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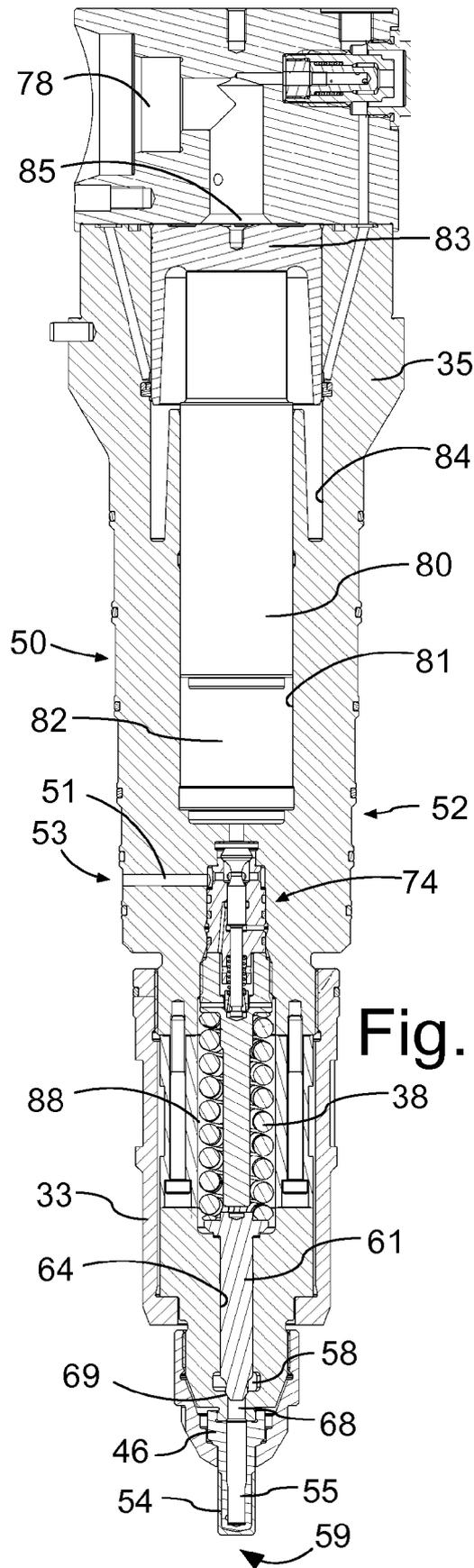
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(54) **A FUEL VALVE AND METHOD FOR INJECTING A LIQUID FUEL INTO A COMBUSTION CHAMBER OF A LARGE COMPRESSION-IGNITING TURBOCHARGED TWO-STROKE INTERNAL COMBUSTION ENGINE FIELD**

(57) A fuel valve (50) for injecting liquid fuel into the combustion chamber of a large slow running two-stroke turbocharged compression-igniting internal combustion engine, comprising an elongated valve housing (52) with a rear end and a front end, a nozzle (54) comprising an elongated nozzle body extending from a base (46) to a closed tip (59), a main bore (55) extending from the base (46) to the closed tip (59) and a plurality of nozzle holes (56) connected to the main bore (55), the nozzle (54) being disposed at the front end of the elongated valve housing (52) with the base (46) connected to the front end, a fuel inlet port (53) in the elongated fuel valve housing (52) for connection to a source (60) of pressurized liquid fuel, an axially displaceable valve needle (61) slidably received in a longitudinal needle bore (64) in the elongated valve housing (52) with a clearance between the valve needle (61) and the needle bore (64), the valve needle (61) having a closed position and an open position, the valve needle (61) rests on a valve seat (69) in the closed position and the valve needle (61) has lift from the valve seat (69) in the open position and the valve needle (61) being biased towards the closed position,

the seat (69) being disposed in the elongated valve housing (52) between a fuel chamber (58) in the valve housing (52) and an outlet port (68) in the front end of the elongated valve housing (52), the outlet port (68) connecting directly to the main bore (55) in the nozzle (54), the fuel chamber (58) being connected to the fuel inlet port (53), the clearance opening at one end of the needle bore (64) to the fuel chamber (58), a lubricating oil inlet port (70) for connection to a source of pressurized lubricating oil (57), a lubricating oil supply conduit (47) connecting the lubricating oil inlet port (70) to the clearance at a first position (P1) along the length of the needle bore (64), an ignition liquid inlet port (67) for connection to a source of pressurized ignition liquid (65), and an ignition liquid conduit (66) extending from the ignition liquid inlet port (67) to the chamber (58) or to the clearance at a second position (P2) along the length of the needle bore (64) that is closer to the fuel chamber (58) than the first position (P1).

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## Description

### FIELD

**[0001]** The present disclosure relates to a fuel valve for injecting fuel into a combustion chamber of a large two-stroke turbocharged compression-ignition internal combustion engine with a fuel supply system operating with liquid fuel, in particular difficult or unreliable to ignite liquid fuel and to a method for injecting a liquid fuel, in particular a liquid fuel that is difficult or unreliable to ignite into the combustion chamber of a large two stroke compression-ignition internal combustion engine.

### BACKGROUND ART

**[0002]** Large low-speed turbocharged two-stroke compression-igniting engines of the crosshead type are typically used in propulsion systems of large ships or as prime mover in power plants. Very often, these engines are operated with heavy fuel oil.

**[0003]** Recently, there has been a demand for large turbocharged two-stroke compression-igniting engines to be able to handle alternative types of fuel, such as gas, methanol, coal slurry, water-oil mixtures, petroleum coke and others.

**[0004]** Several of these alternative fuels, such as water-oil mixtures have the potential to reduce costs and emissions.

**[0005]** However, there are problems associated with using a water mixtures in a large low-speed uniflow turbocharged two-stroke internal combustion engine.

**[0006]** One of those problems is the willingness and predictability of these fuels to compression-ignite upon injection into the combustion chamber and both willingness and predictability are essential to have under control in a compression-ignited engine. Therefore, existing large low-speed uniflow turbocharged two-stroke internal combustion engines use pilot injection of oil or other ignition liquid simultaneously with the injection of the difficult or unreliable to ignite fuel to ensure reliable and properly timed ignition of the fuel. The problem is present for several types of fuels that are challenging to ignite, such as e.g. fuel oil-water mixtures.

**[0007]** Large low-speed uniflow turbocharged two-stroke internal combustion engines are typically used for the propulsion of large ocean going cargo ships and reliability is therefore of the utmost importance. Operation of these engines with alternative fuels is still a relatively recent development and reliability of the operation with gas has not yet reached the level of conventional fuel. Therefore, existing large low-speed two-stroke diesel engines are all dual fuel engines with a fuel system for operation on an alternative fuel such as e.g. gaseous fuel and a fuel system for operation with fuel oil so that they can be operated at full power running on the fuel oil only.

**[0008]** Due to the large diameter of the combustion chamber of these engines, they are typically provided

with three fuel injection valves per cylinder, separated by an angle of approximately 120° around the central exhaust valve. Thus, with a dual fuel system there will be three fuel alternative fuel valves per cylinder and three conventional fuel oil valves per cylinder and thus, the top cover of the cylinder is a relatively crowded place.

**[0009]** In the existing dual fuel engines the fuel oil valves have been used to provide the pilot oil injection during operation with gaseous fuel. These fuel oil valves are dimensioned so as to be able to deliver fuel oil in an amount required for operating the engine at full load on fuel oil only. However, the amount of oil injected in a pilot injection should be as small as possible to obtain the desired reduction in emissions. Dosage of such a small amount with a full size fuel injection system that can also deliver the large amount necessary for operation at full load poses significant technical problems, and is in practice very difficult to achieve and therefore the pilot oil dosage has in existing engines been with a larger quantity per fuel injection event than desirable, especially at medium and low load. The alternative of an additional small injection system that can handle the small pilot amount is a considerable complication and cost up. Further, additional small pilot oil injection valves render the top cover of the cylinder even more crowded.

**[0010]** EP3070321 discloses a fuel valve for injecting low flashpoint liquid fuel into the combustion chamber of a large two-stroke turbocharged self-igniting internal combustion engine, The fuel valve has an elongated fuel valve housing with a nozzle with a nozzle holes, a fuel inlet port in the elongated fuel valve housing for connection to a source of pressurized liquid fuel, an actuation liquid port in the elongated fuel valve housing, an axially displaceable valve needle slidably received in a longitudinal bore in the elongated valve housing, the valve needle having a closed position where the valve needle rests on a valve seat and an open position where the valve needle has lift from the valve seat, the valve needle) being biased towards the closed position, a fuel chamber surrounding the valve needle and opening to the valve seat, a pump piston received in a first bore with a pump chamber in the first bore on one side of the pump piston, an actuation piston received in a second bore with an actuation chamber in the second bore on one side of the actuation piston, the pump piston being connected to the actuation piston to move in unison therewith, the actuation chamber (85) being connected to an actuation liquid port, the pump chamber having an outlet connected to the fuel chamber and an inlet connected to a fuel inlet port, a sealing liquid inlet port, a conduit connecting the sealing liquid inlet port to the first bore for sealing the pump piston in the first bore.

**[0011]** In general it is not desirable to operate with a separate pilot injection of ignition liquid for several reasons. It has proved difficult to obtain a reliable injector operation below 3% of the MCR load. Secondly any external ignition, out in the cylinder, will require at least a minimum amount of fuel, the long term function of the

pilot injection has further not been verified. It is expected that worn down fuel pumps might degrade the pilot injection function. Additionally, it is expected that the rapid pilot injection profile could cause increased wear on the fuel system.

**[0012]** Some of these fuels also have a low flashpoint which gives rise to safety concerns. The construction of known fuel valves, always has leakage between the shaft of the valve needle and the bore in which the shaft is guided, due to the design of the needle. Therefore, a supply of pressurized sealing liquid 'sealing oil' is applied to the clearance between the shaft and the bore, both for sealing purposes, but also for lubrication purposes. In order to keep leakage to a minimum the clearance is kept as small as possible with very narrow tolerances and such a small clearance requires lubrication between the shaft and the bore.

**[0013]** Separation of sealing oil and fuel is difficult, in case the two fluids has been mixed thus causing error is in the system. Detection of fuel in the lubrication oil system will result of shut down of the engine, and it is often difficult to trouble shoot the root cause.

**[0014]** Another safety related issue is the requirement by the ship classification societies that low flashpoint fuels are not allowed to remain in the fuel valves and the tubing leading to the fuel valves when the engine is not operated on the low flashpoint fuel, e.g. when the engine is not operating or when it is a dual fuel engine that is operated on another type of fuel. Thus, provisions have to be made for purging the fuel valves and the tubing or piping leading to the fuel valves.

**[0015]** Another challenge of these low flashpoint fuels is their relatively poor lubrication properties, which prevents the use of very small clearances between moving parts without applying a lubrication liquid.

#### DISCLOSURE

**[0016]** On this background, it is an object of the present application to provide a fuel valve for a large turbocharged compression-ignited two-stroke internal combustion engine that overcomes or at least reduces the problems indicated above.

**[0017]** This object is according to one aspect achieved by providing a fuel valve for injecting liquid fuel into the combustion chamber of a large slow running two-stroke turbocharged compression-igniting internal combustion engine, the fuel valve comprising an elongated valve housing with a rear end and a front end, a nozzle comprising an elongated nozzle body extending from a base to a closed tip, a main bore extending from the base to the closed tip and a plurality of nozzle holes connected to the main bore, the nozzle being disposed at the front end of the elongated valve housing with the base connected to the front end, a fuel inlet port in the elongated fuel valve housing for connection to a source of pressurized liquid fuel, an axially displaceable valve needle slidably received in a longitudinal needle bore in the elon-

gated valve housing with a clearance between the valve needle and the needle bore, the valve needle having a closed position and an open position, the valve needle rests on a valve seat in the closed position and the valve needle has lift from the valve seat in the open position and the valve needle being biased towards the closed position, the seat being disposed in the elongated valve housing between a fuel chamber in the valve housing and an outlet port in the front end of the elongated valve housing, the outlet port connecting directly to the main bore in the nozzle, the fuel chamber being connected to the fuel inlet port, the clearance opening at one end of the needle bore to the fuel chamber, a lubricating oil inlet port for connection to a source of pressurized lubricating oil, a lubricating oil supply conduit connecting the lubricating oil inlet port to the clearance at a first position along the length of the needle bore, an ignition liquid inlet port for connection to a source of pressurized ignition liquid, and an ignition liquid conduit extending from the ignition liquid inlet port to the chamber or to the clearance at a second position along the length of the needle bore that is closer to the fuel chamber than the first position.

**[0018]** The advantage of supplying an ignition liquid into the nozzle of the fuel injection valve that injects the difficult to ignite liquid fuel is that the engine can operate without an external pilot injection via a separate pilot valve. The ignition instead takes place inside the nozzle of the fuel valve that injects the difficult to ignite liquid fuel. The ignition liquid ignites inside the chamber in the nozzle where the initial flame is sheltered from the combustion chamber, giving it a better probability of igniting the liquid fuel that follows after or simultaneously during the injection event. This allows for a significantly reduced ignition-liquid consumption. Tests have indicated that levels well below 1% of MCR load are possible.

**[0019]** By providing an independent supply of ignition liquid, separate from e.g. the lubricating oil system, the dosage of ignition liquid can be controlled more accurately and reliably and the type of ignition liquid can easily be changed. Full control of the ignition liquid quantity, is obtained by varying upstream clearances and supply pressure, without compromising the action of the sealing oil system. The ignition liquid is no longer restricted to system oil. For example, more easily ignited liquids, such as diesel oil or DME (Dimethyl ether), can be used.

**[0020]** In a first possible implementation of the first aspect the ignition liquid conduit extends from the ignition inlet port to the fuel chamber at a position adjacent the seat.

**[0021]** In a second possible implementation of the first aspect the ignition liquid conduit extends from the ignition inlet port to the seat.

**[0022]** In a third possible implementation of the first aspect the ignition liquid conduit to the seat is closed by the valve needle when the valve needle rests on the seat.

**[0023]** In a fourth possible implementation of the first aspect the main bore opens to the base.

**[0024]** In a fifth possible implementation of the first as-

pect the source of ignition liquid has a pressure that is higher than the pressure of the source of liquid fuel.

**[0025]** In a sixth possible implementation of the first aspect the fuel valve further comprises an actuation liquid port in the elongated fuel valve housing for connection to a source of pressurized actuation fluid, a pump piston received in a first bore in the valve housing with a pump chamber in the first bore on one side of the pump piston, an actuation piston received in a second bore in the valve housing with an actuation chamber in the second bore on one side of the actuation piston, the pump piston being connected to the actuation piston to move in unison therewith, the actuation chamber being fluidically connected to the actuation liquid port, and the pump chamber having an outlet connected to the fuel chamber and an inlet connected to the fuel inlet port via a non-return valve in the elongated fuel valve housing that prevents flow from the pump chamber to the fuel inlet port.

**[0026]** In a seventh possible implementation of the first aspect the fuel chamber surrounds the valve needle and opening to the valve seat with the valve seat being arranged between the fuel chamber and the outlet port

**[0027]** In an eighth possible implementation of the first aspect the valve needle is configured to move from the closed position to the open position against the bias when the pressure in the fuel chamber exceeds a predetermined threshold.

**[0028]** In a ninth possible implementation of the first aspect the fuel valve further comprises a cooling liquid inlet port and a cooling liquid outlet port and a cooling liquid flow path for cooling the fuel injection valve, in particular the portion of the fuel valve closest to the front end.

**[0029]** In a tenth possible implementation of the first aspect the elongated valve housing comprises a front portion that is connected to a rear portion, the axially displaceable valve needle being disposed in the front portion, the first bore, the second bore and the matching longitudinal bore being formed in the rear portion.

**[0030]** In an eleventh possible implementation of the first aspect the fuel valve further comprising a conduit connecting the sealing liquid inlet port to the first bore for sealing the pump piston in the first bore.

**[0031]** According to a second aspect there is provided a large slow running two-stroke turbocharged compression-igniting internal combustion engine comprising a fuel valve according the first aspect of any possible implementations thereof.

**[0032]** In a first possible implementation of the second aspect the engine further comprising a source of pressurized fuel with a controlled pressure  $P_f$ , a source of pressurized lubricating oil with a controlled pressure  $P_s$  and a source of pressurized ignition liquid with a controlled pressure  $P_{if}$ .

**[0033]** In a first possible implementation of the second aspect  $P_s$  is higher than  $P_f$  and  $P_{if}$  is higher than  $P_f$ .

**[0034]** In a first possible implementation of the second aspect the engine is configured to ignite the fuel upon entry of the fuel in the main bore inside the nozzle.

**[0035]** According to a third aspect there is provided a method of operating a large two-stroke low-speed turbocharged compression-ignited internal combustion engine, the method comprising supplying pressurized liquid fuel at a first high pressure to a fuel valve of the engine, the fuel valve having an elongated valve housing with a rear end and a front end, the fuel valve having a hollow nozzle with a plurality of nozzle holes connecting the interior of the nozzle to a combustion chamber in a cylinder of the engine, the nozzle comprising a base and an elongated nozzle body, the nozzle being connected with its base to the front end of the elongated valve housing, the nozzle having a closed tip with the nozzle holes arranged close to the tip, supplying ignition liquid at a second high pressure to the fuel valve, the second high pressure being higher than the first high pressure, controlling the injection of the liquid fuel with a displaceable valve needle that cooperates with a seat above the hollow nozzle, a fuel chamber being arranged above the seat, pressuring the fuel chamber with the liquid fuel, delivering a continuous flow of ignition liquid to the fuel chamber and allowing the ignition liquid to accumulate above the seat during periods where the axially displaceable valve needle rests on the seat and starting a liquid fuel injection event by lifting the axially displaceable valve needle from the seat, thereby causing the accumulated ignition liquid to enter the hollow injection nozzle just ahead of the liquid fuel, or delivering a precisely dosed amount of ignition liquid to the seat when the axially displaceable valve needle has lift, and starting a liquid fuel injection event by lifting the axially displaceable valve needle from the seat, thereby causing the accumulated ignition liquid to enter the hollow injection nozzle simultaneously with the liquid fuel.

**[0036]** In a first possible implementation of the third aspect the liquid fuel ignites inside the nozzle with the help of the ignition liquid.

**[0037]** In a first possible implementation of the third aspect the nozzle is kept above 300°C throughout the engine cycle.

**[0038]** Further objects, features, advantages and properties of the fuel valve and engine according to the present disclosure will become apparent from the detailed description.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0039]** In the following detailed portion of the present description, the invention will be explained in more detail with reference to the exemplary embodiments shown in the drawings, in which:

Fig. 1 is a front view of a large two-stroke diesel engine according to an example embodiment,

Fig. 2 is a side view of the large two-stroke engine of Fig. 1,

Fig. 3 is a diagrammatic representation the large two-stroke engine according to Fig. 1, and

Fig. 4 is a diagrammatic representation of an exam-

ple embodiment for one fuel valve of low fuel system of the engine of Fig. 1,

Fig. 5 is a sectional view in diagrammatic representation of an example embodiment of the fuel system of the engine of Fig. 1 of the upper part of a cylinder, Fig. 6 is an elevated view of a fuel valve for using an engine according to Figs. 1 to 3 to an example embodiment,

Fig. 7 is sectional view of the fuel injection valve shown in Fig. 6,

Fig. 7A shows a first embodiment of an enlarged detail of Fig. 7,

Fig. 7B shows a second embodiment of an enlarged detail of Fig. 7,

Fig. 7C shows a third embodiment of an enlarged detail of Fig. 7,

Fig. 7D shows a fourth embodiment of an enlarged detail of Fig. 7,

Fig. 8 is a different sectional view of a low flashpoint fuel injection valve shown in Fig. 6,

Fig. 9 is another different sectional view of a low flashpoint fuel injection valve shown in Fig. 6,

Fig. 9A shows an enlarged detail of Fig. 9.

Fig. 10 is another different sectional view of a low flashpoint fuel injection valve shown in Fig. 6, and

Fig. 11 is another different sectional view of a low flashpoint fuel injection valve shown in Fig. 6.

#### DETAILED DESCRIPTION

**[0040]** In the following detailed description, the compression-igniting internal combustion engine will be described with reference to a large two-stroke low-speed turbocharged internal combustion (Diesel) engine in the example embodiments. Figs. 1, 2 and 3 show a large low-speed turbocharged two-stroke diesel engine with a crankshaft 42 and crossheads 43. Fig. 3 shows a diagrammatic representation of a large low-speed turbocharged two-stroke diesel engine with its intake and exhaust systems. In this example embodiment the engine has four cylinders 1 in line. Large low-speed turbocharged two-stroke diesel engines have typically between four and fourteen cylinders in line, carried by an engine frame 13. The engine may e.g. be used as the main engine in an ocean going vessel or as a stationary engine for operating a generator in a power station. The total output of the engine may, for example, range from 1,000 to 110,000 kW.

**[0041]** The engine is in this example embodiment a diesel (compression-igniting) engine of the two-stroke uniflow type with scavenge ports 19 at the lower region of the cylinders 1 and a central exhaust valve 4 at the top of the cylinders 1. The scavenge air is passed from the scavenge air receiver 2 to the scavenge ports 19 of the individual cylinders 1. A piston 41 in the cylinder 1 compresses the scavenge air, fuel is injected from fuel injection valves (described in detail further below), in the cylinder cover (described in detail further below), com-

bustion follows and exhaust gas is generated. When an exhaust valve 4 is opened, the exhaust gas flows through an exhaust duct associated with the cylinder 1 into the exhaust gas receiver 3 and onwards through a first exhaust conduit 18 to a turbine 6 of the turbocharger 5, from which the exhaust gas flows away through a second exhaust conduit via an economizer 28 to an outlet 29 and into the atmosphere. Through a shaft, the turbine 6 drives a compressor 9 supplied with fresh air via an air inlet 10. The compressor 9 delivers pressurized scavenge air to a scavenge air conduit 11 leading to the scavenge air receiver 2.

**[0042]** The scavenge air in conduit 11 passes an inter-cooler 12 for cooling the scavenge air. In an example embodiment the scavenge air leaves the compressor at approximately 200 °C and is cooled to a temperature between 36 and 80 °C by the intercooler.

**[0043]** The cooled scavenge air passes via an auxiliary blower 16 driven by an electric motor 17 that pressurizes the scavenge air flow when the compressor 9 of the turbocharger 5 does not deliver sufficient pressure for the scavenge air receiver 2, i.e. in low or partial load conditions of the engine. At higher engine loads the turbocharger compressor 9 delivers sufficient compressed scavenge air and then the auxiliary blower 16 is bypassed via a non-return valve 15.

**[0044]** Fig. 4 is a diagrammatic representation of a liquid fuel valve 50 with its connections to the source of liquid fuel 60 (such as e.g. oil-water fuel or a low flashpoint fuel such as e.g. methanol), to a source of cooling liquid (oil) 63, to the source of lubricating liquid 57, to a source of ignition fluid 65, to a source of actuation liquid (oil) 97 via a control valve 96, to a purge control valve 98, and an actuation liquid control valve 98.

**[0045]** A conduit 62 leads from the source of pressurized liquid fuel 62 to the inlet port in the housing of the liquid fuel valve 50. Conduit 62 can be a double walled conduit, e.g. formed by concentric tubes or by a tube inside a solid block material such as the cylinder cover 48. A window valve 61 can be provided in the conduit 62 for being able to disconnect the fuel valve 50 from the source of liquid fuel 60 for being able to purge the fuel valve 50 from flashpoint fuel. The window valve 61 is preferably electronically operated and controlled by the electronic control unit. The electronic control valve 96 controls the injection events and the purge control valve 98 controls purging by preventing a non-return valve from closing.

**[0046]** Fig. 5 shows the top of one of the plurality of cylinders 1 according to an example embodiment. The top cover 48 of the cylinders 1 is provided with a number (typically 2 or 3) of fuel valves 50 for injecting a liquid fuel from a nozzle of the fuel valves 50, into the combustion chamber above the piston 41 in the cylinder 1. In this example embodiment the engine has three liquid fuel valves 50 per cylinder, but it should be understood that a single or two fuel valves 50 may be sufficient, depending on the size of the combustion chamber. The exhaust

valve 4 is placed centrally in the top cover with the liquid fuel valves 50 closer to the cylinder wall.

**[0047]** In an embodiment (not shown), two or three additional fuel oil valves can be provided in the top cover 48 for operation of the engine on fuel oil. The fuel oil valves are connected to a source of high pressure fuel oil in a well-known manner.

**[0048]** The forward portion of the fuel valve 50 that is closest to the nozzle and closest to the combustion chamber is in an embodiment cooled using a cooling liquid, such as cooling oil, for which system oil (lubrication oil) can be used. Hereto, the body of the fuel valve 50 is provided with a cooling liquid inlet port and a cooling liquid outlet port and a flow path (not shown) between the inlet port and the outlet port through the forward portion of the body of the fuel valve 50. The cooling liquid inlet port is connected via a conduit to a source of pressurized cooling liquid 63, such as system oil, and the cooling liquid outlet port is connected via a conduit to a reservoir of cooling liquid.

**[0049]** The body of the fuel valve 50 is also provided with an actuation liquid port for controlling the opening and closing of the fuel valve 50. The control port is connected via a conduit to the source of pressurized actuation liquid 97. The electronically controlled control valve 96, preferably a proportional valve, is placed in the conduit between the source of pressurized actuation liquid 97 and the actuation liquid port for controlling the opening and closing of the fuel valve 50, i.e. for controlling injection event.

**[0050]** The body of the fuel valve 50 is also provided with an ignition liquid inlet port for receiving ignition liquid from a pressurized source of ignition liquid 65 at a pressure  $P_{if}$ .

**[0051]** The engine is provided with an electronic control unit (not shown) that controls the operation of the engine. Signal lines connect the electronic control unit to the electronic control valves 96 and 98 and to the window valves 61.

**[0052]** The electronic control unit is configured to time the injection events of the liquid fuel valve 50 correctly and to control the dosage (volume injected per injection event) of the liquid fuel with the fuel valves 50. The electronic control unit is in an embodiment configured to control the shape of the injection curve (rate shaping), since the fuel valve is capable of adapting to such curves.

**[0053]** In a configuration with low flashpoint fuel the electronic control unit opens and closes the window valve 61 so as to ensure that the supply conduit 62 is filled with pressurized low flashpoint liquid fuel before the start of a fuel injection event. The window valve 61 is closed by the electronic control unit when the fuel valve 50 needs to be purged from low flashpoint fuel.

**[0054]** Fig. 6 is a perspective view of the fuel valve 50 with its elongated valve housing 52, a nozzle 54 is attached to the front end of the elongated valve housing 52 and a lubricating liquid inlet port 70 and a control port 36 for controlling purging. The nozzle 54 is provided with a plurality of nozzle holes 56 that are radially and axially

distributed over the nozzle 54.

**[0055]** Figs. 7,8,9,10 and 11 show sectional views of a fuel valve 50 for injecting liquid fuel into the combustion chamber 41 of the compression-igniting internal combustion engine. The fuel valve 50 has an elongated valve housing 52 with a rearmost end and a nozzle 54 attached to its front end. The nozzle 54 is a separate body that is attached with its base 46 to the front end of the valve housing 52. The rearmost end of the valve housing 52 is provided with a plurality of ports, including a (purge) control port 36, an actuation liquid port 78, an ignition liquid port 67 and a gas leak detection port (not shown), that is connected to a gas detection conduit 34. The rearmost end is enlarged to form a head that protrudes from the cylinder cover 48 when the fuel valve 50 is mounted in the cylinder cover 48. In the present embodiment, the fuel valves 50 are placed around the central exhaust valve 4, i.e. relatively close to the wall of the cylinder liner. The elongated valve housing 52 and the other components of the fuel injection valve 50, as well as the nozzle are in embodiment made of steel, such as e.g. tool steel and stainless steel.

**[0056]** The hollow nozzle 54 is provided with nozzle holes 56 that are connected to the main bore 55 in the nozzle 54 and the nozzle holes 56 are distributed radially and preferably also axially over the nozzle 54. The nozzle holes 56 are axially near to the closed tip 59 and the radial distribution of the nozzle holes 56 is in the present embodiment over a relatively narrow range of approximately  $50^\circ$ . The radial orientation of the nozzle holes 56 is such that the nozzle holes 56 are directed away from the wall of the cylinder liner. Further, the nozzle holes 56 are directed such that they are roughly in the same direction as the direction of the swirl of the scavenge air in the combustion chamber caused by the slanted configuration of the scavenge ports (this swirl is a well-known feature of large two-stroke turbocharged internal combustion engines of the uniflow type).

**[0057]** The tip 59 of the nozzle 54 is in closed, i.e. there is no downwardly directed nozzle hole 46. The nozzle 54 is with its base 46 connected to the front end of the valve housing 52 with the main bore of the nozzle 54 opening towards an outlet opening 68 in front end of the valve housing 52. A valve seat 69 is disposed at the transition between an axial bore forming the outlet opening 68 and a fuel chamber 58.

**[0058]** An axially displaceable valve needle 61 is slidably received with a narrow clearance in a longitudinal bore in 64 the elongated valve housing 52, and lubrication between the axially displaceable valve needle 61 and the longitudinal bore is critical. Hereto, pressurized lubricating liquid is delivered to the clearance between the longitudinal bore 64 in the valve needle via a conduit (channel) 47. The channel 47 connects the clearance between the valve needle 61 and the axial bore to the lubricating oil inlet port 70, which in turn can be connected to the source of pressurized lubricating oil 57 which is pressurized and a pressure  $P_s$ . The lubricating oil prevents leak-

age of fuel into the clearance between the valve needle 61 and the axial bore when operating on low flashpoint fuel. Further, the lubricating oil, provides for lubrication between the valve needle 61 and the axial bore 64. In an embodiment, the pressure of the source of lubricating oil 57 is at least above the supply pressure of the source of liquid fuel but can be well below the maximum pressure in the pump chamber 82 during an injection event as long as the aggregated flow in the clearance between the pump piston 80 and the 1st bore 81 is in the direction towards the pump chamber 82.

**[0059]** The valve needle 61 has a closed position and an open position. The valve needle 61 is provided with a conical section that is shaped to match the valve seat 69. In the closed position the conical section of the valve needle rests on the valve seat 69. The conical section has lift from the valve seat 69 in the open position and the valve needle 61 is resiliently biased towards the closed position by a pre-tensioned helical spring 38. The pre-tensioned helical spring 38 acts on the valve needle 61 and biases the valve needle 61 towards its closed position where the conical section rest on the seat 69.

**[0060]** The helical spring 38 is a helical wire spring that is received in a spring chamber 88 in the elongated fuel valve housing 52. Cooling oil flows through the spring chamber 88. One end of the helical spring 38 engages an end of the spring chamber 88 and the other end of the helical spring 38 engages a widened section or flange on the valve needle 61, thereby resiliently urging the valve needle towards the valve seat 69.

**[0061]** The elongated valve housing 52 is provided with a fuel inlet port 53 for connection to a source of pressurized liquid fuel 60, via the low fuel supply conduit 62. The fuel inlet port 53 connects to a pump chamber 82 in the valve housing 52 via a conduit 51 and a non-return valve 7. The non-return valve 74 (suction valve) is provided inside the valve housing 52. The non-return valve 74 ensures that liquid fuel can flow through the conduit 51 to the pump chamber 82, but not in the opposite direction.

**[0062]** A pump piston 80 is slidably and sealingly disposed in a first bore 81 in the elongated fuel valve housing 52 with a pump chamber 82 in the first bore 81 on one side of the pump piston 80. An actuation piston 83 is slidably and sealingly disposed in a second bore 84 in the valve housing 52 with an actuation chamber 85 in the second bore 84 on one side of the actuation piston 83. The pump piston 80 is connected to the actuation piston 83 to move in unison therewith, i.e. the pump piston 80 and the actuation piston 83 can slide in unison their respective bores 81,84. In the present embodiment the pump piston 80 and the actuation piston 83 performed by a single body, however, it is noted that the pump piston 80 and the actuation piston 83 can be separate interconnected bodies.

**[0063]** The actuation chamber 85 is fluidically connected to an actuation liquid port 78. The electronic control valve 96 controls the flow pressurized actuation liquid to

and from the actuation liquid port 78 and thereby to and from to the actuation chamber 85.

**[0064]** At the start of injection event, the electronic control unit commands the electronic control valve 96 to allow actuation liquid into the actuation chamber 85. The pressurized actuation liquid in the actuation chamber 85 acts on the actuation piston 83, thereby creating a force that urges the pump piston 81 into the pump chamber 82. Thereby the pressure of the liquid fuel in the pump chamber 82 increases. In embodiment the diameter of the actuation piston 83 is larger than the diameter of the pump piston 80 and thus the pressure in the pump chamber 82 will be correspondingly higher than the pressure in the actuation chamber 85 and the combination of the actuation piston 83 and pump piston 80 acts as a pressure booster.

**[0065]** One or more channels (conduits) 57 fluidically connect the pump chamber 82 to the fuel chamber 58 and thereby to the valve seat 69 that is located at the bottom of the fuel chamber. The valve seat 69 faces the fuel chamber 58 that surrounds the valve needle 61. The valve needle 61 is configured to move away from the nozzle 54 to obtain lift, and towards the nozzle 54 to reduce lift. In its open position the valve needle 61 has lift from the seat 69 thereby allowing flow of liquid fuel from the pump chamber 82 to the fuel chamber 58, past the valve seat 69 and via an outlet port 68 to the main bore 55 in the nozzle 54. The low flashpoint liquid leaves the main bore 55 via the nozzle holes 56.

**[0066]** The valve needle 61 gets lift when the pressure of the liquid fuel in the pump chamber 82 exceeds the force of the helical spring 38. Thus, the valve needle 61 is configured to open against the bias of the spring 38 when the pressure of the fuel in the pump chamber 82 (and in the fuel chamber 55) in exceeds a predetermined threshold. The pressure in the fuel is caused by the pump piston 80 acting on the low flashpoint liquid fuel in the pump chamber 82.

**[0067]** The valve needle 61 is configured to be biased to move towards the nozzle 54 with the conical section moving towards the valve seat 69. This happens when the pressure in the liquid fuel decreases when the pump piston 80 no longer acts on the fuel in the pump chamber 82 and the closing force of the helical spring 38 on the valve needle 61 becomes larger than the opening force of the low flashpoint liquid fuel on the valve needle 61.

**[0068]** When the electronic control unit ends an injection event it commands the electronic control valve 96 to connect the actuation chamber 85 to tank. The pump chamber 82 is connected to the pressurized source of liquid fuel 60 and the supply pressure of the low flashpoint liquid fuel that flows in via the non-return valve 74 will urge actuation piston 83 into the actuation chamber 85 until it has reached the position that is shown in Fig. 7 with the pump chamber 82 completely filled with liquid fuel so that the fuel valve 50 is ready for the next injection event. Fig. 8 shows the position of the pump piston 82 and the actuation position 83 near the end of an injection

event with a major part of the pump chamber 80 depleted from liquid fuel.

**[0069]** An injection event of the liquid fuel is controlled by the electronic control unit ECU through the length of the activation timing and the length of the stroke of the pump piston 82 (rate shaping). The amount of low fuel injected in one injection event is determined by the length of the stroke of the pump piston 80. Thus, upon a signal from the electronic control unit the actuation liquid pressure is raised in the actuation chamber 85.

**[0070]** At the end of the injection event the electronic control valve 96 removes the pressure from the actuation chamber 85 and the force of the pressurized liquid fuel in the pump chamber 82 causes the actuation piston 83 to be pushed back in the second bore 85 until it hits the end of the second bore 85 and the pump chamber 82 is completely filled with liquid fuel and the fuel valve 50 is ready for the next injection event.

**[0071]** In an embodiment (not shown) the fuel valve 50 comprises pressure booster form of a plunger with two different diameters, with the large diameter part of the plunger facing a chamber with a port that is connected to the control valve 96 and the larger diameter part of the plunger facing a chamber with a port that is connected to the conduits (channel) 51 and 47 so as to boost the lubricating oil pressure during a fuel injection event thus ensuring that the lubricating pressure is high exactly at the time when it is most needed to provide high lubricating pressure.

**[0072]** The fuel valve 50 is provided with a lubrication oil inlet port 70 for connection to a source of pressurized lubrication oil and provided with a conduit 30 extending from the lubrication oil inlet port 70 to the first bore 81 for sealing and lubricating the pump piston 80 in the first bore 81. In an embodiment, the pressure of the source of lubrication oil 57 is at least almost as high as the maximum pressure in the pump chamber 82 during an injection event.

**[0073]** In an embodiment, the fuel valve 50 is provided with means to selectively allow flow from the pump chamber 82 towards the fuel inlet port 53 for purging the fuel valve 50. The means to selectively allow flow from the pump chamber 82 towards the fuel inlet port 53 comprise means to selectively deactivate the non-return function of the non-return valve 74 (suction valve).

**[0074]** The valve needle 69 is configured to move from the closed position to the open position against the bias of the helical spring 38 when the pressure in the fuel chamber 58 exceeds a predetermined threshold.

**[0075]** The elongated valve housing 52 is in an embodiment provided with a cooling liquid inlet port 45 and a cooling liquid outlet port 32 and a cooling liquid flow path 44 for cooling the fuel injection valve 50, in particular the portion of the fuel valve 50 closest to the front end, e.g. closest to the nozzle and the heat from the combustion chamber. The cooling liquid is in an embodiment system lubrication oil from the engine. In an embodiment the cooling liquid flow path includes the spring chamber

88 in which the helical spring 38 is received.

**[0076]** In an embodiment the elongated valve housing 52 comprises a front portion 33 that is connected to a rear portion 35. The axially displaceable valve needle 61 being disposed in the front portion 33, the first bore 81, the second bore 84 and the matching longitudinal bore being formed in the rear portion 35.

**[0077]** The fuel valve 50 is in an embodiment provided a conduit 47 extending from the sealing and lubrication liquid inlet port 70 to the longitudinal needle bore 64 at a position P1 along the length of the longitudinal needle bore 64 for sealing the valve needle 61 in the longitudinal needle bore 64. The sealing oil flows from position P1 through the clearance both upwards to the chamber surrounding the helical spring and downwards towards the fuel chamber 58. The portion of the ignition liquid that flows to the actuation chamber 74 mixes with the cooling oil. This has no substantial effect on the cooling oil.

**[0078]** In the present first embodiment the portion of the ignition liquid that flows to the fuel chamber 58 meets the pressure of ignition liquid that is supplied to the clearance by an ignition liquid conduit 66 that extends from the ignition liquid inlet port 67 through the valve housing 52 to the clearance at a position P2 that is closer to the fuel chamber 58 than position P1. The ignition liquid inlet port 67 is connected to the source of pressurized ignition liquid 65. Since the pressure of the sealing oil is higher than that of the ignition liquid the sealing oil will prevent ignition liquid from leaking back into the sealing oil system.

**[0079]** The ignition fluid that is delivered to the clearance via the ignition liquid conduit 66 migrates along the axial extend of the clearance to the fuel chamber 58 and accumulates at the bottom of the fuel chamber 58 i. e. just above the seat 69 while the axially movable valve needle 61 rests on the seat 69, as shown in Fig. 7a.

**[0080]** The dimensions of the clearance are precisely controlled and selected so that the appropriate amount of ignition liquid is collected at the bottom of the fuel chamber 58 in the time during an engine cycle where the axially movable valve member 61 rests on the seat 69. An appropriate amount of ignition liquid is the amount that is sufficient for creating a reliable and stable ignition, may for example be in the range of 0,1 mg to 200 mg, depending e.g. on the engine size and load. The dimensions of the clearance are chosen such in relation to the properties of the ignition liquid, such as e.g. viscosity, that a constant flow of ignition liquid of an appropriate magnitude is achieved when the source of ignition liquid has a pressure that is a margin above the pressure of the source of the liquid fuel.

**[0081]** Upon a signal from the electronic control unit the liquid fuel pressure is raised the fuel chamber 58 and the valve needle 61 is lifted from the seat 69 in a movement from its closed position to its open position. The ignition liquid accumulated at the bottom of the fuel chamber 58 (Fig. 7a) enters the main bore 55 in the nozzle 54 first, followed by the liquid fuel, i.e. the liquid fuel pushes

the ignition liquid ahead and into the main bore 55. Thus, the ignition liquid that was accumulated in the combustion chamber 58 will enter the main bore 55 in the nozzle 54 just ahead of the liquid fuel. At the moment just before the opening of the fuel valve 50, the main bore 55 is filled with a mixture of compressed hot air and residual unburned fuel, due to the compression of the scavenging air in the combustion chamber (the nozzle holes 56 allow flow of air from the combustion chamber into the main bore 55). Thus, shortly after the opening of the fuel valve 50 there is hot compressed air, ignition liquid and liquid fuel present inside the main bore 55. This leads to ignition of the liquid fuel already inside the hollow nozzle 54.

**[0082]** At the end of the injection event the electronic control unit removes the pressure from the actuation chamber 85 and the force of the helical spring 38 causes the valve needle 61 to return to the seat 69.

**[0083]** According to a second example embodiment that is essentially identical to the first example embodiment described above, the delivery of the ignition liquid is not to the clearance but instead to the seat 69. This embodiment is illustrated with reference to Fig. 7b. The ignition liquid conduit 66 opens to the seat 69. The opening angle of the conical tip of the valve needle 61 is slightly sharper than the opening angle of the conical seat 69 and thus there is a narrow gap between the tip of the valve needle and the valve seat 69. This narrow gap allows ignition liquid 49 to accumulate in the fuel chamber 58 at and just above the valve seat 69 whilst the valve needle 61 rests on its seat 69.

**[0084]** According to a third example embodiment that is essentially identical to the embodiments described above, the delivery of the ignition liquid is to the fuel chamber 58. This embodiment is illustrated with reference to Fig. 7c. The ignition liquid conduit 66 opens to the fuel chamber 58, preferably just above or adjacent seat 69. Ignition liquid 49 accumulates in the fuel chamber 58 above the valve seat 69 whilst the valve needle 61 rests on its seat 69.

**[0085]** According to a fourth example embodiment that is essentially identical to the embodiments described above, the delivery of the ignition liquid is to the seat 69. This embodiment is illustrated with reference to Fig. 7d. The ignition liquid conduit 66 opens to the seat 69. The opening angle of the conical tip of the valve needle 61 is substantially identical to the opening angle of the conical seat 69 and thus valve needle 61 closes off the opening of the ignition liquid conduit 66 to the valve seat when the valve needle 61 rests on the valve seat 69. Ignition liquid is delivered to the valve seat 69 through the ignition liquid conduit 66 opening to the valve seat 69 when the valve needle has lift. In this embodiment the delivery of the appropriate amount of ignition liquid has to take place in a short period of time and therefore the supply pressure of the ignition liquid and or the cross-sectional area of the ignition liquid supply conduit 66 are increased relative to the embodiments described above.

**[0086]** The injection of the liquid fuel is controlled with

the displaceable valve needle 61 that cooperates with the seat 69 above the hollow nozzle 54. The fuel chamber 58 is pressurized with liquid fuel. A small continuous flow of ignition liquid is in accordance with the first-, second- and third embodiment delivered to the fuel chamber 58 and the ignition liquid 49 accumulates above the seat 69 during periods where the valve needle 61 rests on the seat 69 (embodiments according to Figs. 7a, 7b and 7c). A fuel injection event is started by lifting the axially movable valve needle 61 from the seat 69, thereby causing the accumulated ignition liquid 49 to enter the main bore 55 in the hollow injection nozzle 54 just ahead of the liquid fuel. The liquid fuel then ignites inside the nozzle 54 with the help of the ignition liquid.

**[0087]** For the embodiment of Fig. 7d, the ignition liquid is delivered to the valve seat 69 when the valve needle 61 has lift and thus liquid fuel and ignition liquid is delivered to the main bore in the injection nozzle 45 simultaneously.

**[0088]** The engine is configured to compression-ignite the injected liquid fuel with the help of the ignition liquid and without the use of other ignition equipment.

**[0089]** The engine is configured to ignite the liquid fuel upon entry of the main bore inside the nozzle 54.

**[0090]** In an embodiment the nozzle 54 is kept above 300°C throughout the engine cycle. In an embodiment the temperature inside the hollow nozzle 54 is approximately 600 degrees C at the end of the compression stroke.

**[0091]** In an embodiment the fuel valve 50 is provided with a dedicated control valve in a fluidic connection between the pump chamber 82 and the fuel inlet port 53 for selectively allowing flow from the pump chamber 82 to the fuel inlet port 53 for purging of the fuel valve 50. This control valve is preferably opened and closed in response to a control signal. In this embodiment is not necessary to provide means to selectively deactivate the non-return function of the non-return valve 74.

**[0092]** In an embodiment the source of lubrication oil has a controlled pressure  $P_s$  and a source of liquid fuel has a controlled pressure  $P_f$ , with  $P_s$  being higher than  $P_f$ . In this embodiment the controlled pressure  $P_s$  can be lower than the maximum pressure in the pump chamber 82 during a pump stroke. In this case  $P_s$ , the size of the clearance and the maximum pressure in the pump chamber 82 during a pump stroke are interdependently selected such that if low flashpoint liquid fuel enters the clearance and replaces the lubrication liquid along a portion but not all of the length of the pump piston 80 and wherein the sealing liquid replaces substantially all low flashpoint fuel in the clearance before another pump stroke takes place, any remaining of low flashpoint fuel so that there will not be ingress of low flashpoint fuel the lubrication oil system itself.

**[0093]** The term "comprising" as used in the claims does not exclude other elements or steps. The term "a" or "an" as used in the claims does not exclude a plurality. The electronic control unit may fulfill the functions of sev-

eral means recited in the claims.

**[0094]** The reference signs used in the claims shall not be construed as limiting the scope.

**[0095]** Although the present invention has been described in detail for purpose of illustration, it is understood that such detail is solely for that purpose, and variations can be made therein by those skilled in the art without departing from the scope of the invention.

## Claims

1. A fuel valve (50) for injecting liquid fuel into the combustion chamber of a large slow running two-stroke turbocharged compression-igniting internal combustion engine, said fuel valve (50) comprising:

an elongated valve housing (52) with a rear end and a front end,

a nozzle (54) comprising an elongated nozzle body extending from a base (46) to a closed tip (59), a main bore (55) extending from said base (46) to said closed tip (59) and a plurality of nozzle holes (56) connected to said main bore (55), said nozzle (54) being disposed at said front end of said elongated valve housing (52) with said base (46) connected to said front end,

a fuel inlet port (53) in said elongated fuel valve housing (52) for connection to a source (60) of pressurized liquid fuel,

an axially displaceable valve needle (61) slidably received in a longitudinal needle bore (64) in said elongated valve housing (52) with a clearance between said valve needle (61) and said needle bore (64), said valve needle (61) having a closed position and an open position, said valve needle (61) rests on a valve seat (69) in said closed position and said valve needle (61) has lift from said valve seat (69) in said open position and said valve needle (61) being biased towards said closed position,

said seat (69) being disposed in said elongated valve housing (52) between a fuel chamber (58) in said valve housing (52) and an outlet port (68) in said front end of said elongated valve housing (52),

said outlet port (68) connecting directly to said main bore (55) in said nozzle (54),

said fuel chamber (58) being connected to said fuel inlet port (53),

said clearance opening at one end of said needle bore (64) to said fuel chamber (58),

a lubricating oil inlet port (70) for connection to a source of pressurized lubricating oil (57),

a lubricating oil supply conduit (47) connecting said lubricating oil inlet port (70) to said clearance at a first position (P1) along the length of the needle bore (64),

## characterized by

an ignition liquid inlet port (67) for connection to a source of pressurized ignition liquid (65), and an ignition liquid conduit (66) extending from said ignition liquid inlet port (67) to said chamber (58) or to said clearance at a second position (P2) along the length of said needle bore (64) that is closer to said fuel chamber (58) than said first position (P1).

2. A fuel valve according to claim 1, wherein said ignition liquid conduit (66) extends from said ignition liquid inlet port (67) to the fuel chamber (58) at a position adjacent the seat (69).

3. A fuel valve according to claim 1, wherein said ignition liquid conduit (66) extends from said ignition liquid inlet port (67) to said seat (69).

4. A fuel valve according to claim 3, wherein an opening of said ignition liquid conduit (66) to said seat (69) is closed by the valve needle (61) when the valve needle (61) rests on said seat (69).

5. A fuel valve according to any one of claims 1 to 4, wherein said main bore (55) opens to said base (46).

6. A fuel valve according to any one of claims 1 to 5, wherein said source of ignition liquid (65) has a pressure that is higher than the pressure of said source of liquid fuel (60).

7. A fuel valve according to any one of the preceding claims, further comprising an actuation liquid port (78) in said elongated fuel valve housing (52) for connection to a source (60) of pressurized actuation fluid, a pump piston (80) received in a first bore (81) in said valve housing (52) with a pump chamber (82) in said first bore (81) on one side of said pump piston (80),

an actuation piston (83) received in a second bore (84) in said valve housing (52) with an actuation chamber (85) in said second bore (84) on one side of said actuation piston (83),

said pump piston (80) being connected to said actuation piston (83) to move in unison therewith, said actuation chamber (85) being fluidically connected to said actuation liquid port (78), and said pump chamber (82) having an outlet connected to said fuel chamber (58) and an inlet connected to said fuel inlet port (53) via a non-return valve (74) in said elongated fuel valve housing (52) that prevents flow from said pump chamber (82) to said fuel inlet port (53).

8. A fuel valve according to any one of the preceding claims, wherein said fuel chamber (58) surrounds

said valve needle (61) and opening to said valve seat (69) with said valve seat (69) being arranged between said fuel chamber (58) and said outlet port (68)

9. A fuel valve (50) according to any one of the preceding claims, wherein said valve needle (69) is configured to move from said closed position to said open position against said bias when the pressure in said fuel chamber (58) exceeds a predetermined threshold. 5
10. A fuel valve (50) according to any one of the preceding claims, further comprising a cooling liquid inlet port and a cooling liquid outlet port and a cooling liquid flow path (44) for cooling the fuel injection valve (50), in particular the portion of the fuel valve (50) closest to said front end. 10
11. A fuel valve (50) according to any one of the preceding claims, wherein said elongated valve housing (52) comprises a front portion (33) that is connected to a rear portion (35), said axially displaceable valve needle (61) being disposed in said front portion (33), said first bore (81), said second bore (84) and said matching longitudinal bore being formed in said rear portion (35). 20
12. A fuel valve (50) according to any one of claims 7 to 11, further comprising a conduit (30) connecting said sealing liquid inlet port (70) to said first bore (81) for sealing said pump piston (80) in said first bore. 25
13. A large slow running two-stroke turbocharged compression-igniting internal combustion engine (1) comprising a fuel valve (50) according to any of the preceding claims. 30
14. An engine according to claim 13, further comprising a source of pressurized fuel (60) with a controlled pressure  $P_f$ , a source of pressurized lubricating oil (57) with a controlled pressure  $P_s$  and a source of pressurized ignition liquid (65) with a controlled pressure  $P_{if}$ . 35
15. An engine according to claim 14, wherein  $P_s$  is higher than  $P_f$  and wherein  $P_{if}$  is higher than  $P_f$ . 40
16. An engine according to any one of claims 13 to 15 configured to ignite said fuel upon entry of the fuel in the main bore (55) inside the nozzle (54). 45
17. A method of operating a large two-stroke low-speed turbocharged compression-ignited internal combustion engine, said method comprising: 50
- supplying pressurized liquid fuel at a first high pressure to a fuel valve (50) of said engine, said fuel valve having an elongated valve hous-

ing (52) with a rear end and a front end, said fuel valve (50) having a hollow nozzle (54) with a plurality of nozzle holes (56) connecting the interior (55) of said nozzle (54) to a combustion chamber in a cylinder (1) of said engine, said nozzle (54) comprising a base (46) and an elongated nozzle body, said nozzle (54) being connected with its base (46) to said front end of said elongated valve housing (52), said nozzle (54) having a closed tip (59) with said nozzle holes (56) arranged close to said tip (59), supplying ignition liquid at a second high pressure to said fuel valve (50), said second high pressure being higher than said first high pressure, controlling the injection of the liquid fuel with a displaceable valve needle (61) that cooperates with a seat (69) above said hollow nozzle (54), a fuel chamber (58) being arranged above said seat (69), pressuring said fuel chamber (58) with said liquid fuel, delivering a continuous flow of ignition liquid to said fuel chamber (58) and allowing said ignition liquid to accumulate above the seat (69) during periods where the axially displaceable valve needle (61) rests on the seat (69) and starting a liquid fuel injection event by lifting said axially displaceable valve needle (61) from said seat (69), thereby causing said accumulated ignition liquid to enter the hollow injection nozzle (54) just ahead of the liquid fuel, or delivering a precisely dosed amount of ignition liquid to said seat (69) when the axially displaceable valve needle (61) has lift, and starting a liquid fuel injection event by lifting said axially displaceable valve needle (61) from said seat (69), thereby causing said accumulated ignition liquid to enter the hollow injection nozzle (54) simultaneously with the liquid fuel.

18. A method according to claim 17, wherein said liquid fuel ignites inside said nozzle (54) with the help of said ignition liquid.

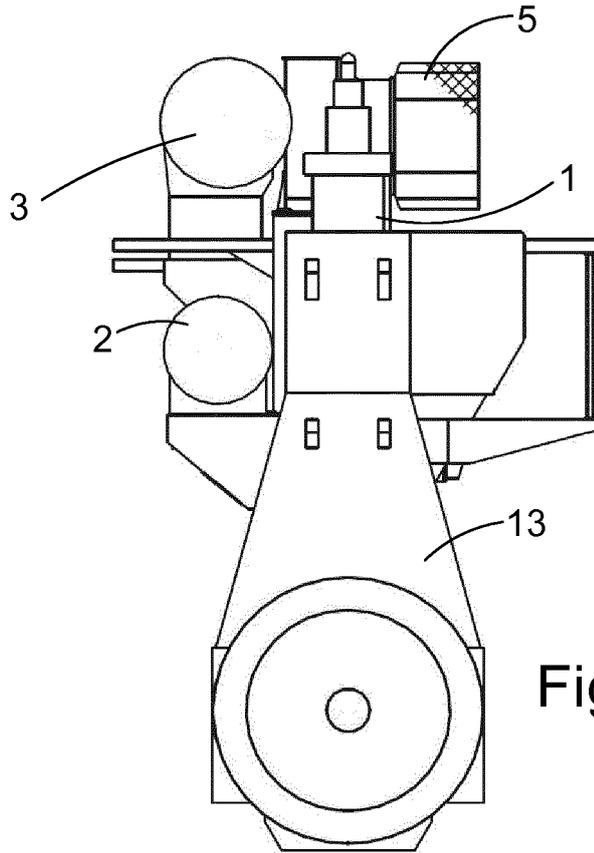


Fig. 1

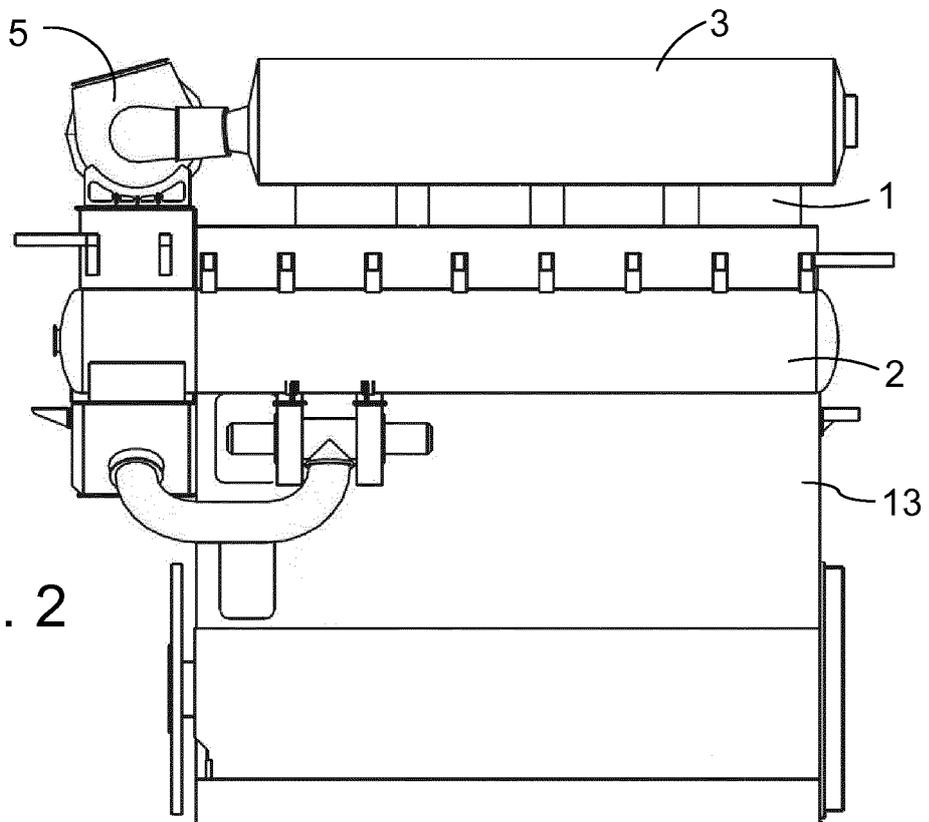


Fig. 2

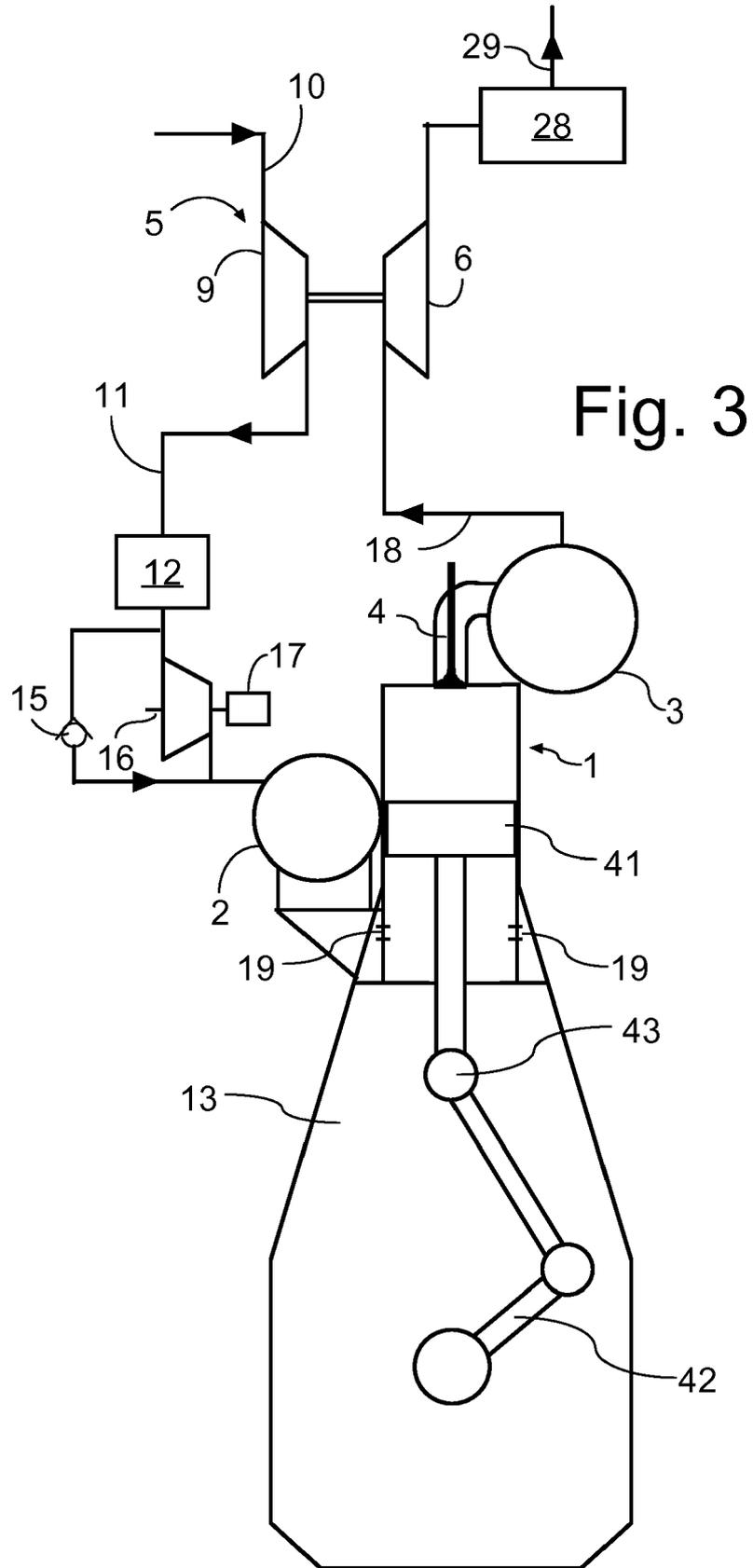
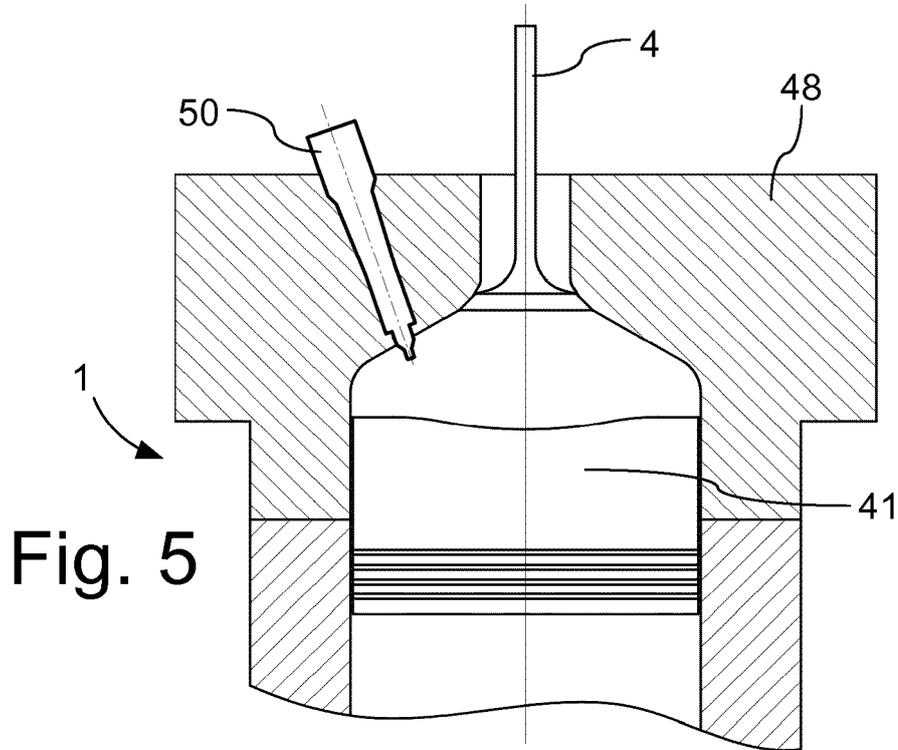
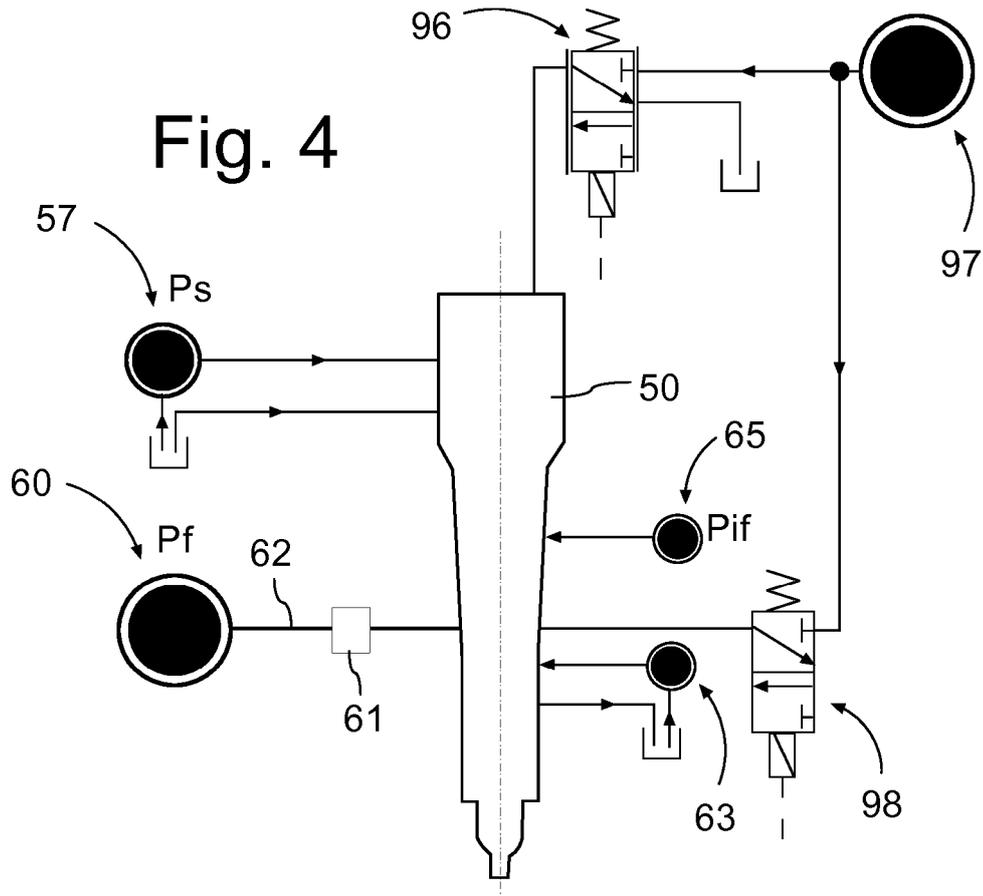


Fig. 3



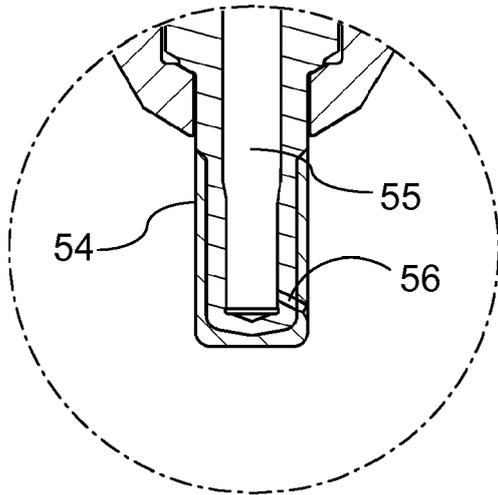


Fig. 9A

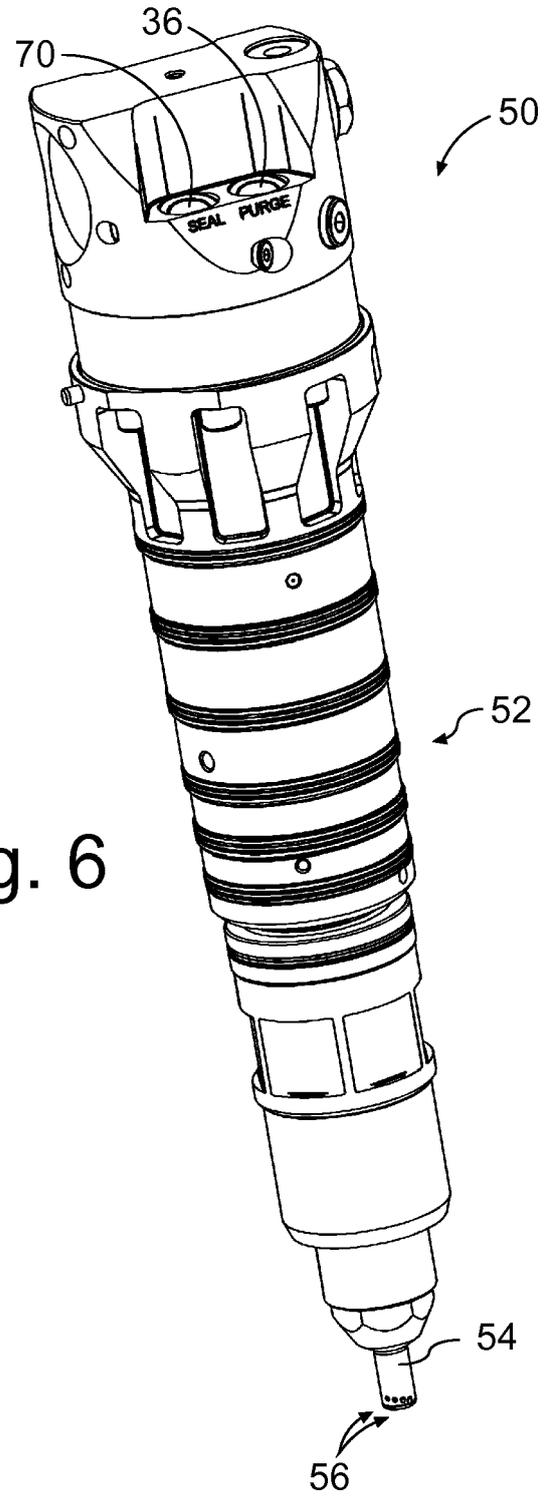


Fig. 6



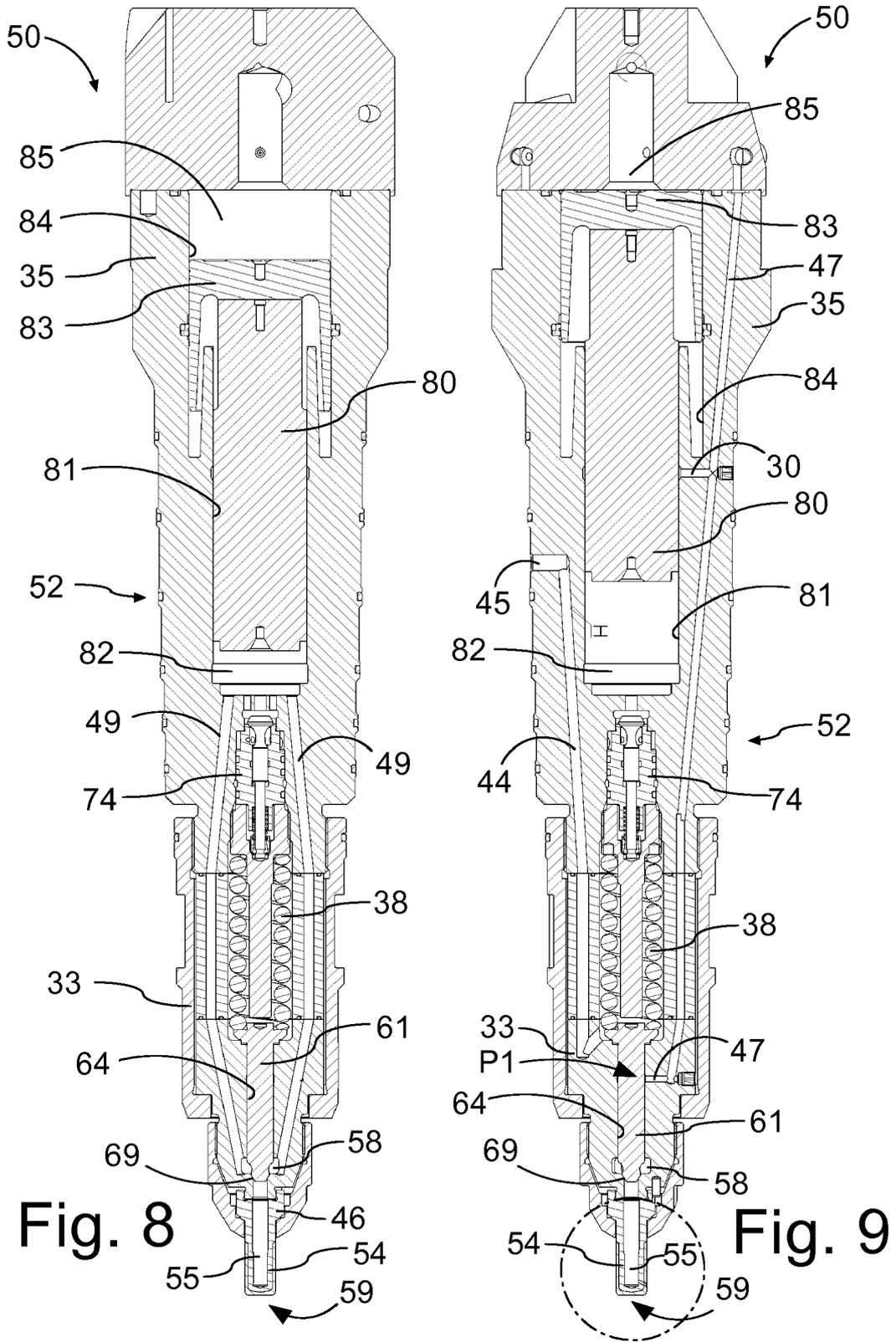


Fig. 8

Fig. 9

Fig. 10

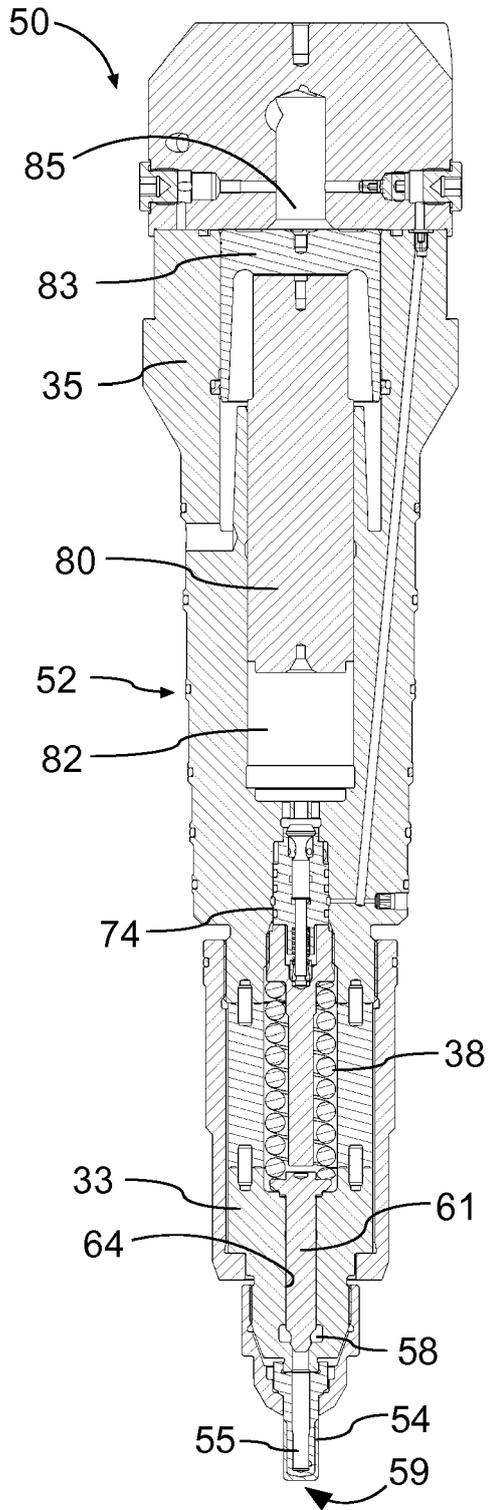
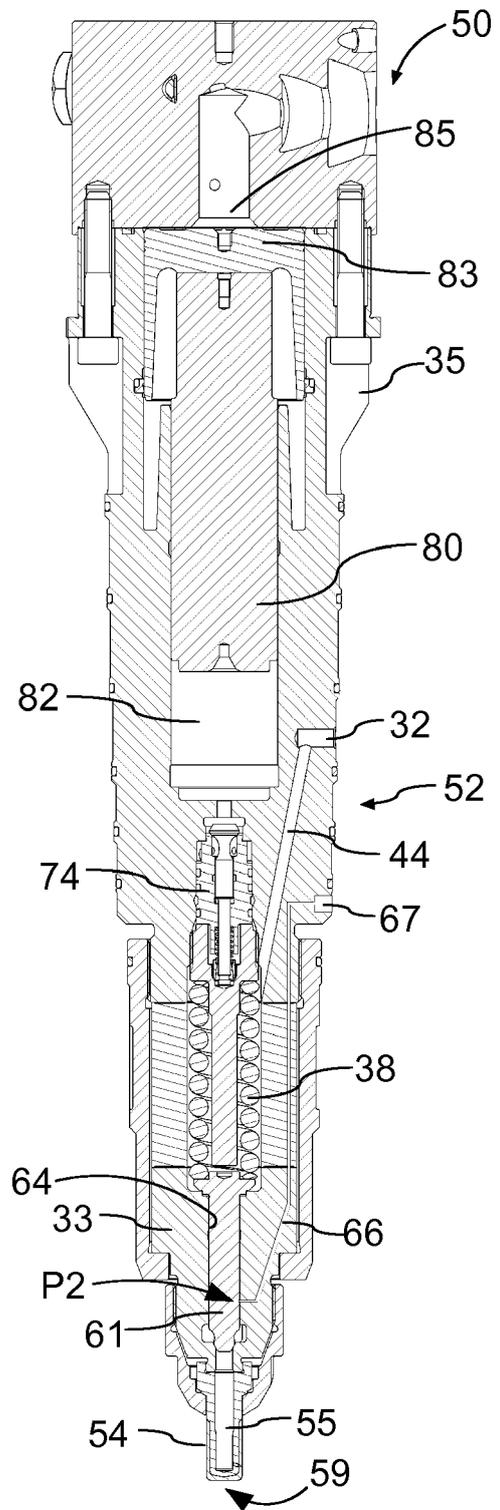


Fig. 11





EUROPEAN SEARCH REPORT

Application Number  
EP 17 20 3729

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A	* paragraph [0031] - paragraph [0070]; figures 4,7,8,9 *	1-16	
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A	* paragraph [0057] - paragraph [0067]; figures 4,6-8 * * abstract *	1-16	TECHNICAL FIELDS SEARCHED (IPC)  F02M F02B
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Place of search <b>The Hague</b>		Date of completion of the search <b>7 March 2018</b>	Examiner <b>Hermens, Sjoerd</b>
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document	

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ON EUROPEAN PATENT APPLICATION NO.

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
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