

SUBSURFACE SAFETY VALVE

FIELD OF THE INVENTION

5 The present invention relates to a safety valve and more particularly to a subsurface safety valve.

BACKGROUND OF THE INVENTION

10 Subsurface safety valve is a common fixture in most well bores used in the hydrocarbon industry. A subsurface safety valve is typically located within the well bore, beneath ground surfaces, and operated during production of hydrocarbon products. In the event of any failure or damages to the well bore, the subsurface safety valve will be closed to isolate the well bore from the ground surface, to prevent underground hydrocarbon
15 products from being passing through the well bore to the ground surface. Conventional safety valves are actuated by hydraulic pressure, and with a mechanism to close the valve typically driven by a spring in the valve.

Reliability of springs has been an issue faced by downhole equipment producers,
20 as these equipment are inaccessible for repair without high cost operations like shutting off the well and pulling completions. The springs typically fail due to radial expansion, twisting, or bending under a compressive load, resulting in the spring getting stuck within the valve thus not able to return to its original state to shut off the valve. This causes the spring to lose its function of providing the spring force and is potentially dangerous in
25 safety valves where springs are compressed for long periods of time. Thus, the problem might not be discovered in time and the safety valve will no longer provide isolation of well bore in the event of an accident or emergency situation.

It is therefore desirable to provide a subsurface safety valve which can be reliably
30 actuated to effect isolation of well bore in case of need.

SUMMARY OF THE INVENTION

According to one aspect, embodiments of the present invention provide a subsurface safety valve which includes a housing and a flow tube disposed in the housing.

5 The flow tube is movable relative to the housing between a first position and a second position. A flapper is movably coupled to the flow tube, and an actuator end is coupled to the flow tube to provide a first force. A first magnetic member is coupled to housing, and a second magnetic member is coupled to the flow tube. After the actuator end is activated, the first force acts on the flow tube to move the flow tube to the first position. Following

10 the movement of the flow tube to the first position, the flapper is moved to an open position to allow a fluid to enter the flow tube from the first opening. When the actuator end is deactivated, a second force generated by the first and second magnetic elements moves the flow tube to the second position. Following the movement of the flow tube to the second position, the flapper is moved to a close position to cover the flow tube, hence

15 to prevent the fluid from entering the flow tube.

Other aspects and advantages of the present invention will become apparent from the following detailed description, illustrating by way of example the inventive concept and technical solution of the present invention.

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DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention are disclosed hereinafter with reference to the drawings, in which:

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FIG. 1 is a schematic showing a hydrocarbon production setting.

FIG. 2 is a side view of a subsurface safety valve according to one embodiment of the present invention.

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FIG. 3 is an exploded perspective view of Fig. 2.

FIG. 4 is a sectional view (A-A) of Fig 2, showing the subsurface safety valve in an open position.

5 FIG. 5A is an enlarged partial view of Fig. 4 showing a mid housing of the subsurface safety valve.

FIG. 5B is an enlarged partial view of Fig. 4 showing a flow tube of the subsurface safety valve.

10 FIG. 5C is an enlarged partial view of Fig. 4 showing the mid housing and the flow tube of the subsurface safety valve.

FIG. 5D is an enlarged partial view of Fig. 4 illustrating operation of the subsurface safety valve.

15 FIG. 6 is a sectional view (A-A) of Fig 2 showing the subsurface safety valve in a close position.

FIG. 7 is an enlarged partial view of Fig. 6.

20 FIG. 8 is a cross sectional partial view of a subsurface safety valve in an open position according to another embodiment of the present invention.

FIG. 9 is a sectional view (B-B) of FIG. 8.

25 FIG. 10 is an isometric view of section B-B of FIG. 8.

FIG. 11 is a cross sectional partial view of Fig. 8 when the subsurface safety valve in a close position.

30 FIG. 12A is a cross sectional partial view of a subsurface safety valve in an open position according to yet another embodiment of the present invention.

FIG. 12B is a cross sectional partial view of Fig. 12A when the subsurface safety valve in a close position.

- 5 FIG. 13A is a cross sectional partial view of a subsurface safety valve in an open position according to a further embodiment of the present invention.

FIG. 13B is an enlarged partial view of Fig. 13A.

- 10 FIG. 14A is a cross sectional partial view of a subsurface safety valve shown in Fig. 13A when the subsurface safety valve in a close position.

Fig. 14B is an enlarged partial view of Fig. 14A

15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, in a hydrocarbon production setting 1, a subsurface safety valve 10 is typically deployed above a production zone 7 within a formation 9, and is connected to the surface rig 3 via production line 5. Under normal operation, subsurface safety valve 10 is opened to allow underground hydrocarbon substance or product 8 e.g. crude oil and/or gas to enter and pass through, and to flow from the production zone 7 up to the rig 3 where it is captured, stored and transported. Subsurface safety valve 10 is maintained opened by hydraulic pressure via a hydraulic line from the surface rig 3. In times of emergency, where the hydraulic lines no longer supply hydraulic pressure either due to failure or deliberate shut down of surface hydraulic pump, subsurface safety valve 10 will automatically shut close, ceasing the flow of hydrocarbon up the production line 5.

Referring to Figs. 2 to 7, according to one embodiment of the present invention, a subsurface safety valve 10 comprises a tubular upper housing 101 with threaded ends, a port 153 located near an end of the upper housing 101 and adjoined to a first hydraulic chamber 195 which is a bore running through the upper housing 101. A dynamically sealed piston 151 is moveably disposed in first hydraulic chamber 195 and is affixed to an

actuator end 13A of a flow tube 13. Upper housing 101 is connected to a mid housing 103 which is in turn connected to a lower housing 105, via a threaded connection.

Mid housing 103 includes an interior second chamber 191 therein disposes a
5 tubular opening sleeve 11 with flanges on the top end which enables the opening sleeve 11 to be affixed to the upper housing 101, and flow tube 13 disposed within second chamber 191. Second chamber 191 maybe filled with well fluid during normal operation of hydrocarbon production. Flow tube 13 has an inner diameter slightly larger than the outer diameter of opening sleeve 11, hence allowing flow tube 13 to be slidable relative to the
10 opening sleeve 11 and mid housing 103. Flow tube 13 is thus able to move along a downward axial direction 130A and upward axial direction 130B relative to mid housing 103, between a first position at which a first opening 1301 of flow tube 13 extends out of mid housing 103, as shown in Figs. 5C, 5D, and a second position at which first opening 1301 is positioned inside mid housing 103, as shown in Figs. 6 and 7.

15 Flow Tube 13 has a flange 13F on the top end from which actuator end 13A extends. A first force F11 generated by the hydraulic pressure acts on flow tube 13 through piston 151 and actuator end 13A. Actuator end 13A is activated upon supply of the hydraulic pressure to act first force F11 to move flow tube 13.

20 Lower housing 105 has an interior flapper chamber 193 formed therein. A flapper seat 107 is disposed in flapper chamber 193. Flapper seat 107 is secured to the lower housing 105 via fasteners e.g. a bolt. A flapper 17 is rotatably connected to flapper seat 107, and is spring-loaded by a torsion spring 171 which bias flapper 17 from an open
25 position as shown in Fig. 5C, toward a close position as shown in Fig. 6.

As shown in Figs. 5A to 5D, a first magnetic element 173 is coupled to mid housing 103, and a second magnetic element 183 is coupled to flow tube 13. In the present embodiment, first magnetic element 173 is coupled to mid housing 103 by way of
30 being formed integral with and located at a first annular region of mid housing 103, and second magnetic element 183 is coupled to flow tube 13 by way of being formed integral with and located at a second annular region of flow tube 13. Another words, mid housing

103 is partially or fully magnetized, forming first magnetic element 173 therein. Flow tube 13 is also partially or fully magnetized, forming second magnetic element 183 therein. The mode of magnetization of first and second magnetic elements 173, 183 may be achieved by implanting permanent magnetic material or component in mid housing 103 and flow tube 13, or electrically magnetizing certain portions of mid housing 103 and flow tube 13, respectively.

The first and second magnetic elements are positioned with magnetic poles oriented along opposite directions. The positional relationship of first and second magnetic elements 173, 183 is such that, when flow tube 13 is at the first position relative to mid housing 103, as shown and with reference to the orientation in Figs. 5C and 5D, first magnetic element 173 is positioned with magnetic south pole 173S at the top side of mid housing 103, and second magnetic element 183 is positioned with magnetic south pole 183S at the bottom side of mid housing 103. Magnetic north pole 183N of second magnetic element 183 is positioned between magnetic south pole 173S and magnetic north pole 173N of first magnetic element 173. There is therefore a second force i.e. a magnetic force F12 generated between first magnetic element 173 and second magnetic element 183, by the attraction between magnetic north pole 183N and magnetic south pole 173S, and by the repellant force between magnetic north pole 183N and magnetic north pole 173N. First and second magnetic elements may be centrally aligned relative to each other about the axial direction 130A-130B.

The inner surface of the flow tube 13 and/or external surface of mid housing 103 may be covered or coated with a layer of mu-metal 1832, 1732, respectively, to provide a magnetic shield for mid housing 103 and flow tube 13, to improve the magnetic performance of first and second magnetic elements 173, 183 and the effectiveness of second force F12.

When hydraulic pressure is supplied from the ground surface, first force F11 acts on actuator end 13A via piston 151. Actuator end 13A is then actuated to act first force F11 on flow tube 13. First force F11 overcomes second force F12, to move flow tube 13 to the first position, as shown in Fig. 5D. When flow tube 13 is at the first position, the

first opening 1301 of flow tube 13 is extended out of mid housing 103 which causes the flapper 17 to move, to an open position to allow underground hydrocarbon product 8 e.g. crude oil to enter flow tube 13 via first opening 1301, and pass through subsurface safety valve 10.

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During normal operation, hydraulic pressure is continuously supplied from the surface through the hydraulic line into the port 153, hence actuator end 13A remains continuously activated to act first force F11 on flow tube 13, to maintain first opening 1301 at outside of mid housing 103 where flapper 17 is at the open position.

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In case of emergency, the hydraulic pressure may be shut down or reduced either voluntarily or otherwise, resulting in a loss of hydraulic pressure in the first chamber 195 hence first force F11 is removed. Actuator end 13A is therefore deactivated, and the second force F12 prevails which moves flow tube 13 to the second position, as shown in Figs. 6 and 7. Following the movement of flow tube 13 to the second position, flapper 17 is rotated, by the spring force of torsion spring 171, to a close position to cover the first opening 1301 of flow tube 13. As such, underground hydrocarbon product is prevented from entering flow tube 13.

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When flow tube 13 is at the second position, as shown in Fig. 7, magnetic north pole 183N of second magnetic element 183 is aligned with magnetic south pole 173S of first magnetic element 173 along a lateral direction 129 and meanwhile, magnetic south pole 183S of second magnetic element 183 is aligned with magnetic north pole 173N of first magnetic element 173 along lateral direction 129. First and second magnetic elements 173, 183 are therefore at an equilibrium position relative to each other, to maintain flow tube 13 at the second position.

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After the emergency situation is cleared and/or it is desirable to resume normal production, hydraulic pressure is supplied again to generate first force F11 and activates actuator end 13A which in turn, applies first force F11 on flow tube 13. First force F11 overcomes second force F12 to move flow tube 13 downward to extend first opening 1301 out of mid housing 103. Following downward movement of flow tube 13, flapper 17 is

opened again to allow hydrocarbon product to enter and pass through subsurface safety valve 10.

In an alternate embodiment as shown in Figs. 8 to 11, a subsurface safety valve 20 includes a mid housing 203 and a flow tube 23 moveably disposed in mid housing 203. An actuator end 23A on flow tube 23, after activated following the supply of hydraulic pressure, acts a first force F21 on flow tube 23. Mid housing 203 has a first magnetic element 273 coupled to one sidewall segment. First magnetic element 273 has a magnetic south pole 273S on top segment 203c and a magnetic north pole 273N on bottom segment 203d (FIG. 9 and 10). The remaining housing segment 203e of mid housing 203 is not magnetized.

Flow tube 23 is magnetized to form a second magnetic element 283 integral thereto and located at an annular region of the flow tube 23. Second magnetic element 283 has a magnetic north pole 283N on the top end 23a of flow tube 23, and a magnetic south pole 283S on the bottom end 23b of flow tube 23. Magnetic north pole 283N of second magnetic element 283 is positioned between magnetic north pole 273N and magnetic south pole 273S of first magnetic element 273. Positioned in the above-illustrated manner, first and second magnetic elements 273 and 283 generate a second force F22, i.e. a magnetic force there between, by the repellant effect between magnetic north poles 273N, 283N, and the attraction effect between magnetic north pole 273N and magnetic south pole 283S.

Under normal operation of underground hydrocarbon production, as shown in Fig. 8, a hydraulic pressure is supplied to generate first force F21 to activate actuator end 23A. Actuator end 23A in turn provides first force F21 acting on flow tube 23. First force F21 overcomes second force F22 to move flow tube 23 to a first position where a first opening 2301 is positioned outside of mid housing 203. Following the movement of flow tube 23 to the first position, flapper 27 is rotated to an open position to allow hydrocarbon product 8 to enter flow tube 23 through first opening 2301 and transmitted to ground surface through subsurface safety valve 20. Actuator end 23A may preferably be coupled to the flow tube 23 at the top side wall segment 203c.

In case of emergency or it is desired to stop transportation of hydrocarbon product up to the ground surface, the hydraulic pressure maybe shut down or reduced either voluntarily or otherwise, resulting in a loss of hydraulic pressure on actuator end 23A and
5 flow tube 23. Actuator end 23A is therefore deactivated to remove first force F21. Second force F22 prevails which moves flow tube 23 to the second position, as shown in Fig. 11. When flow tube 23 is moved to second position, first opening 2301 is retracted into mid housing 203. Flapper 27 is rotated, by the spring force of torsion spring 271, to a close position to cover the first opening 2301 of flow tube 23. As such, underground
10 hydrocarbon product is prevented from entering flow tube 23.

When flow tube 23 is at the close position, magnetic north pole 273N and magnetic south pole 273S of first magnetic element 273 are aligned with magnetic south pole 283S and magnetic north pole 283N of second magnetic element 283, respectively, along a
15 lateral direction 229 of mid housing 203, first opening 2301 is retained in mid housing 203 and flapper 27 is remain closed.

Operation of the subsurface safety valve 20 for resuming the normal production may be effected in a similar manner as that described in the previous embodiment.
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In yet another embodiment, referring to Figs. 12A and 12B, a subsurface safety valve 30 includes a mid housing 303 and a flow tube 33 moveably disposed in mid housing 303. An actuator end 33A is coupled to flow tube 33 to provide a first force F31 acting on flow tube 33. A first magnetic element 373 and a second magnetic element 383
25 are moveably disposed in an annular space between mid housing 303 and flow tube 33. First magnetic element 373 has a south magnetic pole 373S on the bottom end and a north magnetic pole 373N on the top end. Second magnetic element 383 has a south magnetic pole 383S on the top end and a north magnetic pole 383N on the bottom end. First magnetic element 373 is coupled to mid housing 303 by abutting against mid housing 303
30 along an upward axial direction 330B. Second magnetic element 383 is coupled to flow tube 33 by abutting against flow tube 33 along downward axial direction 330A. First and second magnetic elements 373, 383 are both sleeve-shaped and are placed with north

magnetic pole 373N of first magnetic element 373 facing north magnetic pole 383N of second magnetic element 383. As such, first and second magnetic elements 373, 383 generate a second force F32 which is a magnetic force to repel first and second magnetic element 373, 383 away from each other.

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Under normal operation of underground hydrocarbon production, as shown in Fig. 12A, a hydraulic pressure is supplied to activate actuator end 33A. Actuator end 33A in turn provides first force F31 acting on flow tube 33. First force F31 overcomes second force F32 to move flow tube 33 to a first position where a first end 3301 is positioned outside of mid housing 303, and moves the first and second magnetic elements 373, 383 to position closer to each other. Following the movement of flow tube 33 to the first position, flapper 37 is rotated to an open position to allow hydrocarbon product 8 to enter flow tube 33 through first opening 3301 and transmitted to ground surface through subsurface safety valve 30.

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In case of emergency or it is desired to stop transportation of hydrocarbon product up to the ground surface, the hydraulic pressure may be shut down either voluntarily or otherwise, resulting in a loss of hydraulic pressure on actuator end 33A and subsequently on flow tube 33. Actuator end 33A is therefore deactivated to remove first force F31.

20 Second force F32 prevails which moves the first and second magnetic elements 373, 383 to position away from each other, and moves flow tube 33 to the second position, as shown in Fig. 12B. When flow tube 33 is moved to the second position, first opening 3301 is retracted into mid housing 303. Flapper 37 is rotated, by the spring force of torsion spring 371, to a close position to cover the first opening 3301 of flow tube 33. As such, underground hydrocarbon product is prevented from entering flow tube 33.

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Operation of the subsurface safety valve 30 for resuming the normal production may be effected in a similar manner as that described in the previous embodiment.

30 In a further embodiment, as show in Figs. 13A, 13B, 14A and 14B, a subsurface safety valve 40 includes a mid housing 403 and a flow tube 43 moveably disposed in mid housing 403. An actuator end 43A is coupled to flow tube 43 to provide a first force F41

to move flow tube 43. Disposed in a space between mid housing 403 and flow tube 43 there are three or more magnetic elements 473 stacked one on top of another, along axial direction 419 of mid housing 403. Compared to subsurface safety valve 30 illustrated in the previous embodiment, subsurface safety valve 40 of the present embodiment adds at least a third magnetic element 4733 to stack on or underneath the first and second magnetic elements 4731, 4732. Third magnetic element 4733 may be positioned between first magnetic element 4731 and mid housing flow tube 43 (Fig. 14A), or between second magnetic element 4732 and housing 403 (Fig. 14B). In either case, adjacent magnetic elements 473 have same magnetic pole facing each other, to generate a second force F42, i.e. a repellant magnetic force between adjacent magnetic elements 473. A top magnetic element 4731 (or 4733) of the plurality of magnetic elements 473 abuts directly against flow tube 43, and a bottom magnetic element 473a abuts directly against housing 403.

Under normal operation of underground hydrocarbon production, as shown in Figs. 13A, 13B, a hydraulic pressure is supplied to activate actuator end 43A. Actuator end 43A in turn provides first force F41 acting on flow tube 43. First force F41 overcomes second force F42 to move flow tube 43 to a first position where a first end 4301 is positioned outside of mid housing 403. Following the movement of flow tube 43 to the first position, flapper 47 is rotated to an open position to allow hydrocarbon product 8 to enter flow tube 43 through first opening 4301 and transmitted to ground surface through subsurface safety valve 40.

In case of emergency or it is desired to stop transportation of hydrocarbon product up to the ground surface, the hydraulic pressure may be shut down or reduced either voluntarily or otherwise, resulting in a loss of hydraulic pressure on actuator end 43A and subsequently on flow tube 43. Actuator end 43A is therefore deactivated, and the second force F42 prevails which moves flow tube 43 to the second position, as shown in Fig. 14A, 14B. When flow tube 43 is moved to the second position, first opening 4301 is retracted in mid housing 403. Flapper 47 is rotated, by the spring force of torsion spring 471, to a close position to cover the first opening 4301 of flow tube 43. As such, underground hydrocarbon product is prevented from entering flow tube 43.

Operation of the subsurface safety valve 40 for resuming the normal production may be effected in a similar manner as that described in the previous embodiment.

It will be appreciable by person skilled-in-the-art that the described safety valve apparatus embodiments do not include a power spring, hence enable a more compact design and allow a larger flow conduit diameter for increased fluid flow volume. The self-centralizing nature of magnets aids in enabling the flow tube movement, without the potential hazard of stuck flow tube due to asymmetrical forces or distorted spring.

The present invention has been described above with reference to its preferred embodiments. However, the present invention is not to be limited in scope by the specific embodiments described here in. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the claims.

CLAIMS

1. A subsurface safety valve comprising:
 - a housing,
 - 5 a flow tube movably disposed in the housing;
 - a flapper movably coupled to a first opening of the flow tube,
 - an actuator end coupled to the flow tube;
 - a first magnetic element coupled to the housing, and
 - a second magnetic element coupled to the flow tube;
 - 10 wherein after the actuator end is activated, the actuator end acts a first force on the flow tube to move the flow tube to a first position following which the flapper is moved to an open position to allow a fluid to enter the flow tube from the first opening, and
 - wherein after the actuator end is deactivated, a second force generated by the
 - 15 first and second magnetic elements moves the flow tube to a second position following which the flapper is moved to a close position to cover the first opening.
2. The subsurface safety valve according to claim 1, wherein the first magnetic
20 element is formed integral with the housing and the second magnetic element is formed integral with the flow tube.
3. The subsurface safety valve according to claim 2, wherein the first and second
25 magnetic elements are positioned with magnetic poles oriented along opposite directions.
4. The subsurface safety valve according to claim 3, wherein when the flow tube is at
the first position, a north magnetic pole of the second magnetic element is
positioned between a south and a north magnetic poles of the first magnetic
30 element with respect to an axial direction of the housing, and the north magnetic pole of the first magnetic element is positioned between the north magnetic pole and a south magnetic pole of the second magnetic element.

5. The subsurface safety valve according to claim 4, wherein when the flow tube is at second position, the north magnetic pole of the second magnetic element is aligned with the south magnetic pole of the first magnetic element along a lateral direction of the housing.
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6. The subsurface safety valve according to claim 5, wherein when the flow tube is at second position, the south magnetic pole of the second magnetic element is aligned with the north magnetic pole of the first magnetic element along the lateral direction of the housing.
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7. The subsurface safety valve according to claim 3, wherein the first magnetic element is located at a sidewall segment of the housing and the second magnetic element is located at an annular region of the flow tube.
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8. The subsurface safety valve according to claim 7, wherein the actuator end is coupled to the flow tube at the side wall segment.
9. The subsurface safety valve according to claim 3, wherein the first magnetic element is located at a first annular region of the housing and the second magnetic element is located at a second annular region of the flow tube.
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10. The subsurface safety valve according to claim 9, wherein the first and second magnetic elements are centrally aligned relative to each other about the axial direction.
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11. The subsurface safety valve according to claim 1, wherein the first and second magnetic elements are movably disposed between the housing and the flow tube, the first magnetic element abuts against the housing and the second magnetic element abuts against the flow tube.
30
12. The subsurface safety valve according to claim 11, wherein the first and second magnetic elements are disposed along an axial direction of the housing, and have

same magnetic poles facing each other such that the second force repels the first and second magnetic elements from each other along the axial direction.

- 5 13. The subsurface safety valve according to claim 12, wherein when the flow tube is at the first position, the first and second magnetic elements are positioned closer to each other and when the flow tube is at the second position, the first and second magnetic elements are positioned away from each other.
- 10 14. The subsurface safety valve according to claim 11, further comprising a third magnetic element disposed between the housing and the flow tube and aligned with the first and second magnetic elements along the axial direction, wherein the third magnetic element is positioned with a magnetic pole facing a same magnetic pole of one of the first and second magnetic element.
- 15 15. The subsurface safety valve according to claim 14, wherein the third magnetic element is disposed between the housing and the first magnetic element and with one of the magnetic poles facing the same magnetic pole of the first magnetic element.
- 20 16. The subsurface safety valve according to claim 14, wherein the third magnetic element is disposed between the flow tube and the second magnetic element and with one of the magnetic poles facing the same magnetic pole of the second magnetic element.
- 25 17. The subsurface safety valve according to claim 11, wherein the housing and the flow tube form an annular space therebetween, wherein the first and second magnetic elements are respective first and second annular rings disposed in the annular space along the axial direction.
- 30 18. The subsurface safety valve according to claim 17, wherein the first and second annular rings are movable in the annular space along the axial direction.

19. The subsurface safety valve according to claim 11, wherein the housing is covered with a layer of mu metal on an outer surface thereof.
20. The subsurface safety valve according to claim 11, wherein the flow tube is
5 covered with a layer of mu metal on an inner surface thereof.

ABSTRACT

SUBSURFACE SAFETY VALVE

5 A subsurface safety valve includes a housing and a flow tube disposed in the housing. The flow tube is movable relative to the housing. A flapper is moveably coupled to the flow tube. An actuator end is coupled to the flow tube to provide a first force. A first magnetic member is coupled to the housing. A second magnetic member is coupled to the flow tube. After the actuator end is activated, the first force acts on the flow tube to
10 move the flow tube to a first position following which the flapper is moved to an open position to allow a fluid to enter the flow tube. When the actuator end is deactivated, a second force between the first and second magnetic elements moves the flow tube to a second position following which the flapper is moved to a close position to cover the flow tube.

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(Fig. 5D)

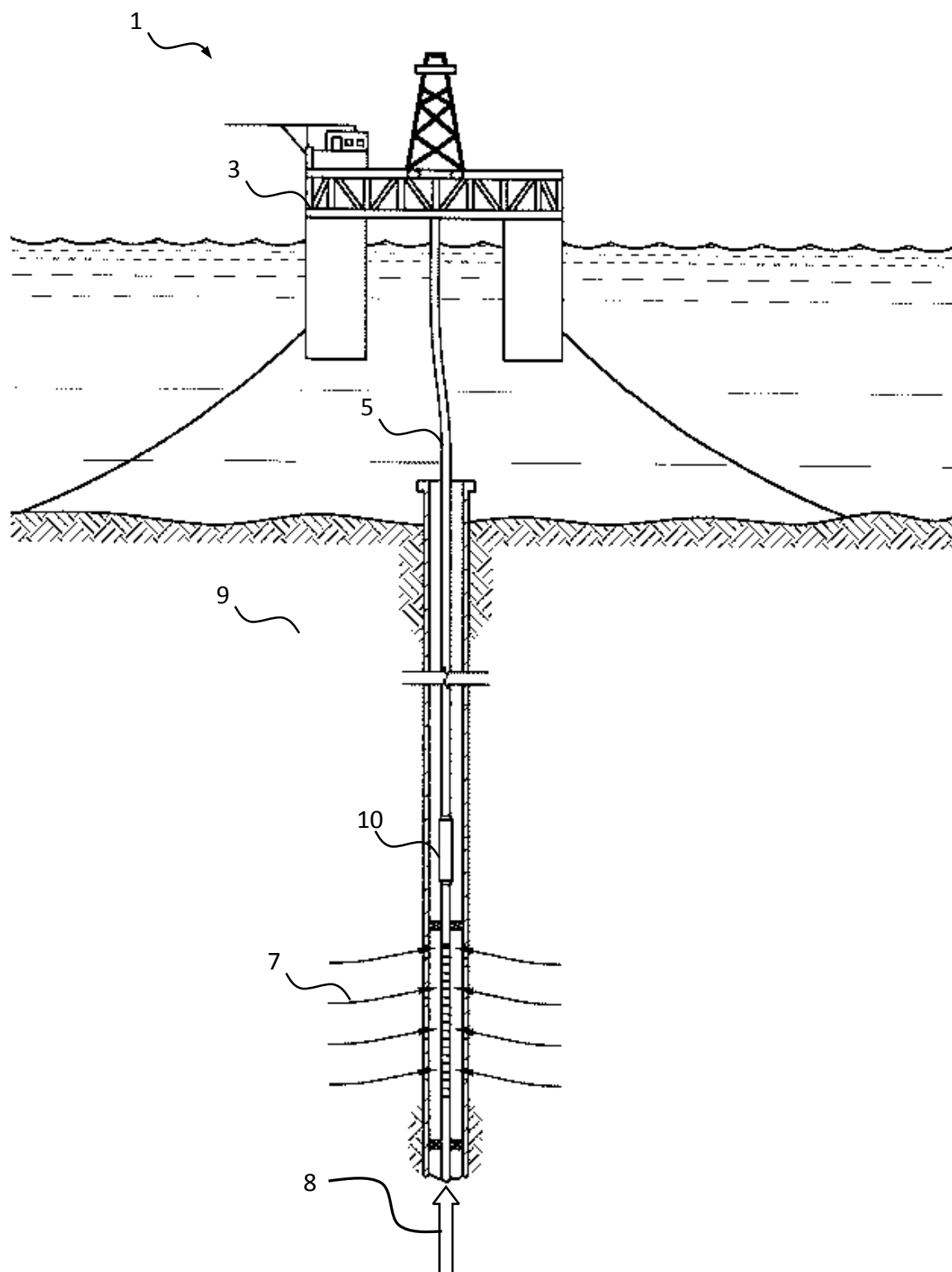


FIG. 1

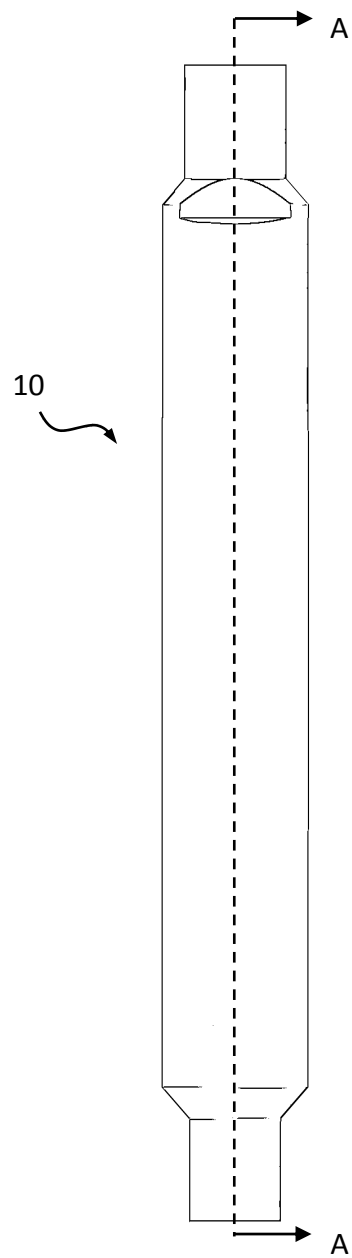


FIG. 2

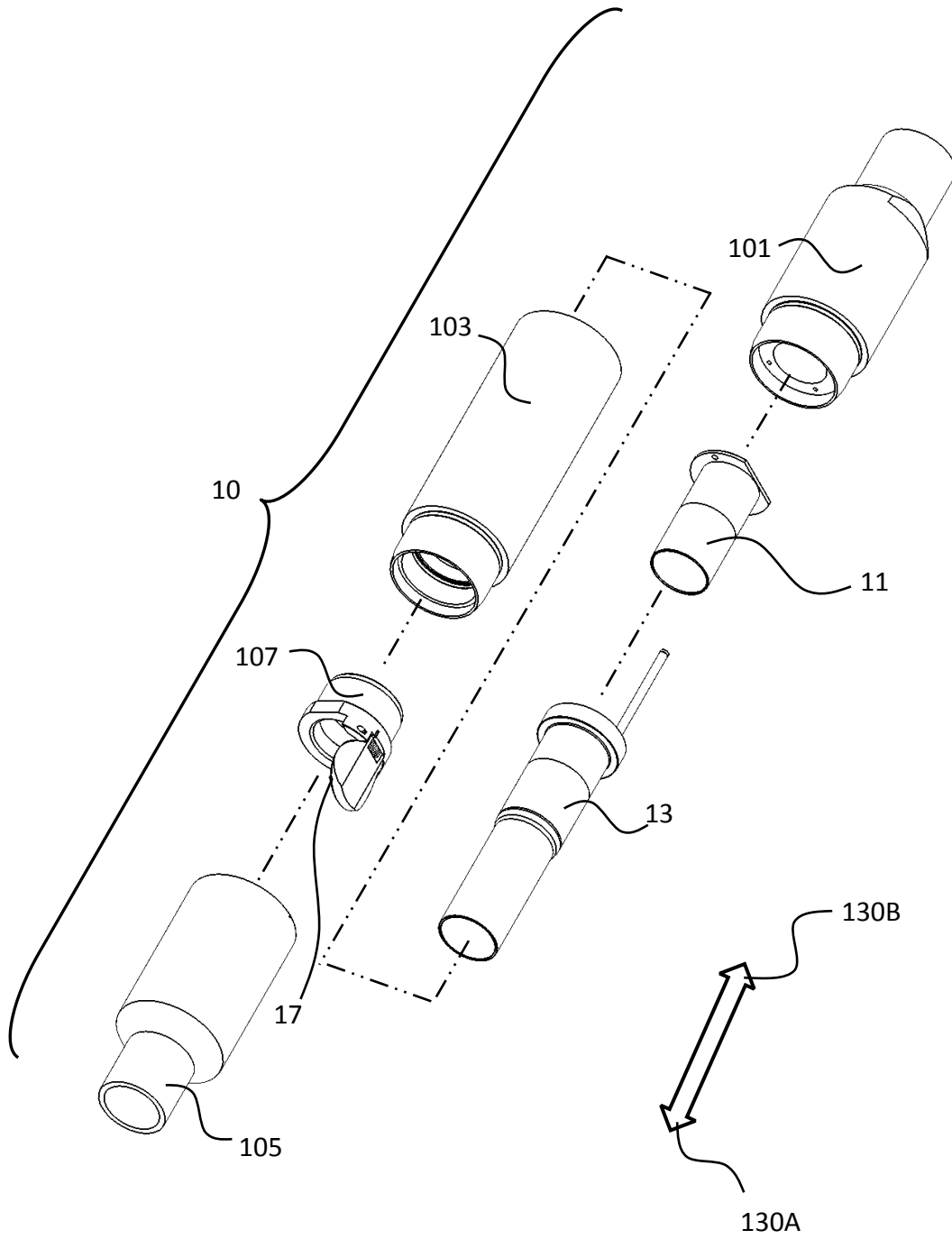


FIG. 3

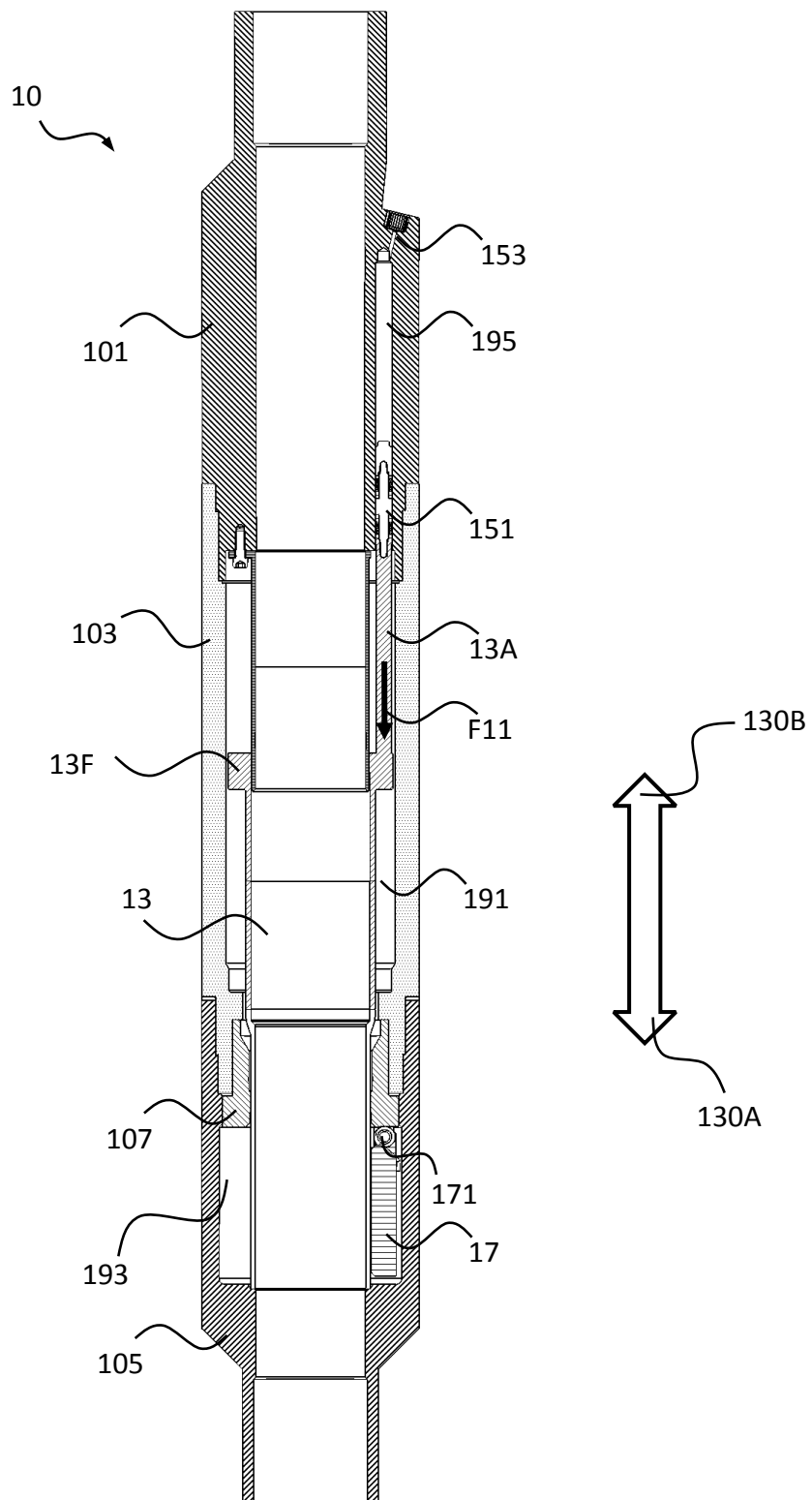
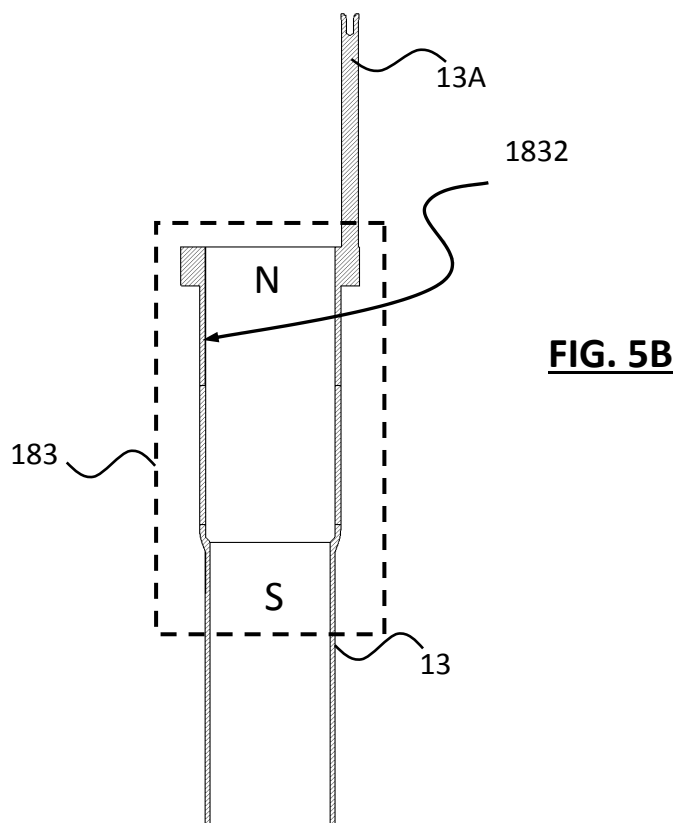
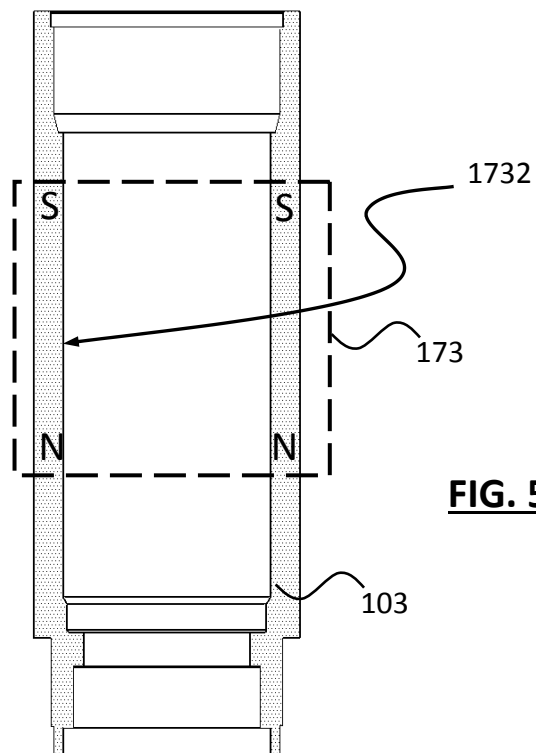


FIG. 4 (A-A)



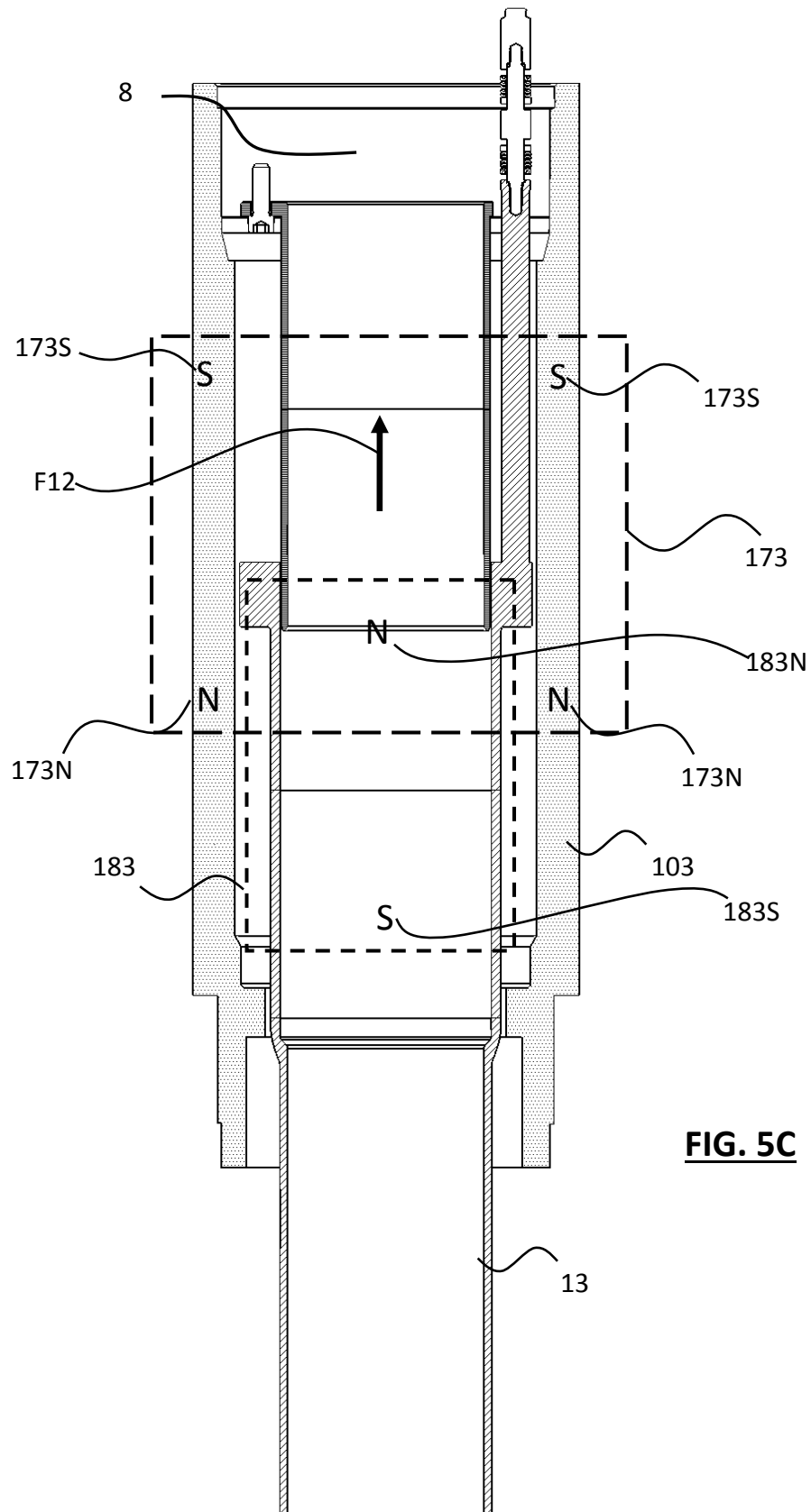


FIG. 5C

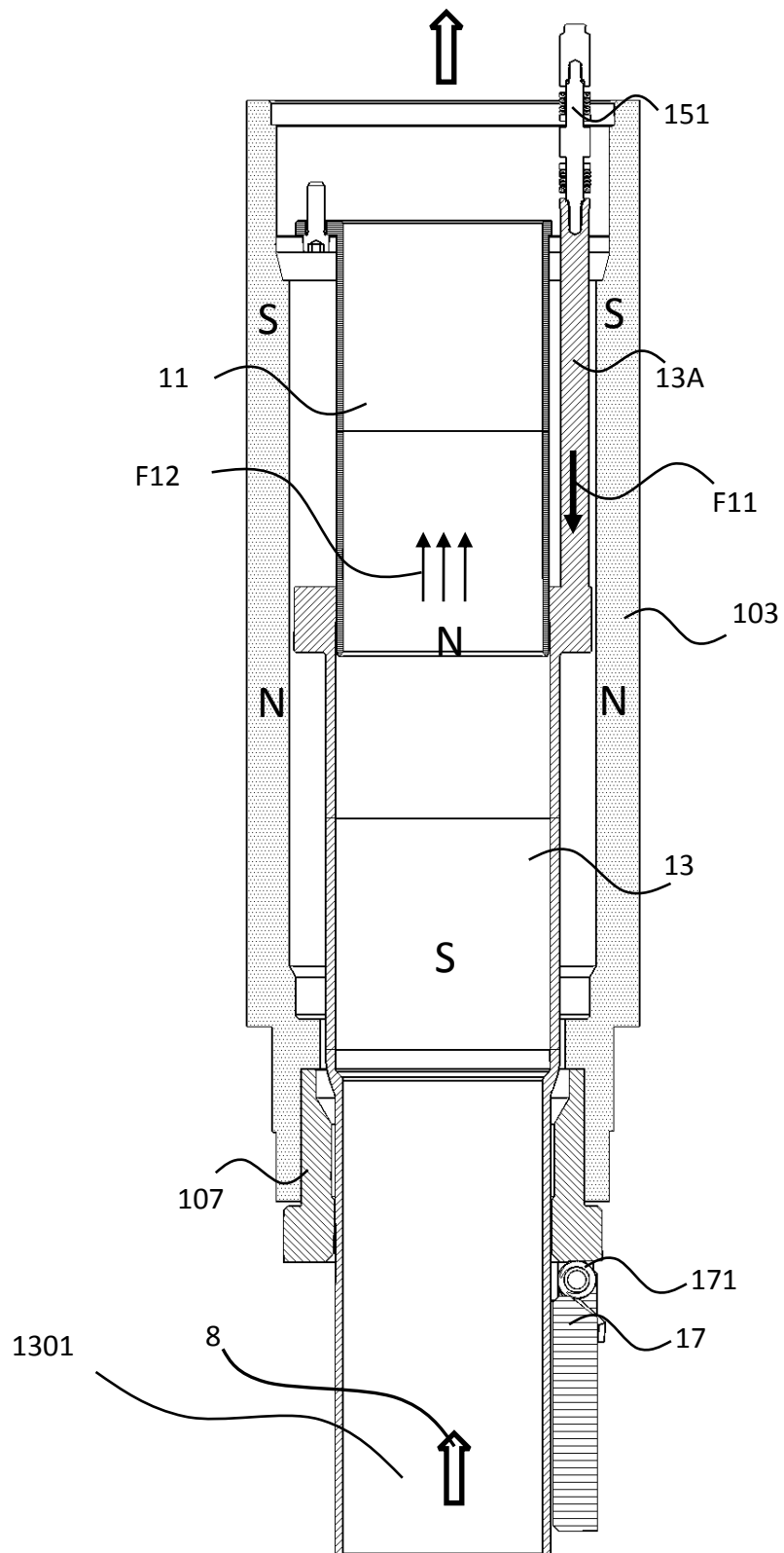


FIG. 5D

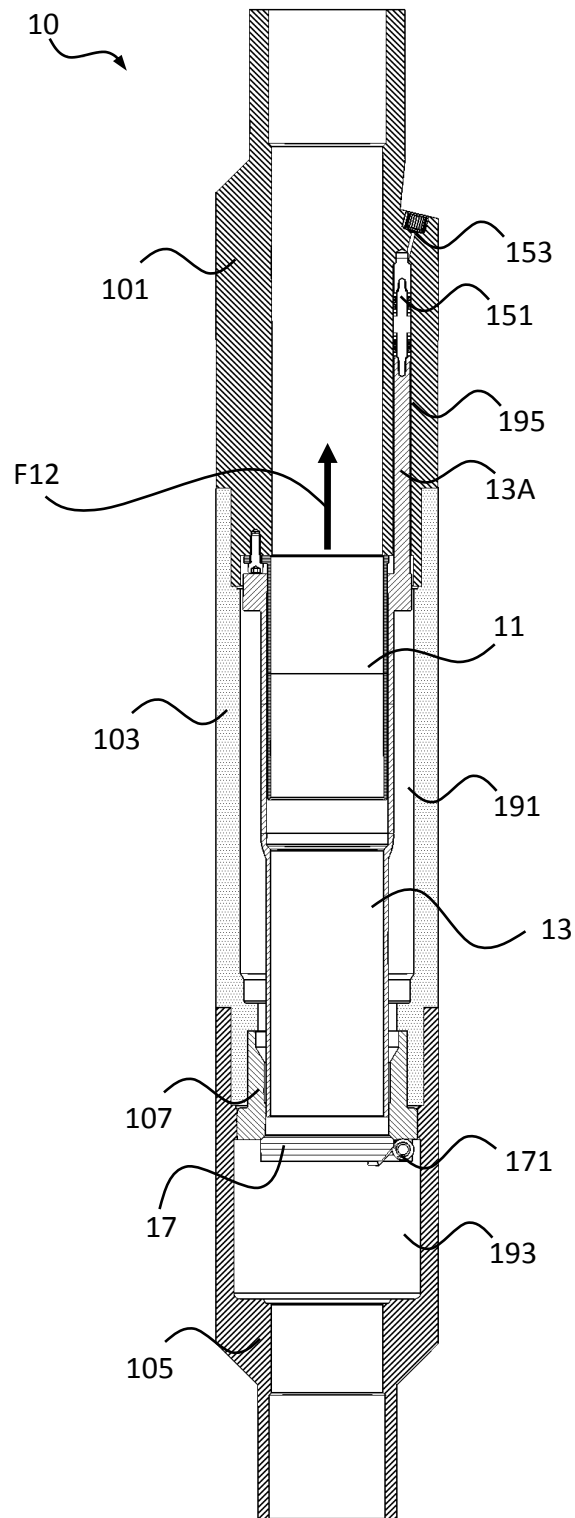


FIG. 6 (A-A)

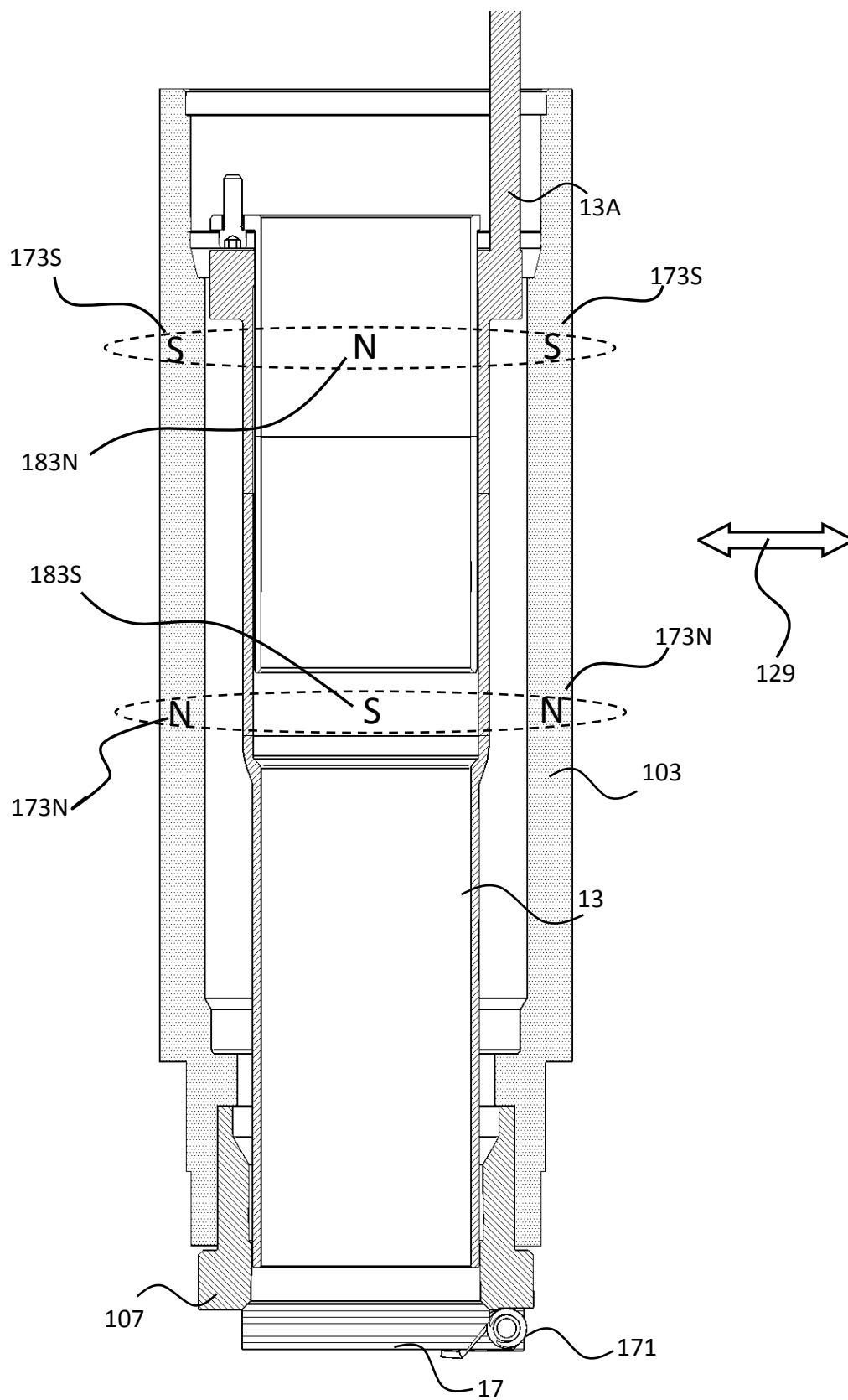


FIG. 7

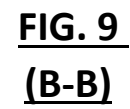


FIG. 9
(B-B)

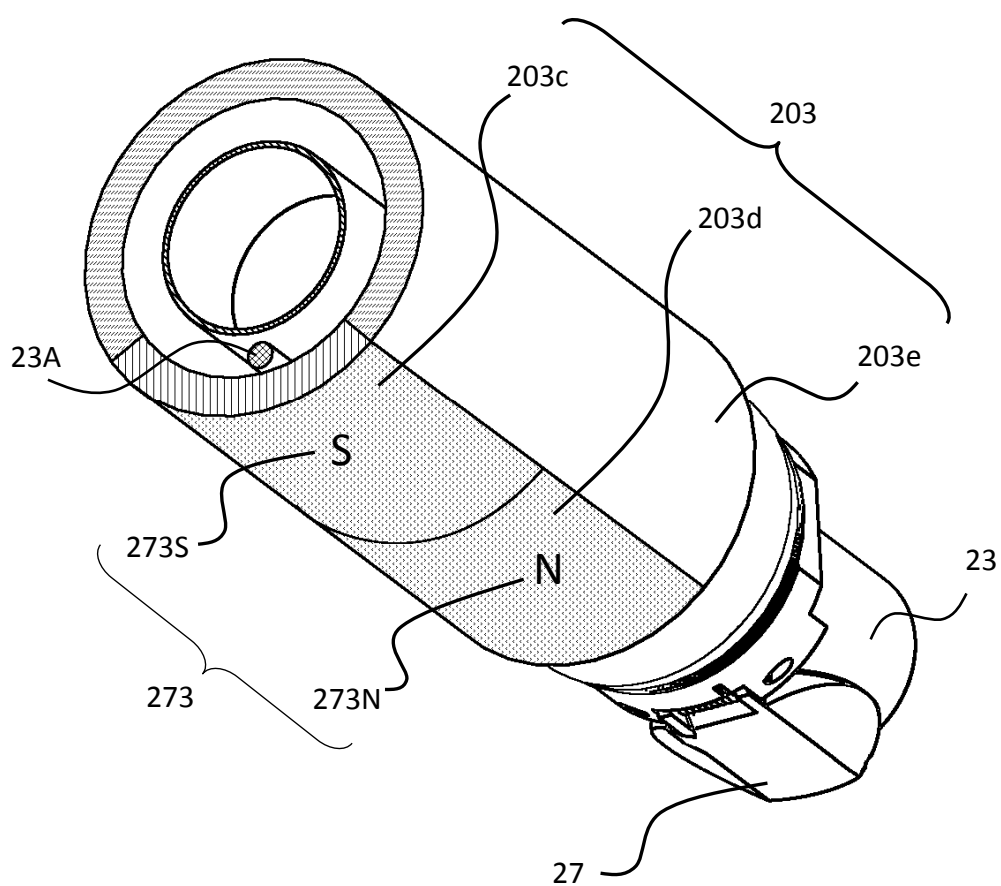


FIG. 10 (B-B)

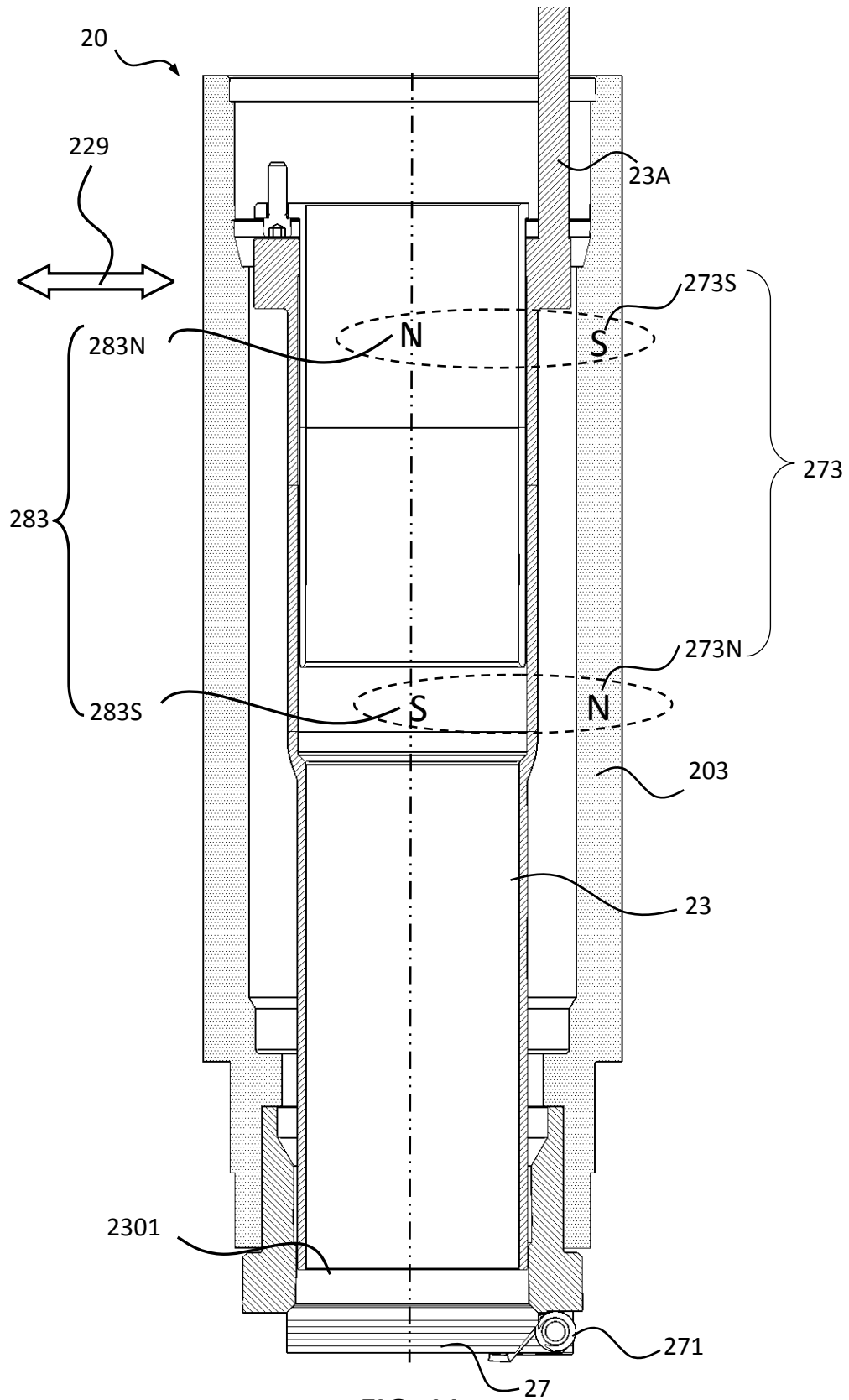
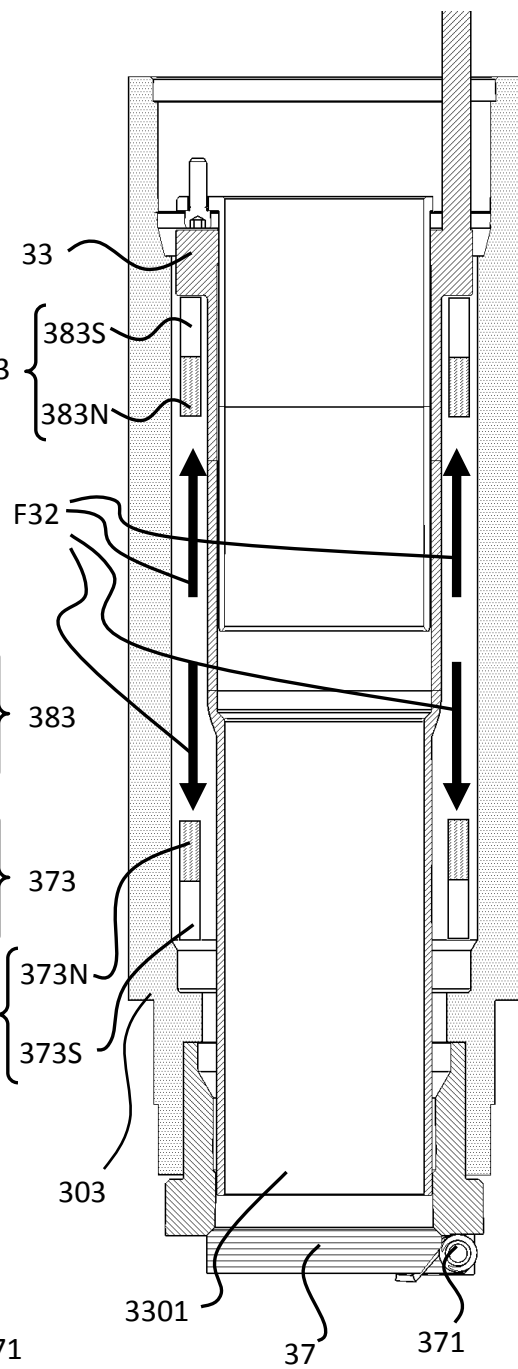
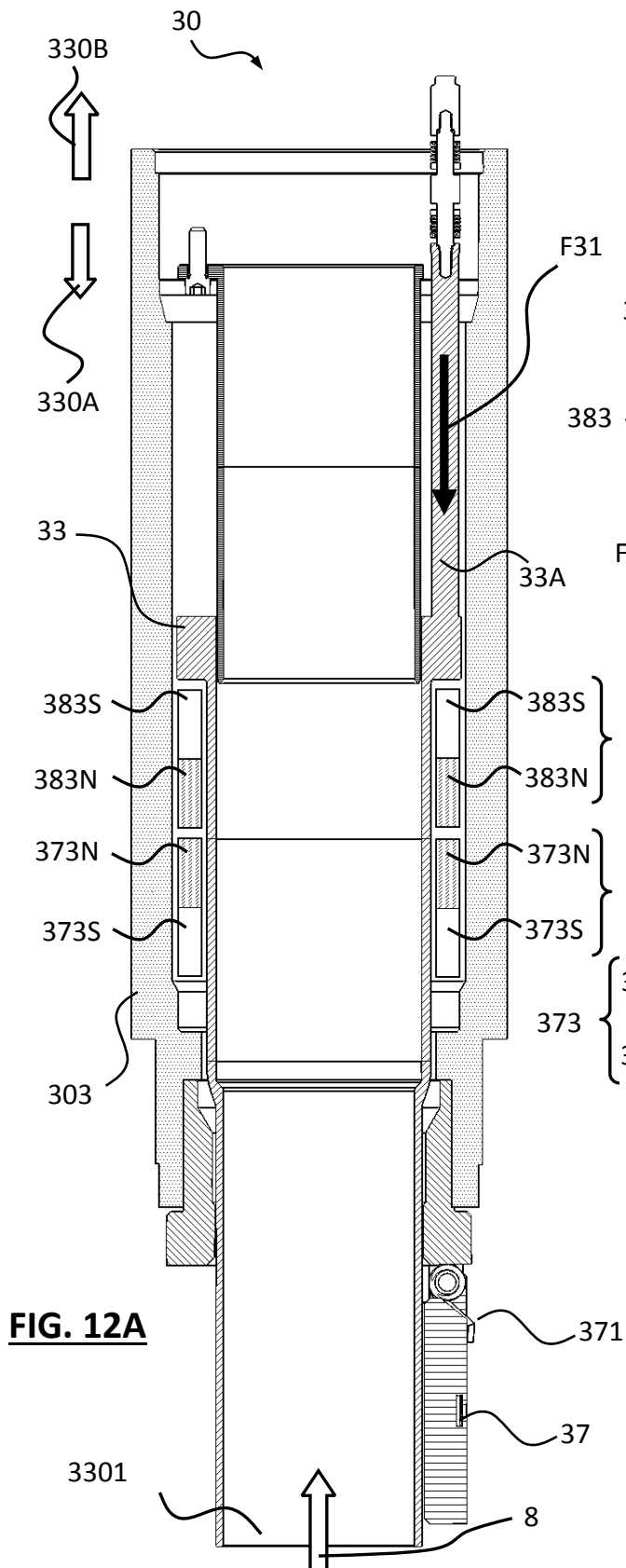


FIG. 11



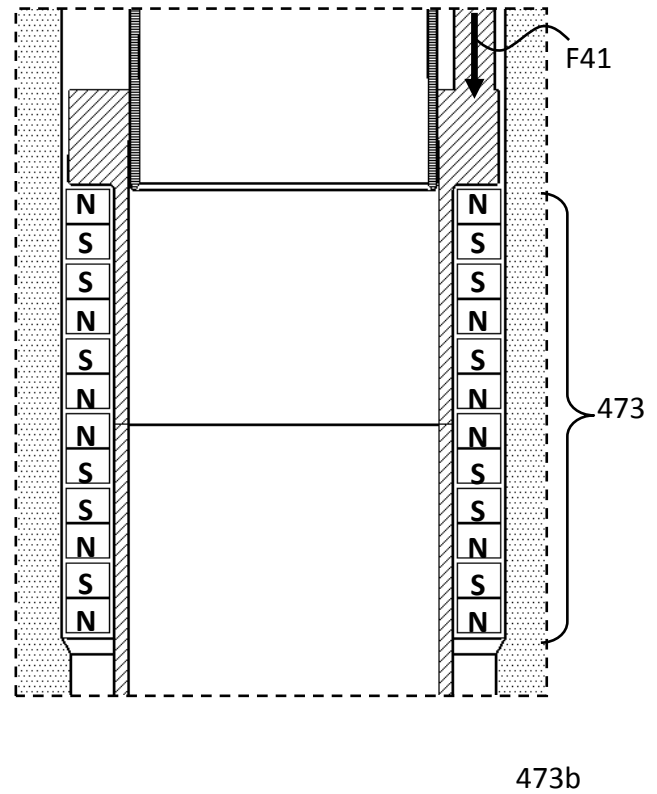
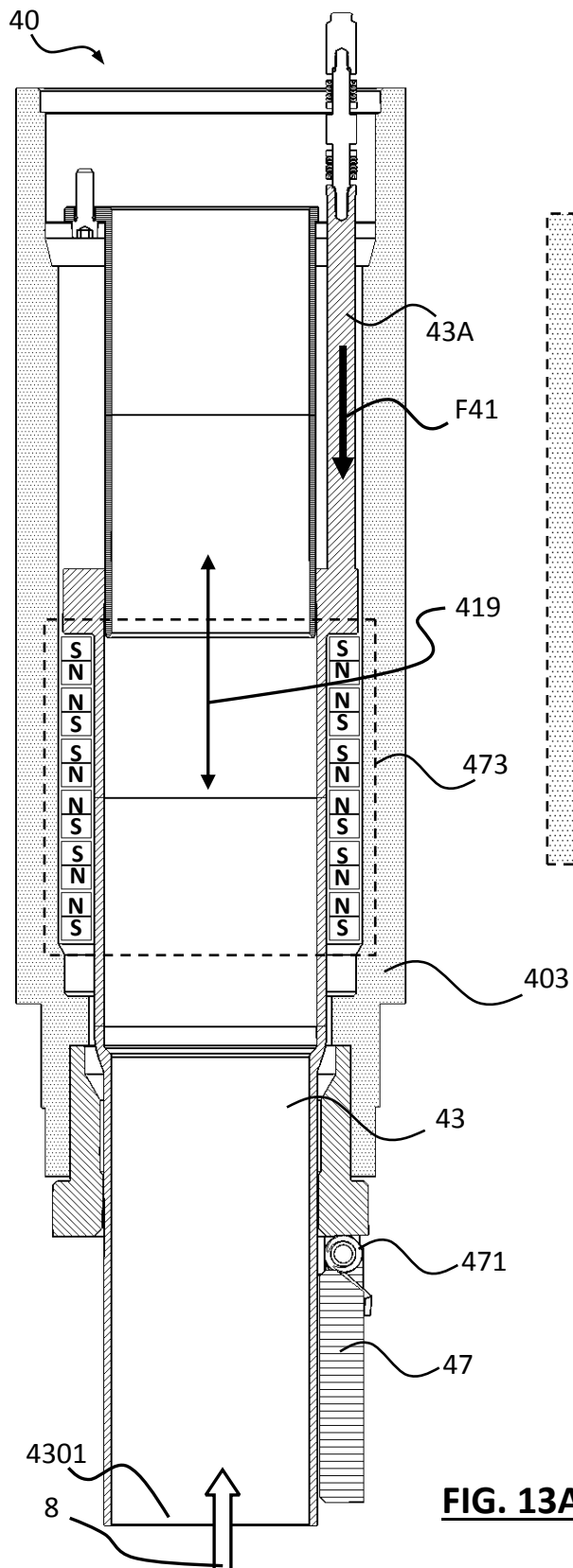


FIG. 13B

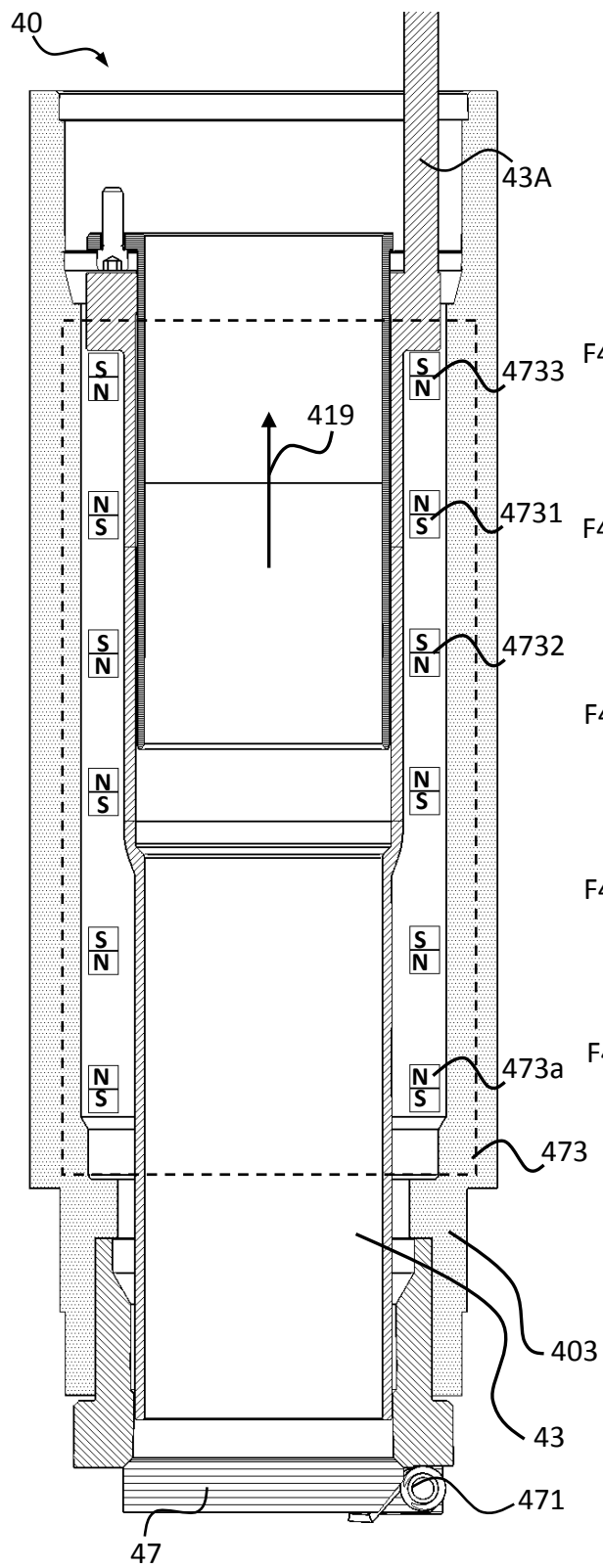


FIG. 14A

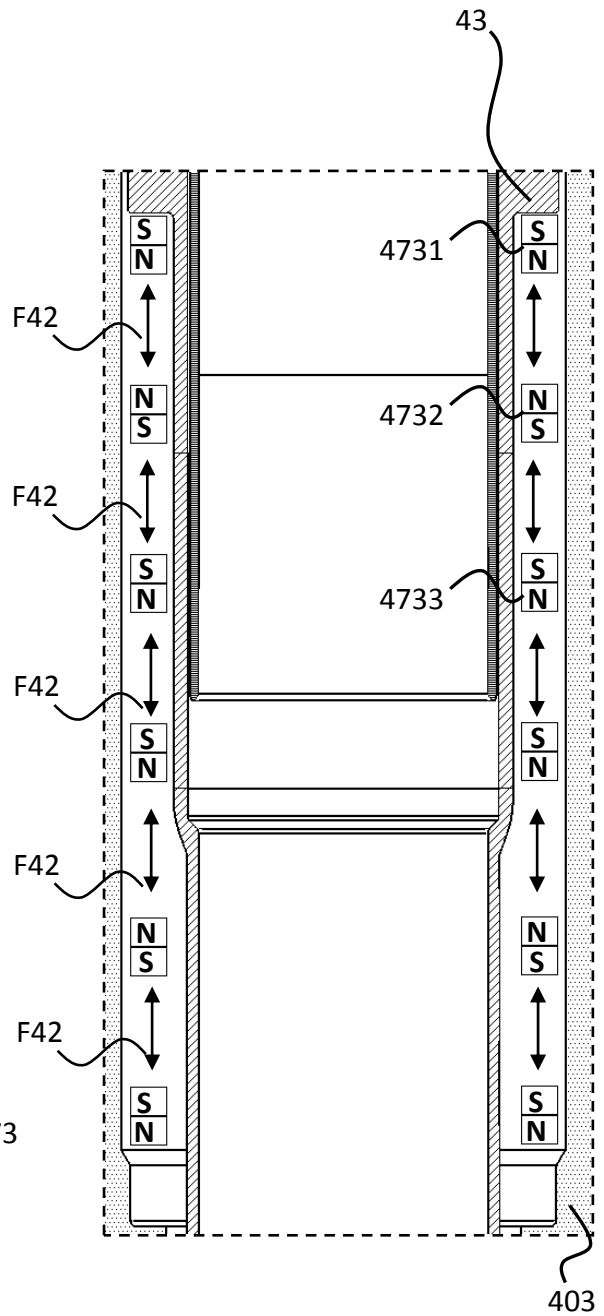


FIG. 14B