the discharge valve.

[0079] The fuel injection system 10 as mentioned above is applicable in internal combustion engines and especially in dual fuel engines which are operated either by gaseous or liquid fuel. It may replace conventional fuel injection systems and may serve as a replacement or retrofit part.

Claims

1. Fuel injection system (10) for use in an internal combustion engine comprising an injection nozzle (18) and a fuel pump (14) adapted for pressurizing fuel and for variably adjusting a feed rate of the pressurized fuel to be discharged to the injection nozzle (18) via a discharge valve of the fuel pump (14), wherein the discharge valve is configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump (14), and wherein, in a non-injection mode of the fuel injection system (10), the fuel pump (14) is configured to pressurize fuel flowing through the fuel pump (14) to a pressure level higher than the opening pressure of the discharge valve.
2. Fuel injection system according to claim 1, wherein the fuel injection system (10) in its non-injection mode is configured to operate the injection nozzle (18) in a closed state, in which the pressurized fuel is prevented from being discharged from the injection nozzle (18).
3. Fuel injection system according to claim 1 or 2, wherein the injection nozzle (10) comprises an injection valve, in particular a pressure sequence valve or a spring-biased valve, configured to open at a predetermined further opening pressure, and the fuel pump (14), in the non-injection mode, is configured to pressurize the fuel discharged from the discharge valve to a pressure level lower than the further opening pressure of the injection valve.
4. Fuel pump (14) for use in a fuel injection system (10) adapted for pressurizing fuel flowing through the fuel pump (14) and for variably adjusting a feed rate of the pressurized fuel to be discharged from the fuel pump (14), and comprising a discharge valve configured to open at a predetermined opening pressure so as to discharge the pressurized fuel from the fuel pump (14), wherein the fuel pump (14), when being operated in a state of a minimal feed rate, is configured to pressurize fuel flowing through the fuel pump (14) to a pressure level higher than the opening pressure of the discharge valve.
5. Fuel pump according to claim 4, wherein the discharge valve is connectable to an injection nozzle (18) of the fuel injection system (10), and the fuel pump (14), when being operated in its state of minimal feed rate, is configured to pressurize the fuel discharged from the discharge valve to a pressure level lower than a further opening pressure, upon which an injection valve of the injection nozzle (18) opens.
6. Fuel pump according to claim 4 or 5, comprising a pump barrel (24) and a plunger (26) for reciprocating movement and rotation within the pump barrel (24) which are configured to set a discharge portion and pressure of a pump stroke in dependence on an angular position of the plunger (26) relative to the pump barrel (24), wherein in particular the plunger (26), relative to the pump barrel (24), is rotatable between a first end position of minimal feed rate and a second end position of maximal feed rate.
7. Fuel pump according to claim 6, wherein the plunger (26) is provided with a feed rate controlling structure (36) which, in the first end position of the plunger (26), is configured to, upon reciprocatingly moving the plunger (26) within the pump barrel (24) along an axial direction (30), time-sequentially block a fuel port (32) provided in the pump barrel (24) so as to pressurize the fuel flowing through the fuel pump (14) to the pressure level higher than the opening pressure of the discharge valve.
8. Fuel pump according to claim 7, wherein the feed rate controlling structure (36) comprises a sealing surface (42) and a recessed surface region (44), wherein the sealing surface (42) at least partially surrounds a plunger axis (30) at a plunger sealing radius (R_{max}) and the recessed surface region (44) at least partially surrounds the plunger axis (30) at a reduced radius (R_{red}).
9. Fuel pump according to claim 8, wherein the sealing surface (42) comprises a first sealing surface section (46) which is aligned with the fuel port (32) when the plunger (26) is positioned in its first end position of

minimal feed rate, and wherein in particular the first sealing surface section (46) has a smallest length of axial extension of the sealing surface (42).

10. Fuel pump according to claim 9, wherein the first sealing surface section (46) has a length of an axial extension that is substantially 1.1 to 1.5 times, in particular 1.25 times, greater than a length of an axial extension of the fluid port (32). 5
11. Fuel pump according to any one of claims 8 to 10, wherein the feed rate controlling structure (36) further comprises a minimal feed groove (50) extending along the axial direction (30), in particular from an end face (52) of the plunger (26), wherein the minimal feed groove (50) and the sealing surface (42), in particular the first sealing surface section (46), are arranged in axial direction, in particular adjacent to one another. 10
12. Fuel pump according to any one of claims 8 to 10, wherein the plunger (26) is provided with a circularly extending groove (54), into which the recessed surface region (44) opens and which is arranged between the sealing surface (42) and a body portion of the plunger (26) having a circumferential sealing surface (56). 15
13. Fuel pump according to claim 12, wherein the minimal feed groove (50), the recessed surface region (44) and the circularly extending groove (54) form a pressure release chamber (58) which is in fluid connection with a pump chamber (28) formed by the end face (52) of the plunger (26) and an inner surface of the pump barrel (24), in particular through the minimal feed groove (50). 20
14. Fuel pump according to any one of claims 9 to 13, wherein the feed rate controlling structure (36) is provided with an interface surface (60) connecting the recessed surface region (44) with the sealing surface (42) in a radial direction, wherein, in the region of the first sealing surface section (46), the interface surface (60) extends in parallel to a circumferential direction and, in the region of a second sealing surface section (46) of the sealing surface (42), extends at least partially as a helix around the plunger axis (30). 25
15. Plunger (26) for use in a fuel pump (14) having an essentially cylindrical base shape for reciprocating movement and rotation within a pump barrel (24) of the fuel pump (14), wherein the plunger (26), for variably adjusting a feed rate of the fuel pump (14), is configured to be rotatably movable within the pump barrel (24) between a first end position of a minimum feed rate and a second end position of a maximum feed rate, and wherein the plunger (26) is provided with a feed rate controlling structure (36) which, upon 30

reciprocatingly moving the plunger (26) within the pump barrel (24) along an axial direction (30) in its first end position, is configured to time-sequentially block a fuel port (32) provided in the pump barrel (24) so as to pressurize fuel present in the pump barrel (24). 35

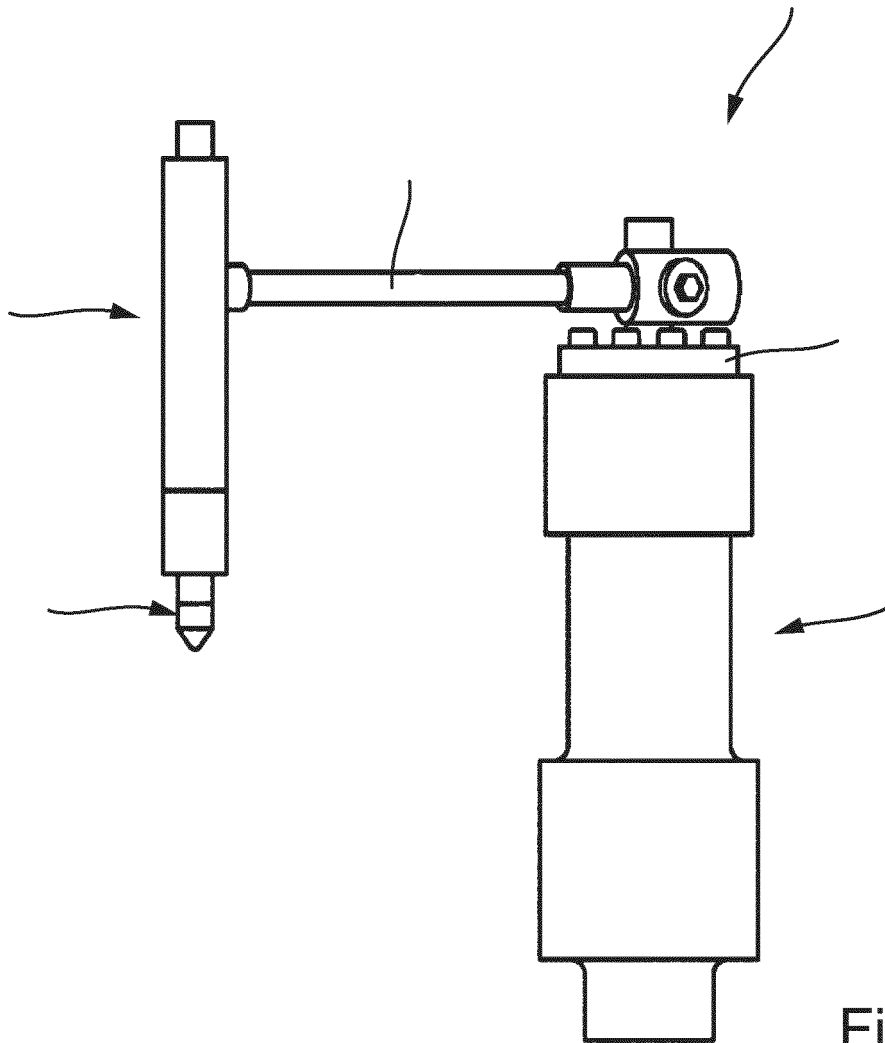


Fig. 1

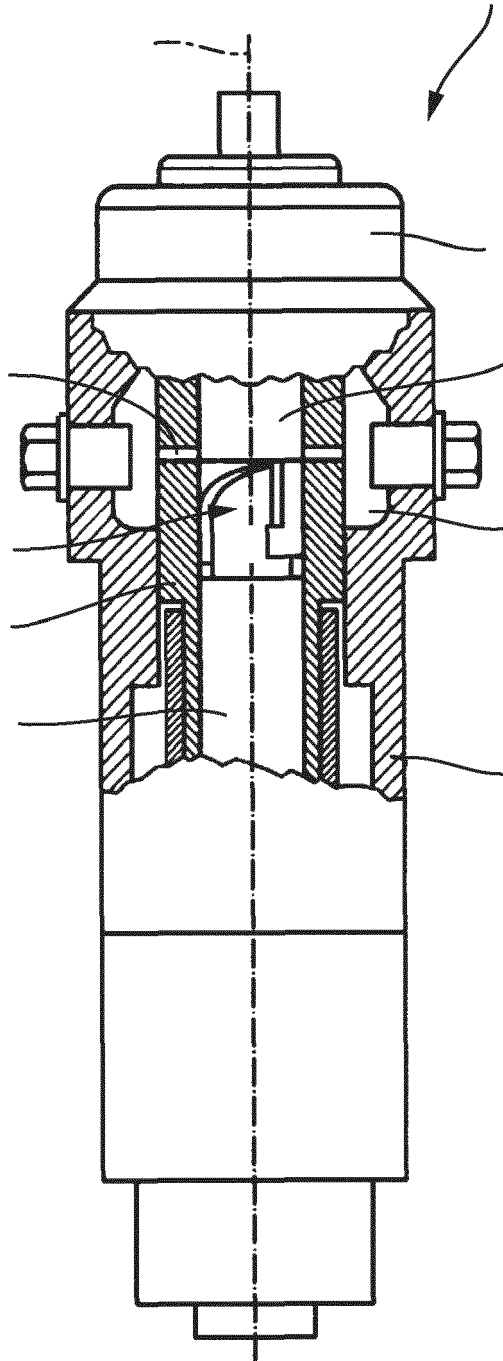


Fig. 2

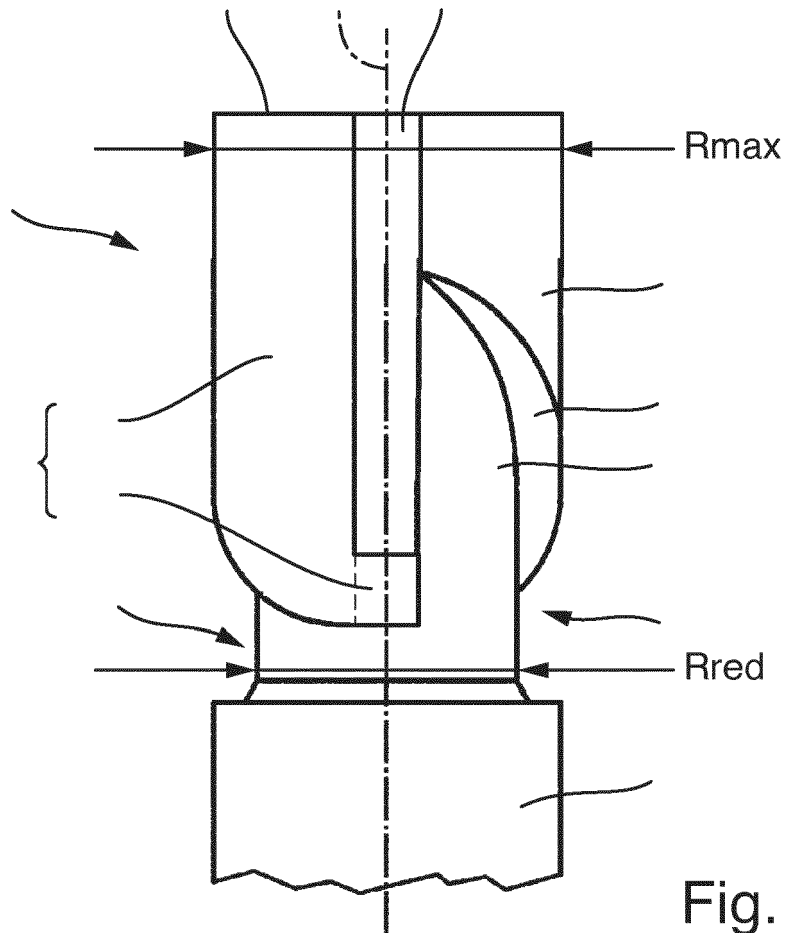


Fig. 3

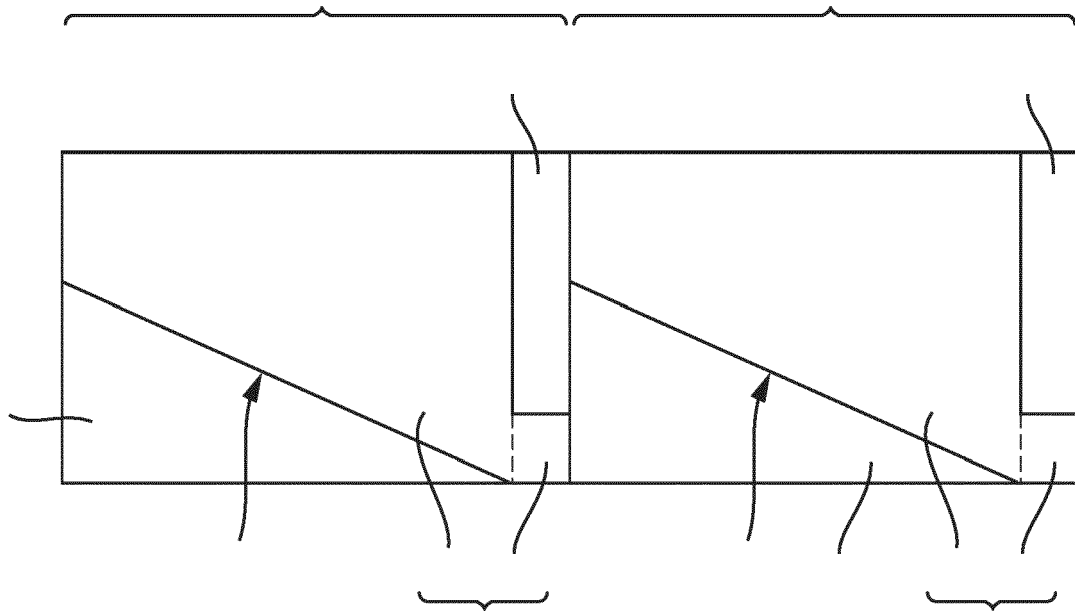


Fig. 4

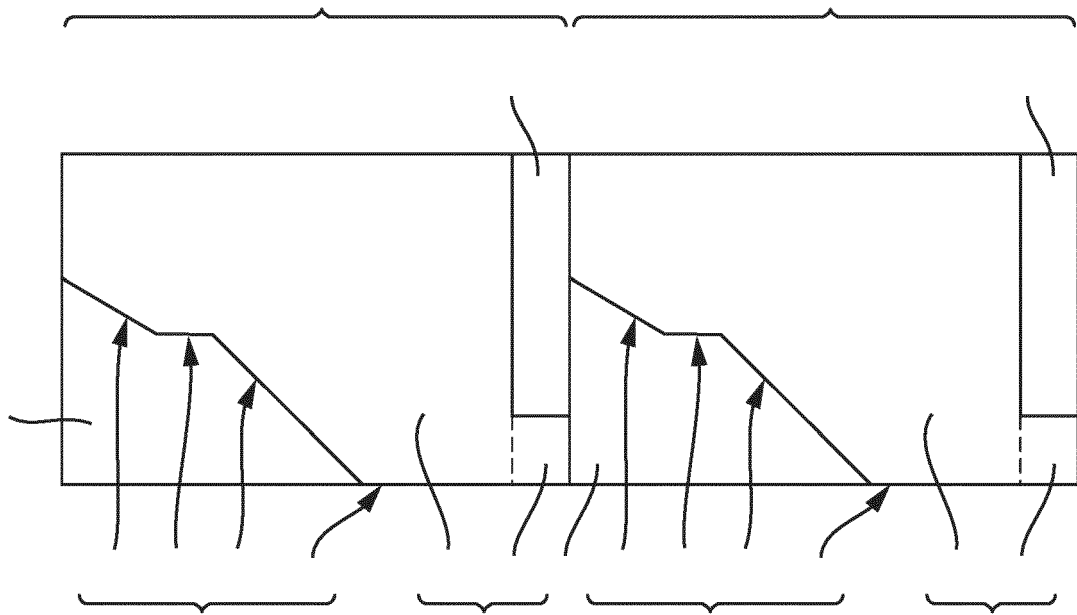


Fig. 5

REFERENCES CITED IN THE DESCRIPTION

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