(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 682 372 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
21.01.2026 Bulletin 2026/04

(21) Application number: **25169526.8**

(22) Date of filing: **09.04.2025**

(51) International Patent Classification (IPC):
F02M 21/02 $^{(2006.01)}$ ***F02M 43/04*** $^{(2006.01)}$
F02M 47/02 $^{(2006.01)}$ ***F02M 61/12*** $^{(2006.01)}$
F02M 47/04 $^{(2006.01)}$

(52) Cooperative Patent Classification (CPC):
F02M 43/04; F02M 21/0218; F02M 47/027; F02M 47/043; F02M 61/12

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH LA MA MD TN

(30) Priority: **17.07.2024 IT 202400016594**

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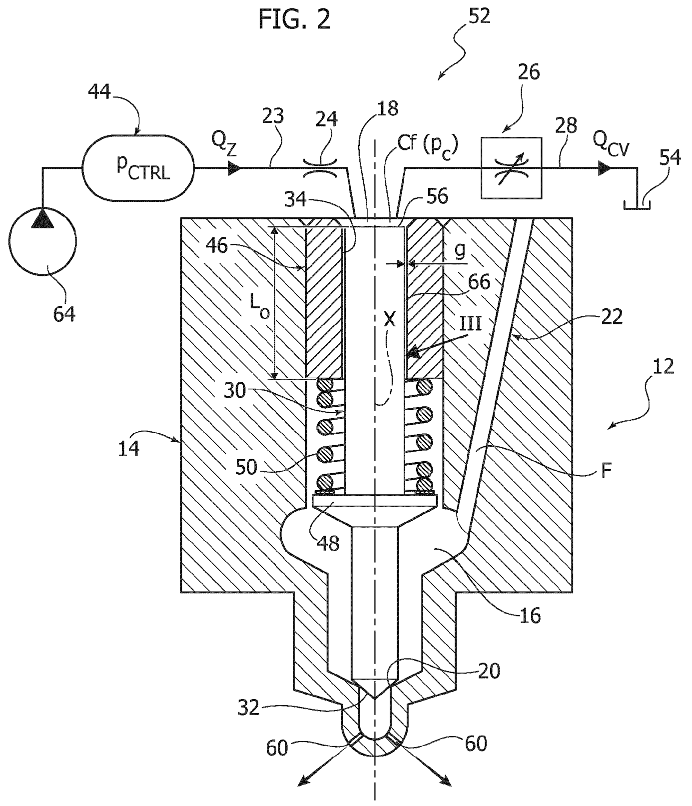
(54) **ELECTRICALLY CONTROLLED INJECTION SYSTEM FOR ALTERNATIVE FUELS**

(57) Injection system (10), comprising an injector (12) including an injector needle (30) and a needle guide surface (34) that guides a movement of the injector needle (30) along a longitudinal axis (X) between a closed position and an open position and vice versa, wherein the needle guide surface (34) has a length ($\boldsymbol{L_0}$) equal to or greater than a minimum length ($\boldsymbol{L_{0,min}}$) calculated so as to prevent fuel leakage through the needle guide surface (34).

FIG. 2



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Description

TEXT OF THE DESCRIPTION

Field of the Invention

[0001] The present invention relates to an injection system including an electrically controlled injector. More specifically, the invention concerns an electrically controlled injection system for alternative fuels.

[0002] The invention has been developed in particular for large engines used, for example, as marine engines or in power plants.

Description of the Related Art

[0003] A traditional common-rail injection system includes a pump that pressurizes the fuel in a high-pressure accumulator (common rail) that supplies the injectors. The injectors are provided with a valve seat and an injection needle movable between a closed position and an open position.

[0004] The pressurized fluid is fed into an injection chamber and a control chamber. The pressure of the fluid in the injection chamber acts in the direction of opening the injection needle. The pressure of the fluid in the control chamber generates a hydraulic force that acts in the direction of closing the injection needle.

[0005] An electrically controlled control valve modulates the hydraulic pressure in the control chamber. The opening of the control valve causes a reduction in the pressure within the control chamber to the point where the force acting to open the injection needle is greater than the force acting to close it. Under this condition, the injection needle lifts from the valve seat, thereby causing the injection of fuel. To terminate the injection, the electrical control of the control valve is deactivated, which causes the valve to close and the pressure in the control chamber to rise until the force acting in the closing direction is greater than the force acting in the opening direction, causing the injection needle to move toward the closed position.

[0006] The fuels traditionally used for large internal combustion engines are fossil fuels derived from petroleum distillation, typically LFO (Light Fuel Oil) and MFO (Marine Fuel Oil).

[0007] Fossil fuels for marine engines lead to levels of atmospheric pollution that are not compatible with the most recent anti-pollution regulations.

[0008] For this reason, alternative fuels derived from renewable sources are gaining increasing attention in the maritime sector, as the need to reduce emissions of carbon oxides from fossil sources and to promote sustainability becomes ever more urgent.

[0009] The most commonly used alternative fuels in the maritime sector, as substitutes for fossil fuels, are typically methanol, ammonia, and hydrogen.

[0010] The adoption of alternative fuels for marine engines is an important step toward the reduction of greenhouse gas emissions.

[0011] However, it is essential to consider the risks associated with these new fuels. Methanol is toxic if inhaled or absorbed through the skin; it is highly volatile and extremely flammable. Ammonia is highly toxic to humans. Exposure can cause irritation to the eyes, skin, and respiratory system. At high concentrations, it can be lethal. Furthermore, ammonia is flammable and can form an explosive mixture with air. Hydrogen is not toxic but can be hazardous in the event of leaks, as it is highly volatile and flammable, and requires special attention during handling and storage.

[0012] Therefore, it is essential to adopt strict safety measures for the handling, storage, and use of these alternative fuels.

Object and Summary of the Invention

[0013] The object of the present invention is to provide a system for injecting alternative fuels that improves safety against the leakage of toxic or flammable substances.

[0014] According to the present invention, this object is achieved by an injection system having the features set out in claim 1.

[0015] Preferred embodiments are the subject of the dependent claims.

Brief Description of the Drawings

[0016] The present invention will now be described in detail with reference to the accompanying drawings, provided purely by way of non-limiting example, in which:

- Figure 1 is a schematic view of an injection system according to the present invention,

- Figure 2 is a schematic axial section of an embodiment of an injector for an injection system according to the present invention,
- Figure 3 is a diagrammatic detail of the part indicated by arrow III in Figure 2, showing a film of low-viscosity fuel penetrating into a gap filled with highly viscous oil, and
- Figures 4 and 5 are schematic axial sections of alternative embodiments of an injector for an injection system according to the present invention.

Detailed Description

[0017] With reference to Figures 1, 2, 4 and 5, 10 indicates an injection system for large combustion engines, for example for marine engines or for power plant engines.

[0018] The injection system 10 comprises an injector 12 including a body 14 and an injector needle 30 movable in the body 14 along a longitudinal axis X. The body 14 has an injection chamber 16 provided with a valve seat 20 and injection holes 60. The body 14 has a control chamber 18 for controlling the movement of the injector needle 30 along the longitudinal axis X. The injector needle 30 has a closing surface 32 that cooperates with the valve seat 20.

[0019] In the body 14, a needle guide surface 34 is provided, which guides the movement of the injector needle 30 along the longitudinal axis X between a closed position and an open position, and vice versa. An annular gap 66 is defined between the needle guide surface 34 and the injector needle 30. The annular gap 66 may have a thickness g between 1 and 50 μm. The annular gap 66 has one end that communicates with the injection chamber 16.

[0020] The injection system 10 comprises a fuel supply line 22 that supplies pressurized fuel F to the injection chamber 16. The fuel F is an alternative fuel from renewable sources, which may be, for example, methanol, ammonia, hydrogen.

[0021] The fuel supply line 22 receives the fuel F from a fuel accumulator 40 that is pressurized by a fuel pump 62. A flow limiting valve 42 is arranged on the fuel supply line 22 between the fuel accumulator 40 and the injection chamber 16.

[0022] The injection system 10 comprises a control circuit 52 including an inlet line 23 provided with a calibrated inlet orifice 24. The inlet line 23 supplies a control fluid Cf to the control chamber 18 through the calibrated inlet orifice 24. The inlet line 23 receives the control fluid Cf from a control fluid accumulator 44 that is pressurized by a control fluid pump 64.

[0023] The control fluid Cf is different from the fuel F and has a viscosity that is at least twice the viscosity of the fuel F. The control fluid Cf may be an oil, for example lubricating oil: SAE 40, SAE 30 or equivalent; fuel oil: LFO, MFO or similar.

[0024] The pressure of the control fluid Cf in the control fluid accumulator 44, indicated as pCTRL, is greater than the pressure of the fuel F in the fuel accumulator 40, indicated as pF.

[0025] The control circuit 52 comprises a discharge line 28 that connects the control chamber 18 to a discharge volume 54. On the discharge line 28 an electrically controlled control valve 26 is arranged to selectively open and close the hydraulic communication between the control chamber 18 and the discharge line 28.

[0026] With reference to Figure 2, in one embodiment the injector 12 may comprise a bushing 46 housed inside the body 14 and having a through hole defining the needle guide surface 34. In the example shown in Figure 2, the injector needle 30 has a head surface 56 facing into the control chamber 18. The annular gap 66 communicates directly with the control chamber 18 so that during operation the annular gap 66 is filled with control fluid Cf. The pressure of the control fluid Cf in the control chamber 18 generates a closing force directly on the injector needle 30. The injector needle 30 may have a radial shoulder 48 located in the injection chamber 16 and at least one compression spring 50 may be arranged between one end of the bushing 46 and the radial shoulder 48.

[0027] With reference to Figure 4, in a possible variant at least one compression spring 50 is arranged inside the control chamber 18, between a shoulder of the body 14 and a radial shoulder 56 of the injector needle 30. Also in this embodiment, the annular gap 66 communicates directly with the control chamber 18 so that during operation the annular gap 66 is filled with control fluid Cf. Also in this embodiment, the injector needle 30 has a head surface 56 facing into the control chamber 18 such that the pressure of the control fluid Cf in the control chamber 18 generates a closing force directly on the injector needle 30.

[0028] With reference to Figure 5, in a possible variant the injector 12 may comprise a control piston 70 coaxial with the injector needle 30 and movable along the longitudinal axis X. The control piston 70 has a first end 72 facing into the control chamber 18 and a second end 74 pressed against the head surface 56 of the injector needle 30. In this case, the pressure of the control fluid Cf in the control chamber 18 generates a closing force on the control piston 70, and the control piston 70 transfers said closing force to the injector needle 30. In this embodiment, the injector 12 comprises a lubrication line 76 that puts the control chamber 18 in fluid communication with the annular gap 66 so that during operation the annular gap 66 is filled with control fluid Cf. At least one compression spring 50 is arranged to press the control piston 70 against the head surface 56 of the injector needle 30.

[0029] In the possible different variants described, the position of the injector needle 30 along the axis X is determined by the balance of two hydraulic forces, which are generated by the action of the pressurized fuel F and the control fluid Cf on respective influence surfaces.

[0030] The pressurized fuel F contained in the injection chamber 16 upstream of the valve seat 20 acts in the direction of lifting the injector needle 30 from the valve seat 20.

[0031] The electrically actuated control valve 26 modulates the pressure of the control fluid Cf in the control chamber 18, which generates a force acting in the direction of closing the injector needle 30. The opening of the control valve 26 causes a reduction in the pressure in the control chamber 18 to the point where the force acting to lift the injector needle 30 prevails over the force acting to keep it closed, causing the injector needle 30 to lift from the valve seat 20 and thereby injecting the fuel F through the injection holes 60.

[0032] As long as the control valve 26 remains open, the control fluid Cf contained in the control chamber 18 remains at an intermediate pressure between the pressure in the inlet line 23 and the pressure in the discharge line 28.

[0033] The section of the calibrated inlet orifice 24 is such as to ensure that the pressure in the control chamber 26 is sufficiently low to keep the injector needle in its maximum lift position.

[0034] When the control valve 26 closes, the control chamber 18 remains in communication with the inlet line 23 only. The oil flow that at this stage continues to enter through the calibrated inlet orifice 24 causes the movement of the injector needle 30 towards the closed position.

[0035] The flow limiting valve 42 serves to limit the maximum quantity of injected fuel, which in effect limits the maximum injection time ($t_{inj,max}$). This prevents, in the event of a malfunction that prevents the complete closing of the injector needle 30, the depressurization of the entire system.

[0036] The injection system 10 according to the present invention is intended to inject an alternative fuel F that may be toxic or flammable.

[0037] Therefore, it is necessary to ensure that there is no risk of the fuel F leaking from the injection chamber 16 through the annular gap 66 formed between the needle guide surface 34 and the injector needle 30.

[0038] According to the present invention, the needle guide surface 34 has a length L_0 in the direction of the longitudinal axis X such as to prevent the pressurized fuel F contained in the injection chamber 16 from leaking through the annular gap 66 to contaminate the control oil Cf contained in the surrounding chambers.

[0039] With reference to Figure 2, due to the fact that the control fluid Cf in the inlet line 23 is at a pressure p_{CTRL} greater than the fuel pressure pF, when the injector needle 30 is closed and at rest, between one injection and the next, there is a continuous leakage of control fluid Cf from the control chamber 18 towards the injection chamber 16, which causes the annular gap 66 to be completely filled with control fluid Cf.

[0040] During the opening phase of the injector needle 30, the pressure pc of the control fluid Cf in the control chamber 18 drops to values lower than the pressure pF of the fuel F. Therefore, the direction of flow in the annular gap 66 is reversed. The fuel F therefore tends to push the control fluid Cf contained in the annular gap 66 towards the control chamber 18.

[0041] However, if the needle guide surface 34 has a length L0 sufficiently long ($L_0>L_{0,min}$), the fuel F does not reach the end of the guide in communication with the control chamber 18 within the maximum injection time ($t_{inj,max}$). At the end of the injection, when the pressure of the control fluid Cf in the control chamber 18 again becomes greater than the pressure pF of the fuel F, the flow in the annular gap 66 returns to its usual direction, expelling the fuel F that entered the annular gap 66 back towards the injection chamber 16, restoring the complete filling of the annular gap 66 with control fluid Cf.

[0042] The criterion for determining the minimum length $L_{0,min}$ of the needle guide surface 34 will be explained in detail below.

[0043] With reference to Figure 3, the maximum velocity $\boldsymbol{w_f}$ of the fuel F in the annular gap 66 can be calculated by solving the Navier-Stokes equations for the liquid contained in the annular gap 66, arriving at formula E1,

$$\textbf{E1} \qquad w_f = \frac{g^2}{8\,\mu_{oil}} \frac{\Delta p}{L}$$

Where:

- $\boldsymbol{L}$ is the length of the portion of the annular gap 66 still completely filled with control fluid Cf,
- $\boldsymbol{\Delta p}$ is the pressure difference at the ends of the considered portion L,
- $\boldsymbol{g}$ is the thickness of the annular gap 66, and
- $\boldsymbol{\mu_{oil}}$ is the viscosity of the control fluid Cf contained in the annular gap 66.

[0044] Since the viscosity of the fuel F is several orders of magnitude lower than that of the control fluid Cf, the pressure drop in the fuel can be neglected, and therefore the pressure drop $\boldsymbol{\Delta p}$ can be simplified as:

$$\textbf{E2} \qquad \Delta p \leq p_F - p_c$$

[0045] Moreover, in order for the injector needle 30 to open, the flow rate $\boldsymbol{Q_{CV}}$ discharged by the control valve 26 must necessarily be greater than the flow rate $\boldsymbol{Q_Z}$ entering through the calibrated inlet orifice (24).

E3 $$Q_{CV} \geq Q_Z$$

[0046] If, for simplicity, ρ denotes the density of the control fluid Cf at the inlet of the injector 12, and $\boldsymbol{A_{CV}}$ and $\boldsymbol{A_Z}$ represent the equivalent flow areas of the electrically controlled valve 26 and the calibrated inlet orifice 24, respectively, the fluid flow rates can be determined by the following expressions:

E4 $$Q_{CV} = A_{CV}\sqrt{2\,\frac{p_c}{\rho}}$$

E5 $$Q_Z = A_Z\sqrt{2\,\frac{p_{CTRL}-p_c}{\rho}}$$

[0047] And therefore, the pressure $\boldsymbol{p_c}$ of the control fluid Cf in the control chamber 18 can be derived as a function of the pressure $\boldsymbol{p_{CTRL}}$ in the inlet line 23:

E6 $$p_c \geq \frac{A_Z^2}{A_{CV}^2+A_Z^2}\,p_{CTRL}$$

[0048] By substituting equations E2 and E6 into E1, and integrating over the maximum injection time $t_{inj,max}$ allowed by the flow limiting valve 42, equation E7 is obtained. This equation expresses the minimum guide length $L_{0,min}$ which-under the worst-case scenario-still ensures that the fuel which has entered the guide 66 is then completely expelled toward the chamber 16 at the end of the injection phase, when the pressure in the control volume rises back to its original value.

$$p_c = p_{CTRL} > p_F \ .$$

E7 $$L_0 > L_{0,min} = \frac{g}{4}\sqrt{\left(p_F - \frac{A_Z^2}{A_{CV}^2+A_Z^2}\,p_{CTRL}\right)\frac{t_{inj,max}}{\mu_{oil}}}$$

Where:

- $\boldsymbol{L_{0,min}}$ is the minimum length in mm of the needle guide surface 34 along the longitudinal axis X,
- ***g*** is the diametral clearance in mm of the injector needle 30 within the needle guide surface 34,
- *p_F* is the pressure in Pa of the fuel F supplied to the injection chamber 16,
- $\boldsymbol{A_Z}$ is the area in mm^2 of the equivalent flow section of the calibrated inlet orifice 24,
- $\boldsymbol{A_{CV}}$ is the area in mm^2 of the equivalent flow section of the electrically controlled valve 26,
- $\boldsymbol{p_{CTRL}}$ is the pressure in Pa of the control fluid Cf,
- $t_{inj,max}$ is the maximum injection duration in seconds,
- μ_{oil} is the viscosity in Pa·s of the control fluid Cf.

[0049] The following table provides an example of the calculation of the minimum length of the needle guide surface 34 for a hypothetical methanol injector in a large marine engine.

Diametral clearance in the needle guide	*g* (mm)	0.010
Fuel F pressure	p_F (Pa)	600 10^5
Control fluid Cf pressure	p_{CTRL} (Pa)	700 10^5
Flow section of orifice 24	A_Z (mm^2)	0.5
Flow section of control valve 26	A_{CV} (mm^2)	0.5
Maximum injection duration	$t_{inj.max}$ (s)	0.015
Viscosity of control fluid Cf	μ_{oil} (Pa s)	0.020
Minimum guide length	$L_{0,min}$ (mm)	10.8

[0050] The present invention may be applied to all cases in which it is desired to inject a fuel (liquid or gaseous) having a viscosity much lower than the viscosity of the control fluid used to control the opening of the injector.
In particular, the invention is especially advantageous in common-rail injection systems for four-stroke engines powered by methanol, ammonia, or gas.

[0051] Naturally, without departing from the principle of the invention, the constructional details and the embodiments may be widely varied with respect to what has been described and illustrated, without thereby departing from the scope of the invention as defined in the following claims.

Claims

1. An injection system (10), comprising:

- an injector (12) including: a body (14) having an injection chamber (16) provided with a valve seat (20) and a control chamber (18), an injector needle (30) having a closing surface (32) which cooperates with said valve seat (20), and a needle guide surface (34) which guides a movement of the injector needle (30) along a longitudinal axis (X) between a closed position and an open position and vice versa, wherein between the injector needle (30) and the needle guide surface (34) an annular gap (66) is formed having one end communicating with the injection chamber (16),
- a fuel supply line (22) feeding pressurized fuel to said injection chamber (16),
- a control circuit (52) including: an inlet line (23), provided with a calibrated inlet orifice (24), which feeds a control fluid to said control chamber (18), a discharge line (28) connecting the control chamber (18) to a discharge volume (54), and an electrically operated control valve (26) to selectively open and close a hydraulic communication between the control chamber (18) and the discharge line (28), wherein the hydraulic pressure in the control chamber (18) generates a force that acts in the direction of closing the injector needle (30),

wherein the needle guide surface (34) has a length **(L_0)** equal to or greater than a minimum length (**$L_{0,min}$**) calculated with the following formula:

$$L_{0,min} = \frac{g}{\mathbf{4}}\sqrt{\left(p_F - \frac{\boldsymbol{A_Z^2}}{\boldsymbol{A_{CV}^2} + \boldsymbol{A_Z^2}}\ \boldsymbol{p_{CTRL}}\right)\frac{t_{inj,max}}{\mu_{oil}}}$$

where:

$L_{0,min}$ is the minimum length in mm of the needle guide surface (34) along the longitudinal axis (X),
g is the diametric clearance in mm of the injector needle (30) in the needle guide surface (34),
p_F is the pressure in Pa of the fuel (F) fed to the injection chamber (16),
A_Z is the area in mm^2 of the equivalent passage section of the calibrated inlet orifice (24),
A_{CV} is the area in mm^2 of the equivalent passage section of the electrically operated control valve (26),
p_{CTRL} is the pressure in Pa of the control fluid (Cf),
$t_{inj,max}$ is the maximum time in s of the fuel injection duration,
μ_{oil} is the viscosity in Pa·s of the control fluid (Cf).

2. The injection system of claim 1, wherein the fuel supply line (22) receives pressurized fuel (F) from a fuel accumulator (40).

3. The injection system of claim 2, comprising a flow limiting valve (42) disposed on said fuel supply line (40) between said fuel accumulator (40) and said injection chamber (16).

4. The injection system of any of the preceding claims, wherein the inlet line (23) of the control circuit (52) receives pressurized control fluid from a control fluid accumulator (44).

5. The injection system of any of the preceding claims, wherein the injected fuel (F) is gaseous or liquid with a viscosity less than half that of the control fluid (Cf).

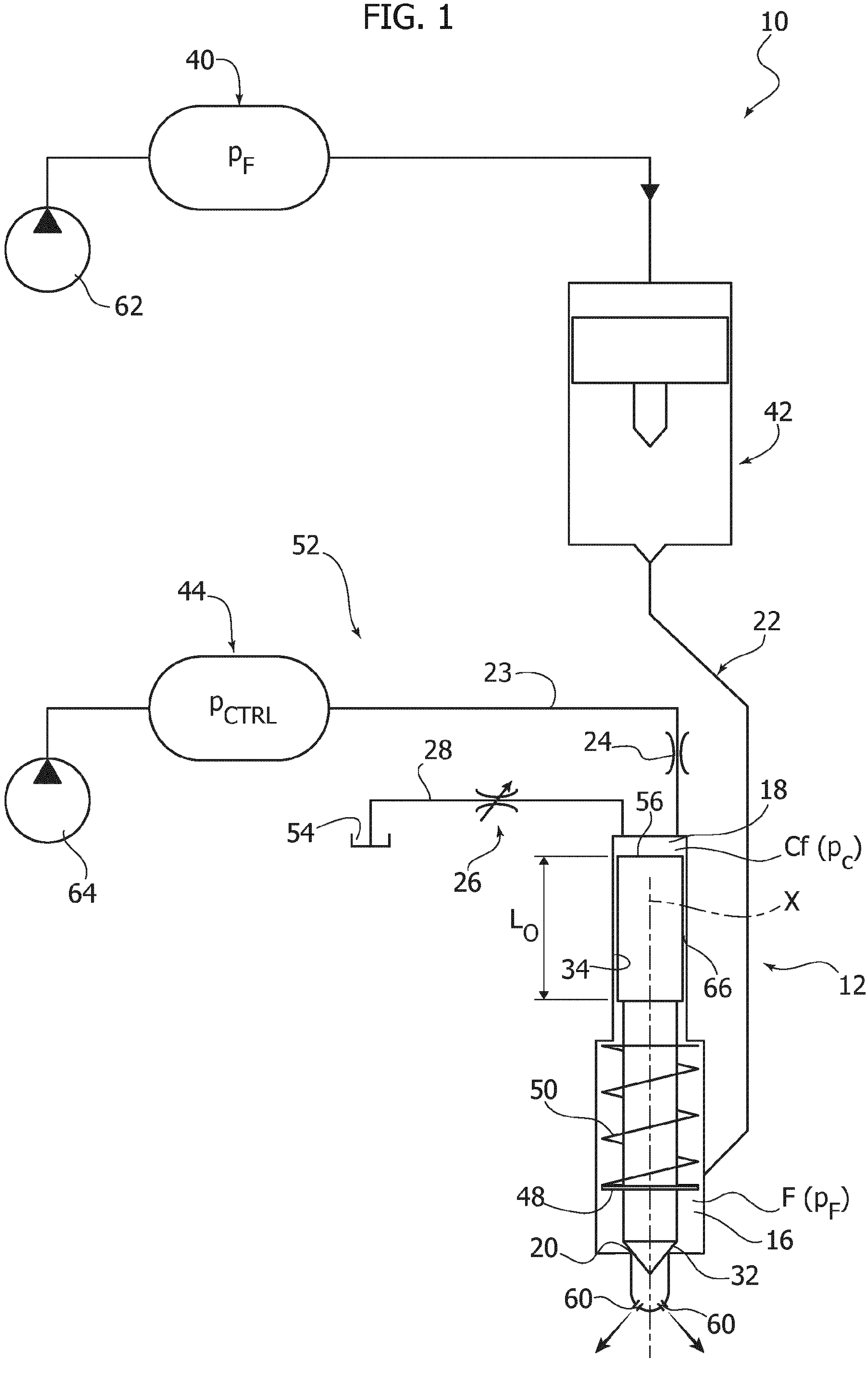
6. The injection system of any of the preceding claims, wherein the control fluid is an oil.

7. The injection system of any of the preceding claims, wherein the injector (12) includes a bushing (46) housed inside the body (14) and having a through hole defining said needle guide surface (34).

8. The injection system of claim 7, wherein the injector needle (30) has a radial shoulder (48) located in the injection chamber (16) and wherein a compression spring (50) is disposed between one end of said bushing and said radial shoulder (48).

9. The injection system of any of the preceding claims, wherein the pressure of the control fluid is greater than the pressure of the fuel.

FIG. 1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Cf (p_c)
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L_O
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F (p_F)
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FIG. 2

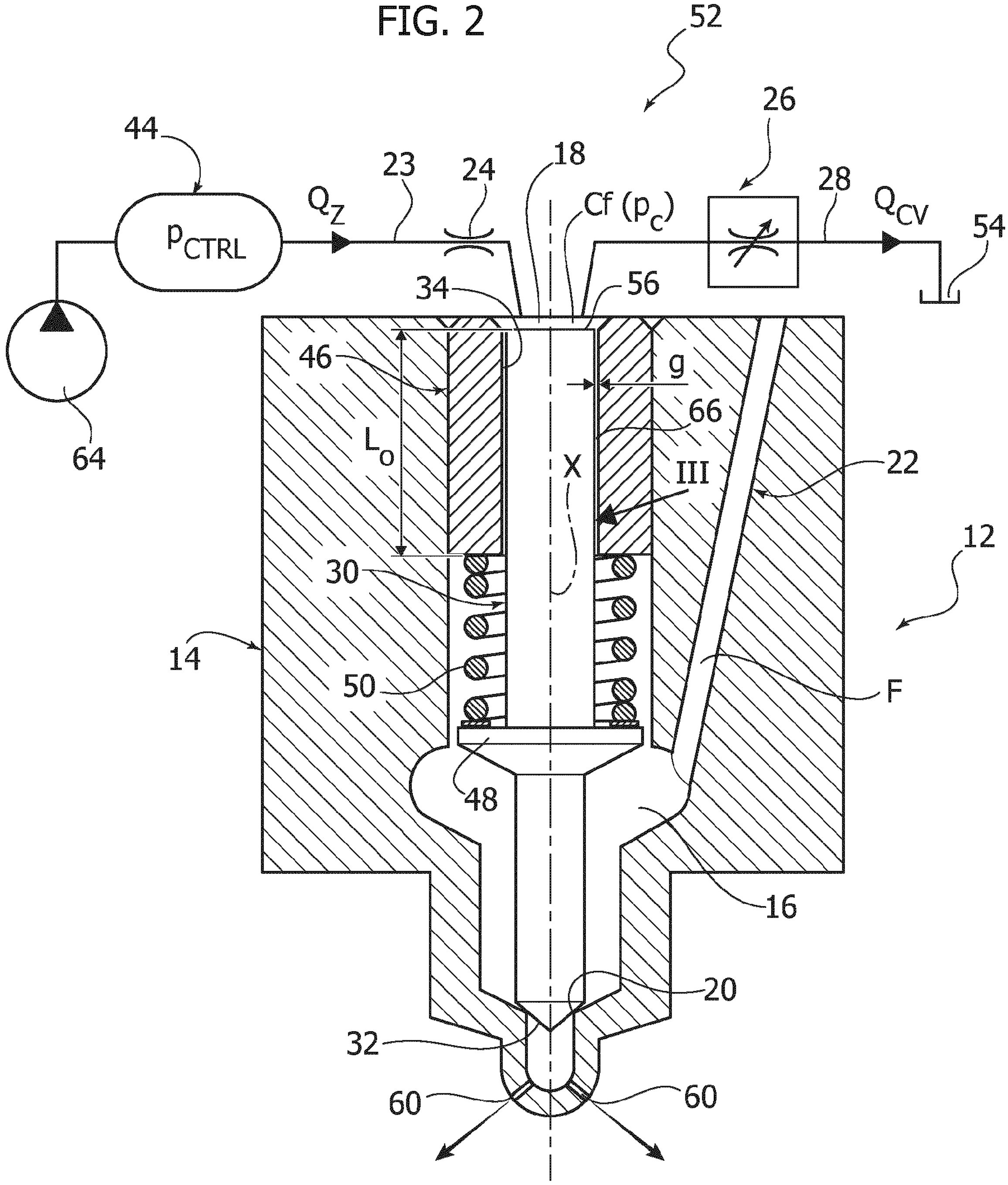
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FIG. 3

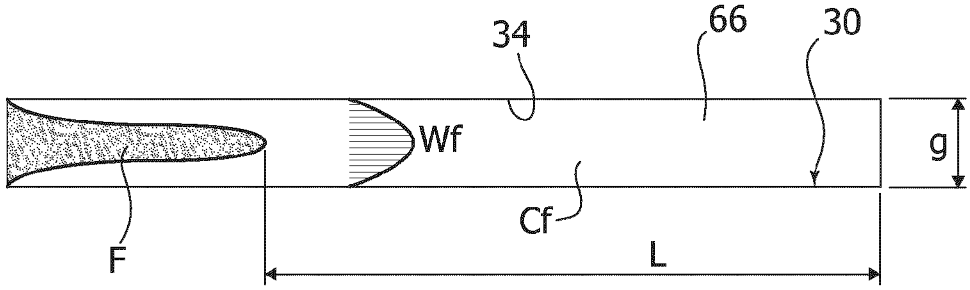
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FIG. 4

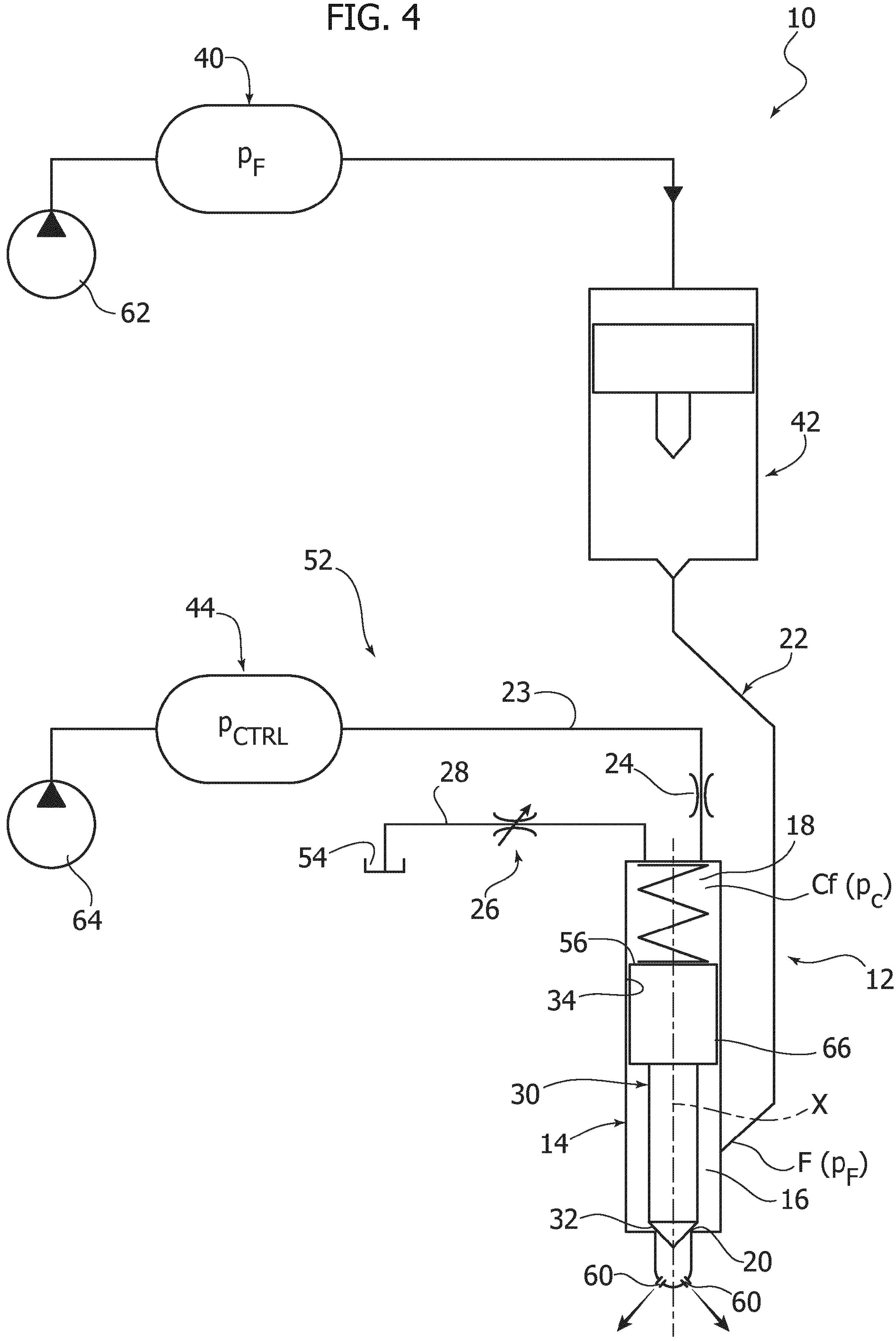
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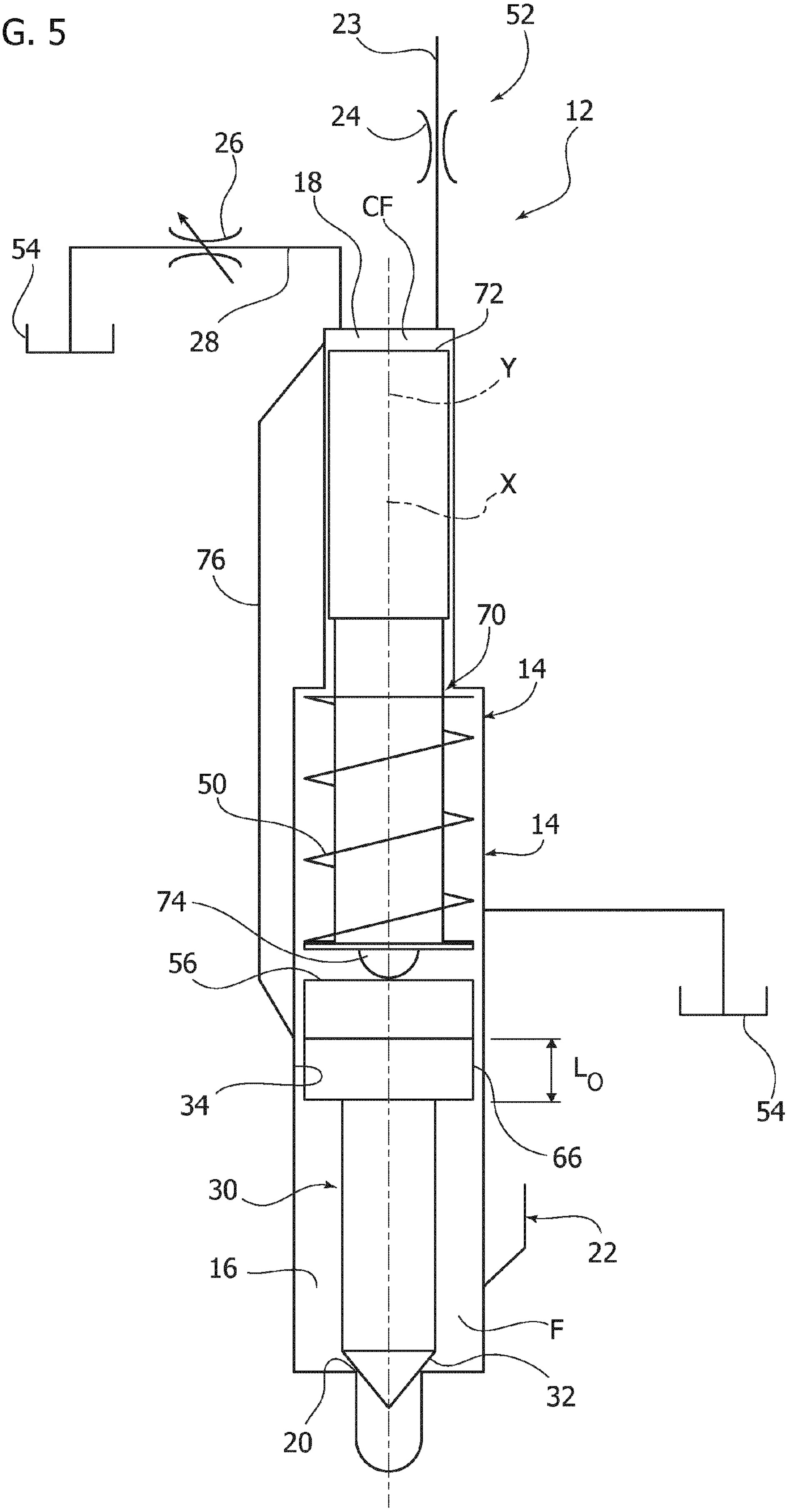
FIG. 5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EUROPEAN SEARCH REPORT

Application Number
EP 25 16 9526

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 3 433 482 B1 (WAERTSILAE FINLAND OY [FI]) 4 May 2022 (2022-05-04) * paragraph [0050]; figures 1-3 * -----	1-9	INV. F02M21/02 F02M43/04 F02M47/02 F02M61/12 F02M47/04
X	US 10 612 503 B2 (LORANGE GMBH [DE]; WOODWARD LORANGE GMBH [DE]) 7 April 2020 (2020-04-07) * figure 1 * -----	1-6,9	

TECHNICAL FIELDS SEARCHED (IPC)

F02M

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	9 September 2025	Morales Gonzalez, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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09-09-2025

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