US009587454B1

(12) **United States Patent**
Beard et al.

(10) **Patent No.: US 9,587,454 B1**
(45) **Date of Patent: Mar. 7, 2017**

(54) **MODULAR ACTUATOR AND HYDRAULIC VALVE ASSEMBLIES AND CONTROL APPARATUS FOR OIL WELL BLOW-OUT PREVENTERS**

(71) Applicants: **Joseph Owen Beard**, Fullerton, CA (US); **Frode Sveen**, Chino, CA (US)

(72) Inventors: **Joseph Owen Beard**, Fullerton, CA (US); **Frode Sveen**, Chino, CA (US)

(73) Assignee: **PacSeal Group, Inc. PacSeal**, Brea, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 159 days.

(21) Appl. No.: **14/161,673**

(22) Filed: **Jan. 22, 2014**

(51) **Int. Cl.**
F16K 31/163 (2006.01)
E21B 33/06 (2006.01)

(52) **U.S. Cl.**
CPC *E21B 33/063* (2013.01)

(58) **Field of Classification Search**
USPC 251/58, 63.4, 249.5, 250; 137/270; 92/129, 136
See application file for complete search history.

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Primary Examiner — John Fox
(74) *Attorney, Agent, or Firm* — William L. Chapin

(57) **ABSTRACT**

A modular apparatus for controlling flow of pressurized hydraulic fluid to and from opening and closing hydraulic actuator cylinders of oil and gas well blow-out preventers (BOP's), utilizes novel rotary hydraulic valve/actuator assemblies, each of which uses a pair of integral double-acting pneumatic actuator cylinders that drive a rack gear coupled to a spur gear located inside the actuator housing which is fixed to a valve rotor shaft that protrudes forward from the valve housing and protrudes through an outer wall of the housing and has a manually operable handle attached thereto, thus enabling multiple valve/actuator assemblies to be mounted in a close side-by-side arrangement to an hydraulic manifold. An air control manifold panel for remotely energizing the pneumatic actuator cylinders includes opening and closing push button control valves on an air manifold connected through air hoses to the actuator cylinders.

19 Claims, 35 Drawing Sheets

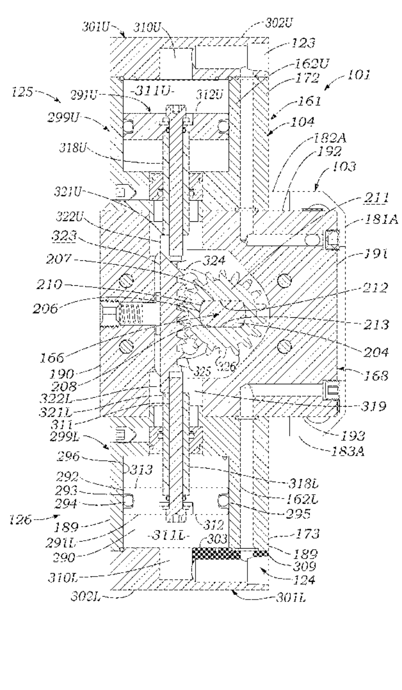


Fig. 1

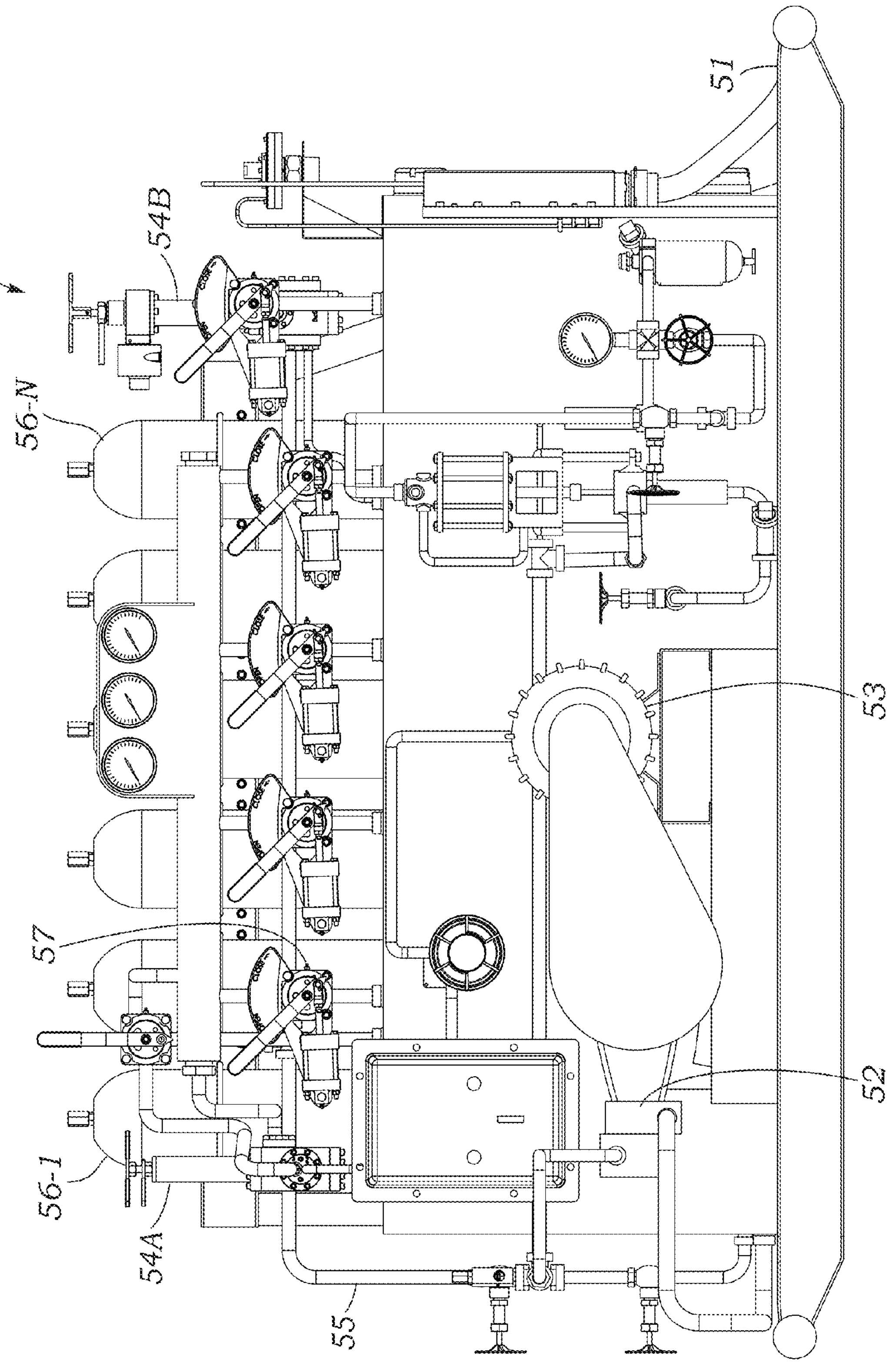


Fig. 4
(PRIOR ART)

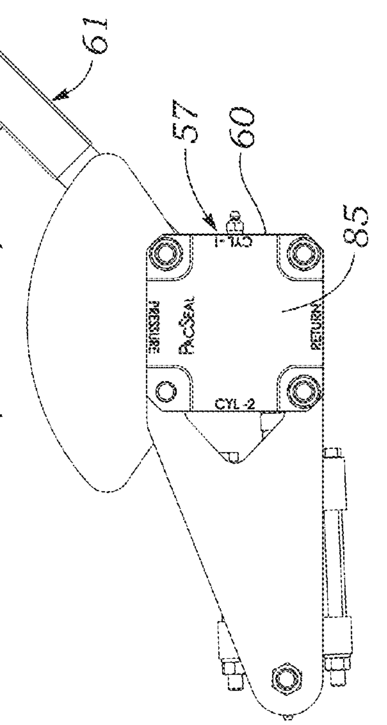


Fig. 5A
(PRIOR ART)

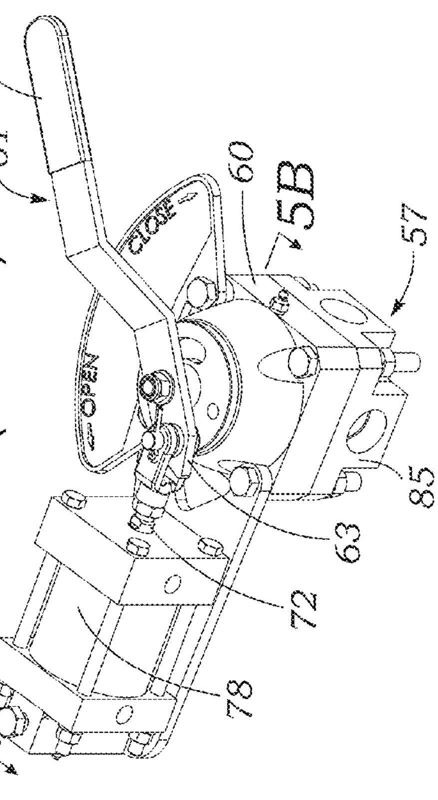


Fig. 2
(PRIOR ART)

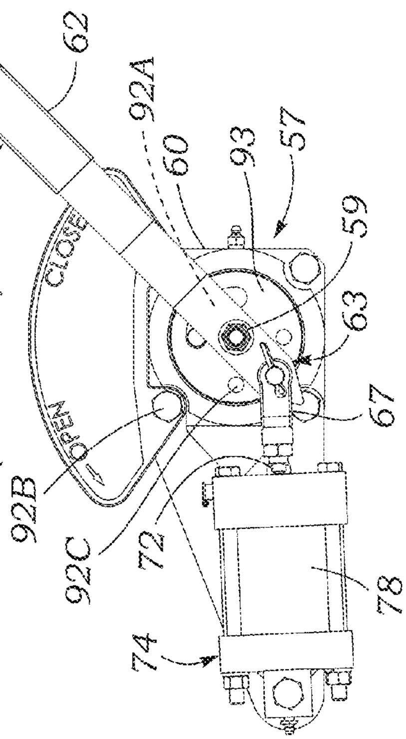
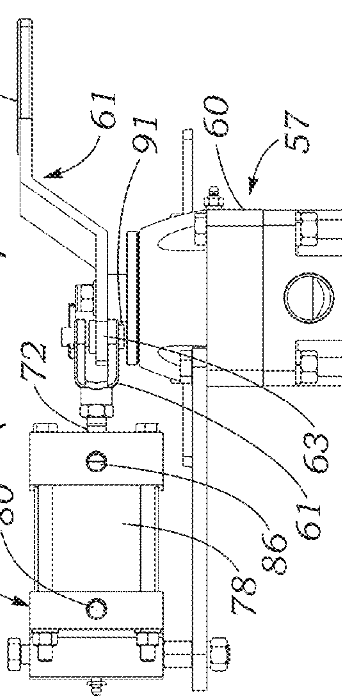


Fig. 3
(PRIOR ART)



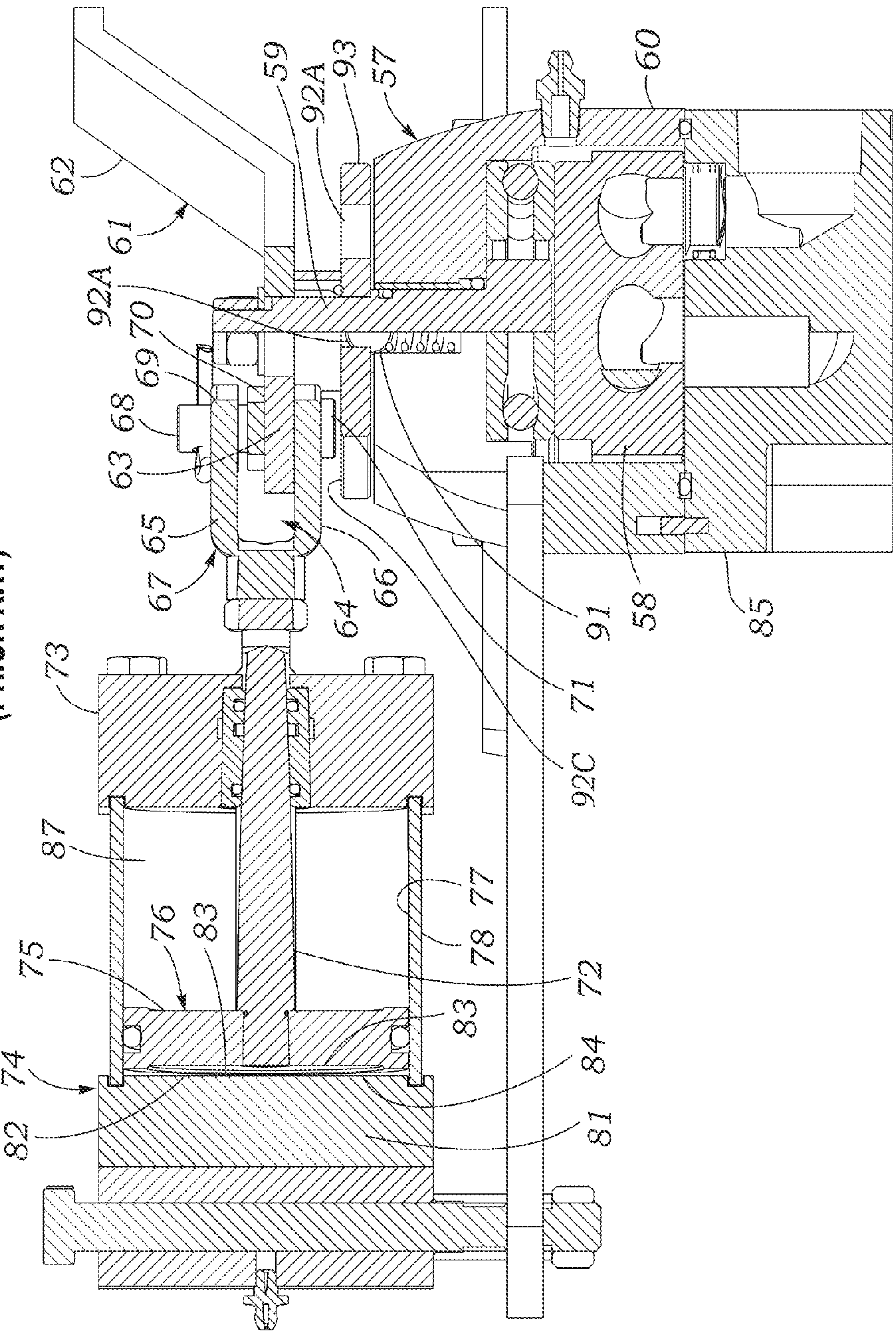
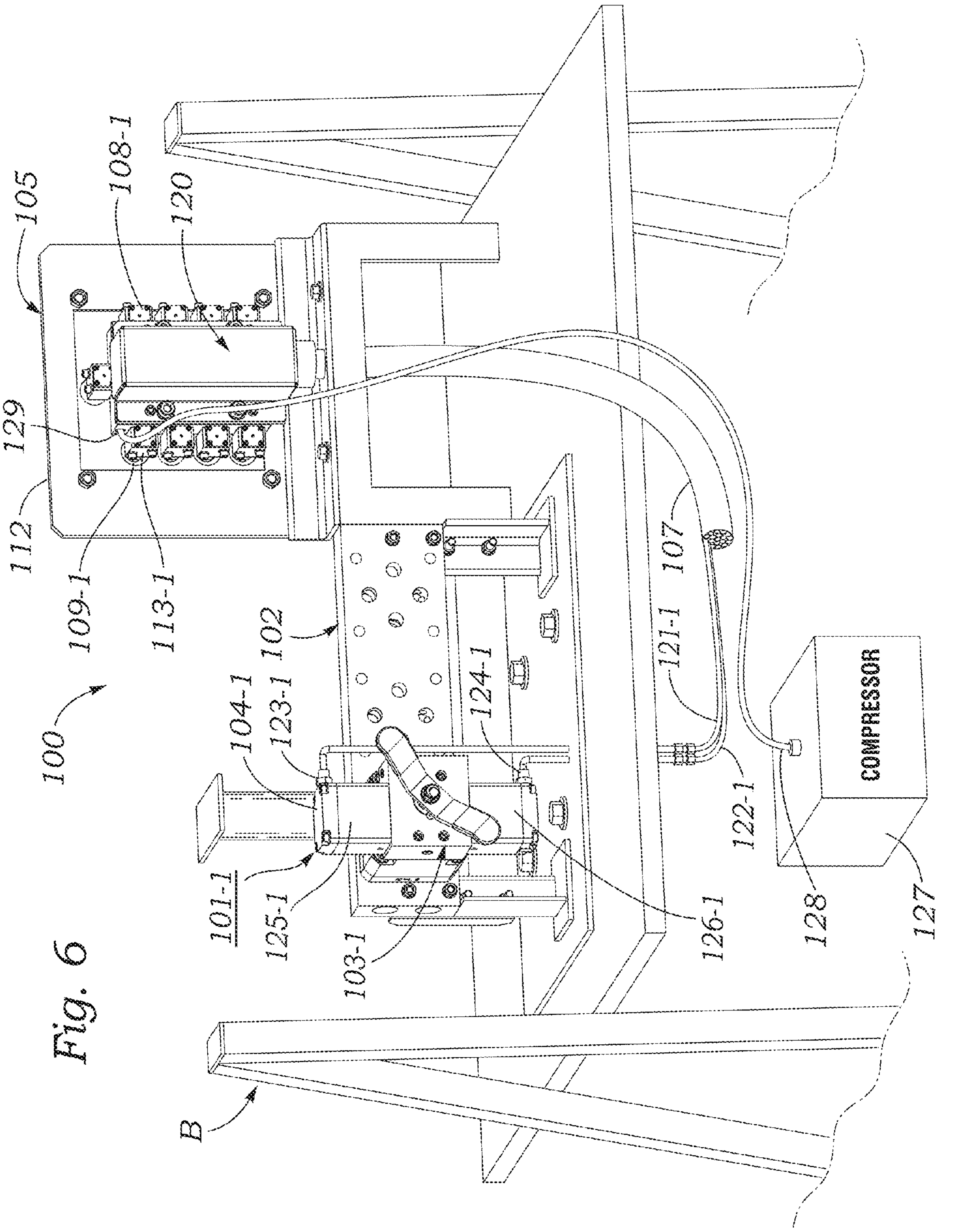


Fig. 5B
(PRIOR ART)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129
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109-1
113-1
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102
104-1
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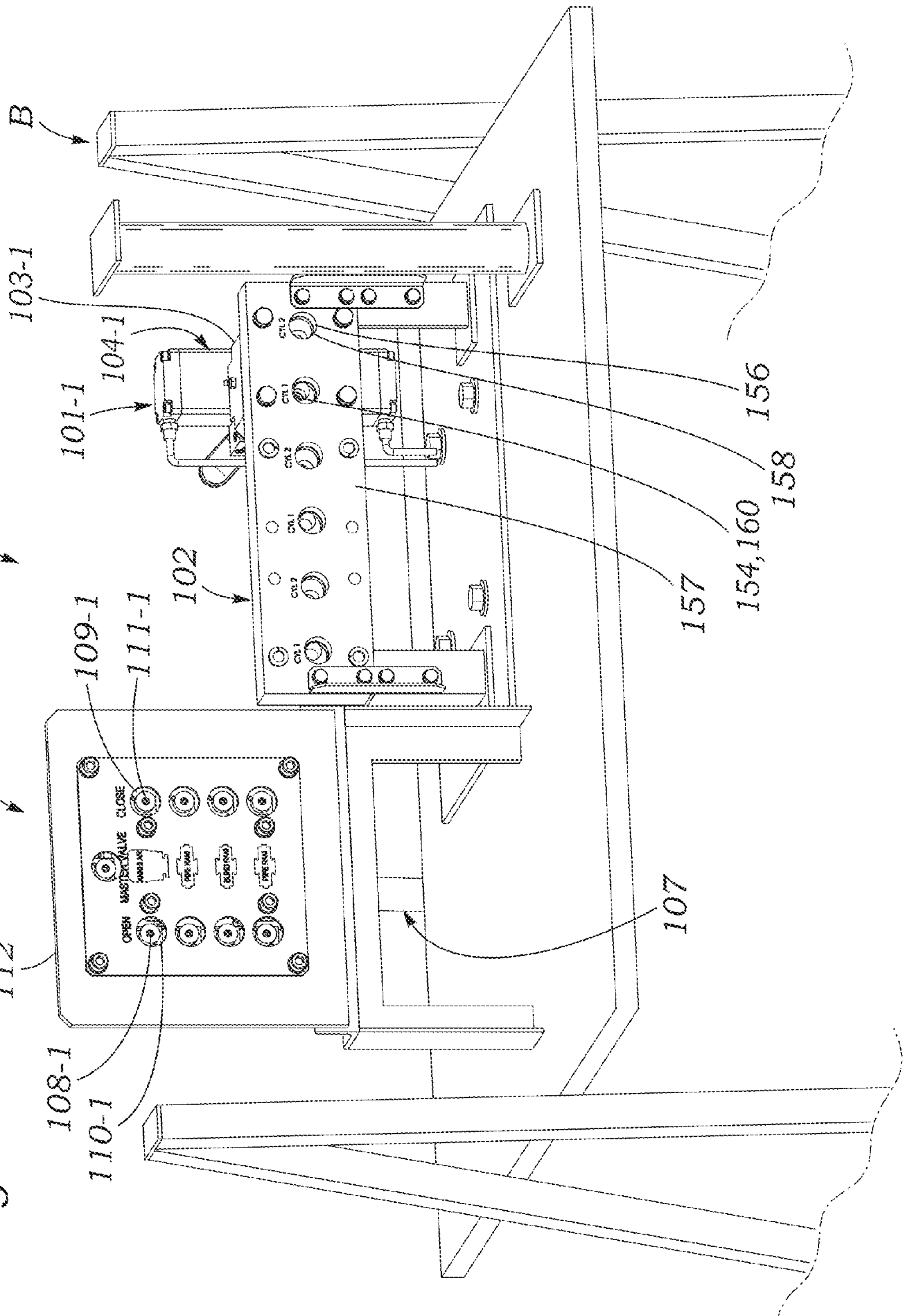
121-1
122-1
COMPRESSOR
101-1
125-1
103-1
126-1
128
127
B

Fig. 6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105
112
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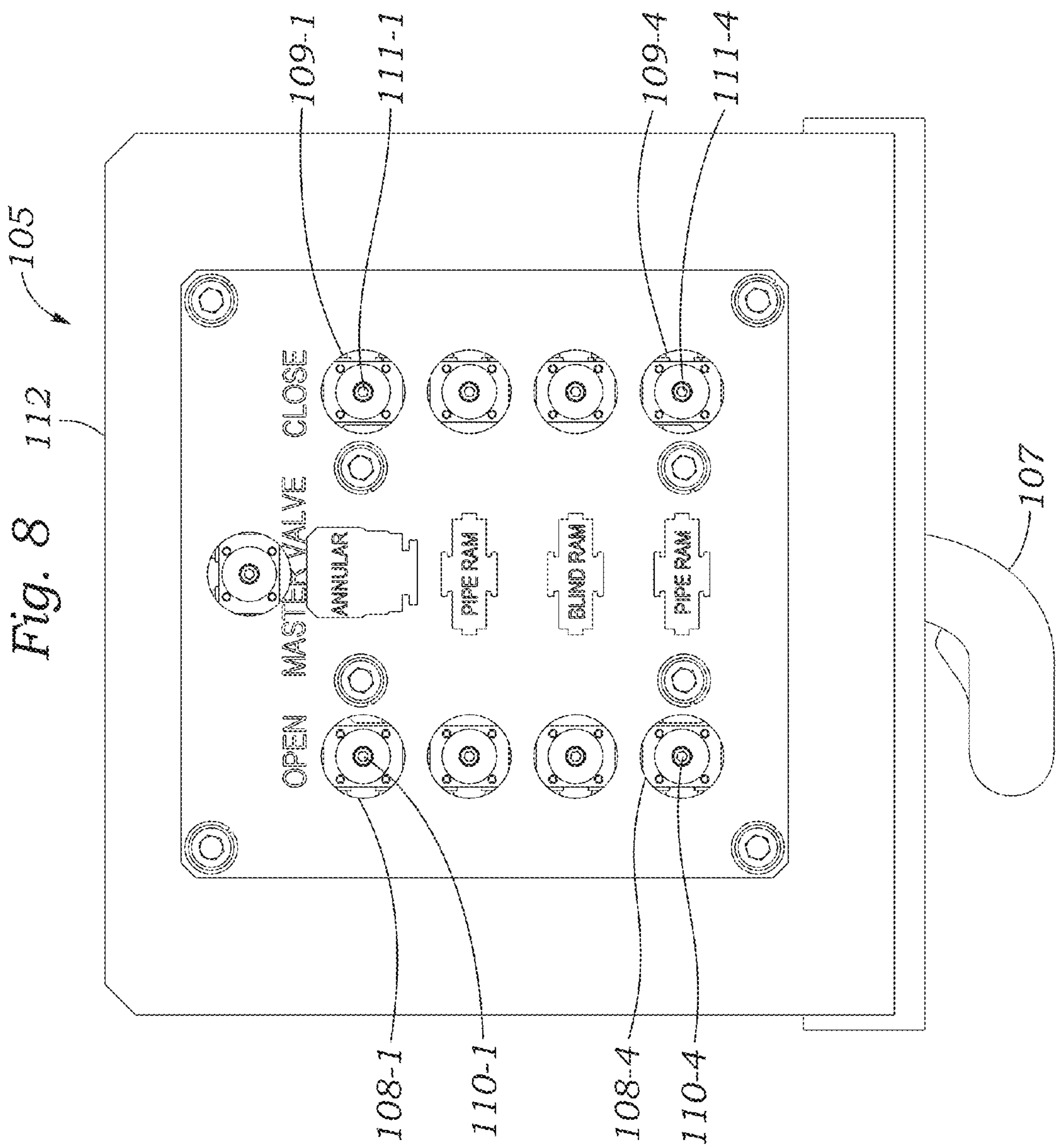
109-1
111-1
OPEN
CLOSE
MASTER VALVE
102
101-1
104-1
103-1
B
156
158
154,160
157
107

Fig. 7


105
112
109-1
111-1
109-4
111-4
CLOSE
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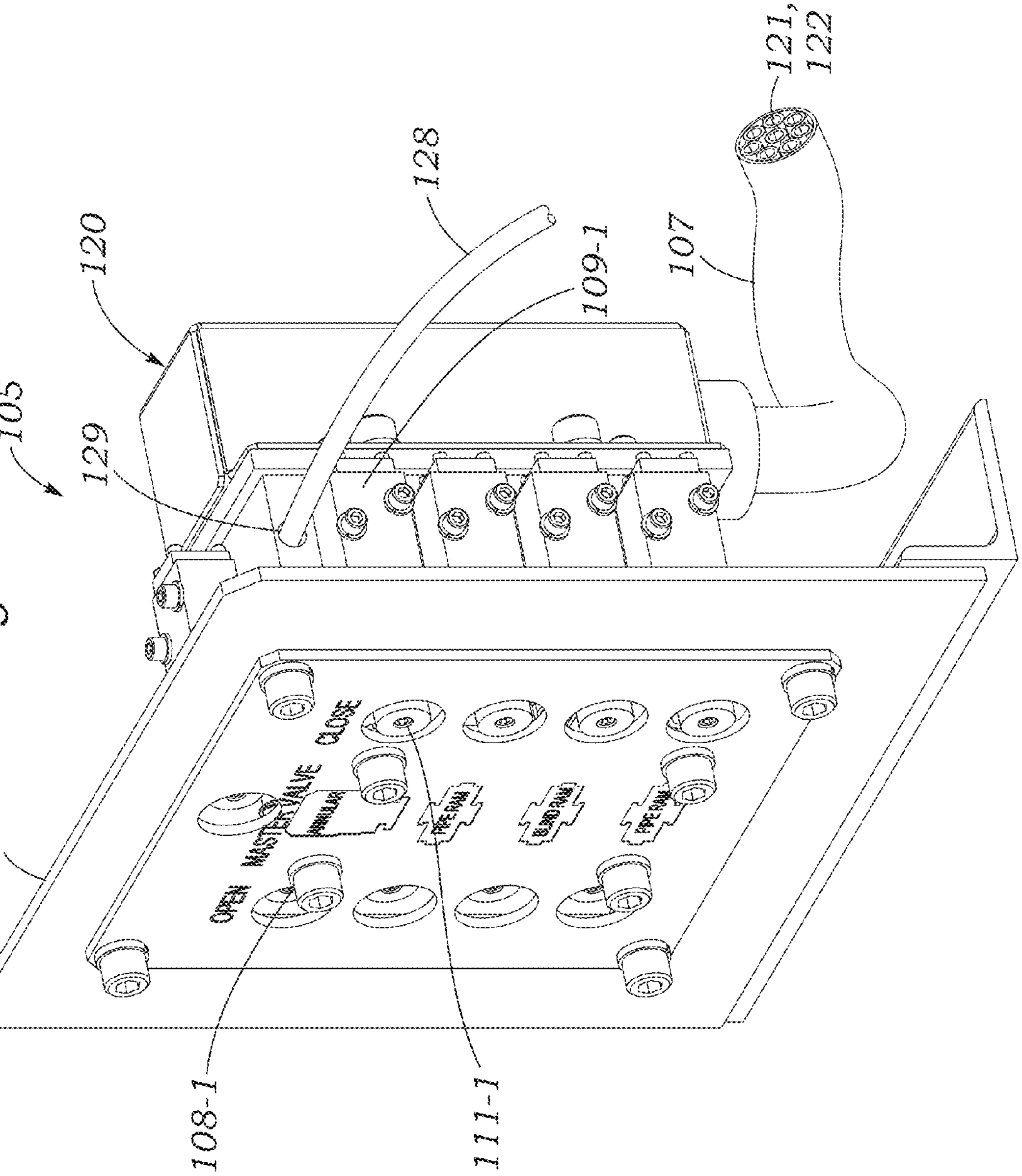
OPEN
ANNULAR
PIPE RAM
BLIND RAM
PIPE RAM
107
108-1
110-1
108-4
110-4

Fig. 8

Fig. 9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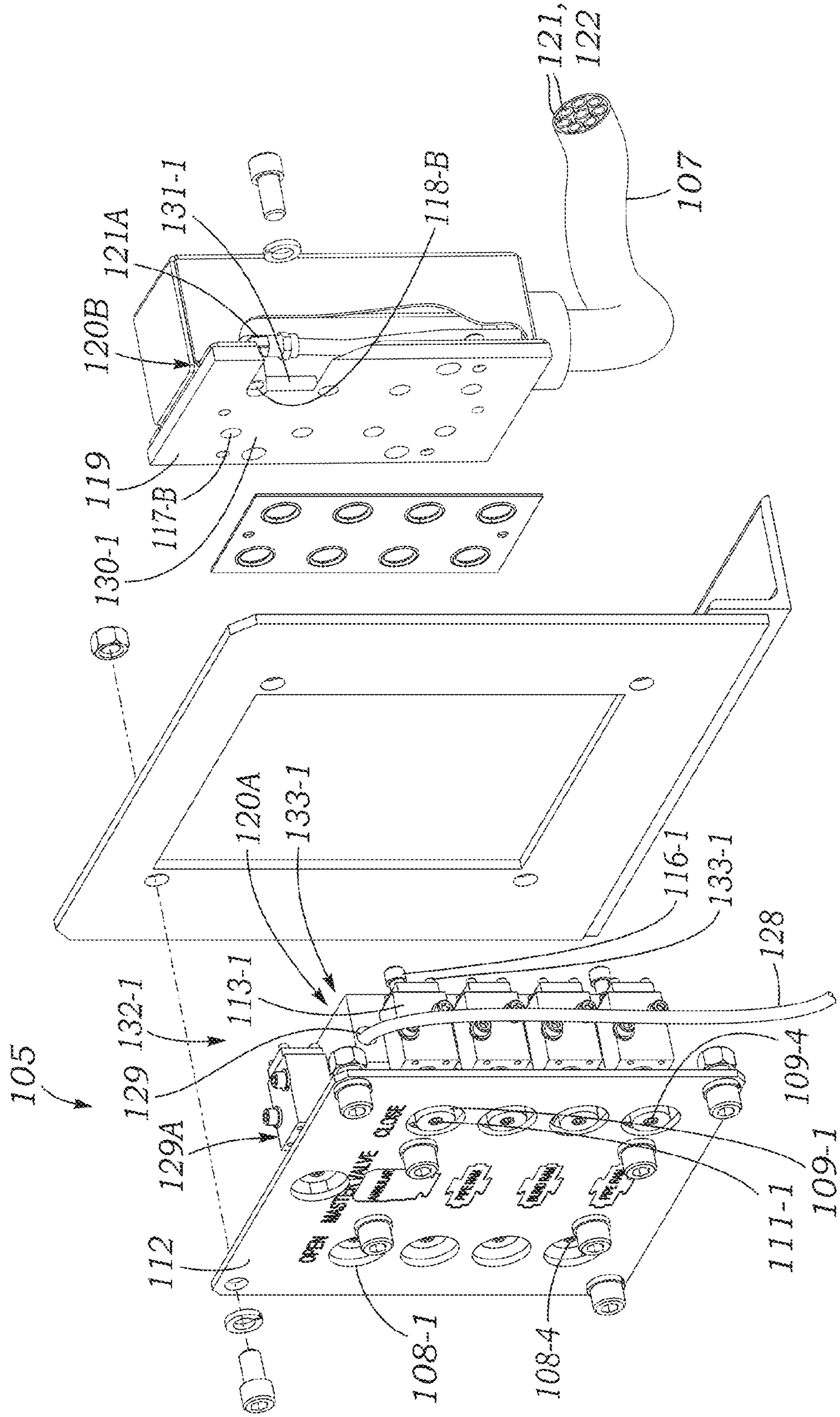
120
128
129
109-1
107
121,
122
112
OPEN
MASTER VALVE
CLOSE
108-1
111-1

Fig. 10A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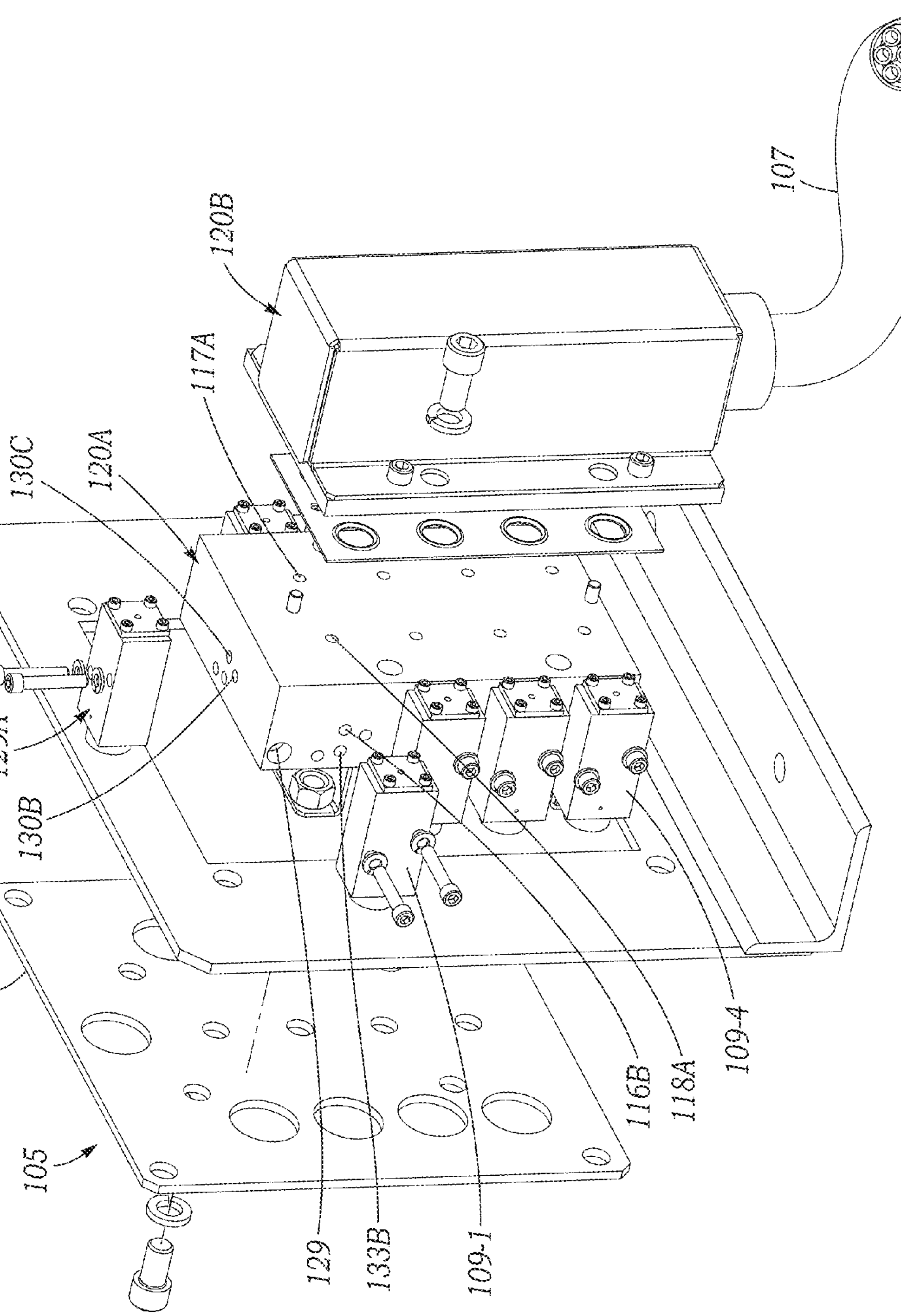
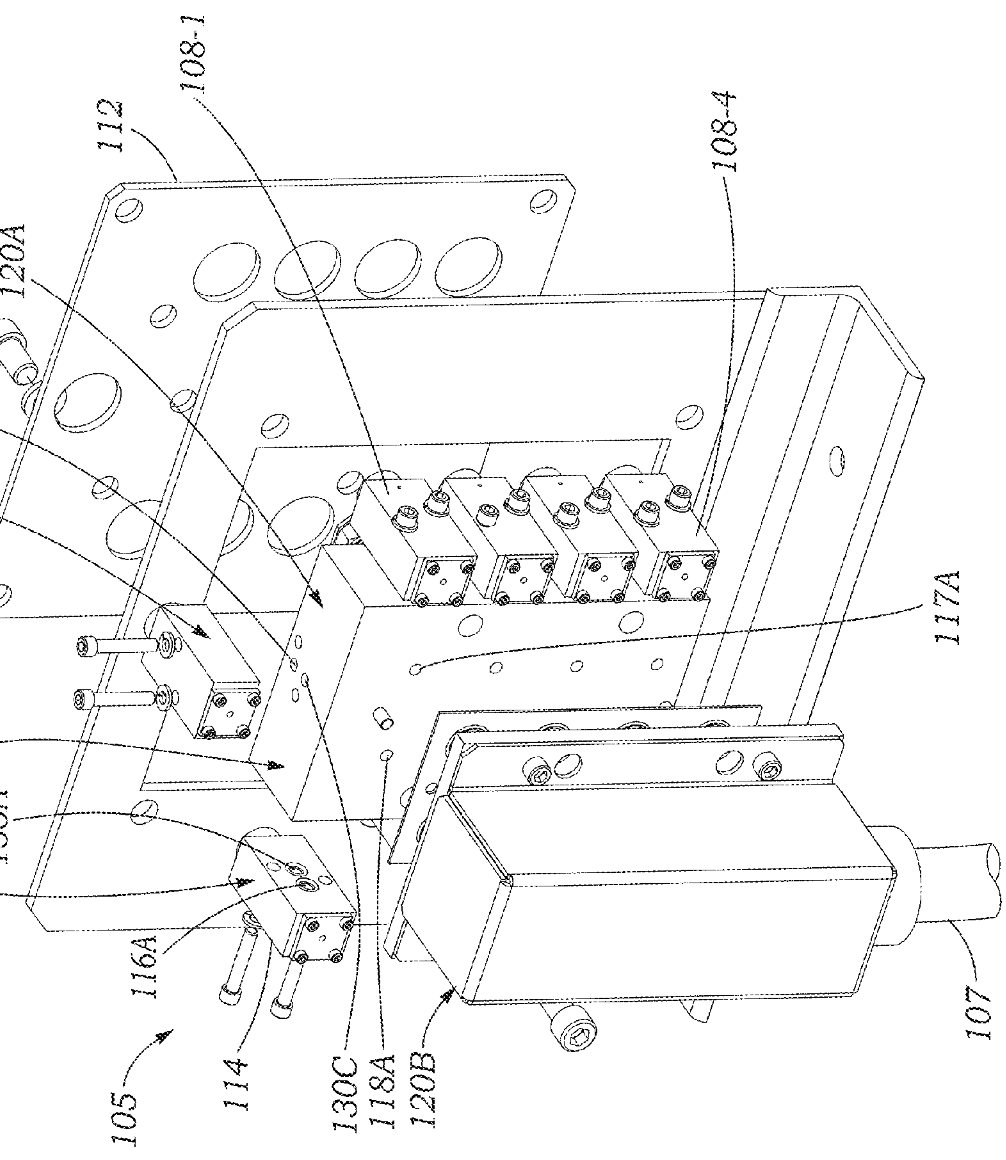
112
129
132-1
113-1
120A
133-1
116-1
133-1
128
109-4
109-1
111-1
108-1
108-4
OPEN
MASTER VALVE
CLOSE
130-1
117-B
119
120B
121A
131-1
118-B
107
121,
122

Fig. 10B



Air Remote Panel, 8-Station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108-4
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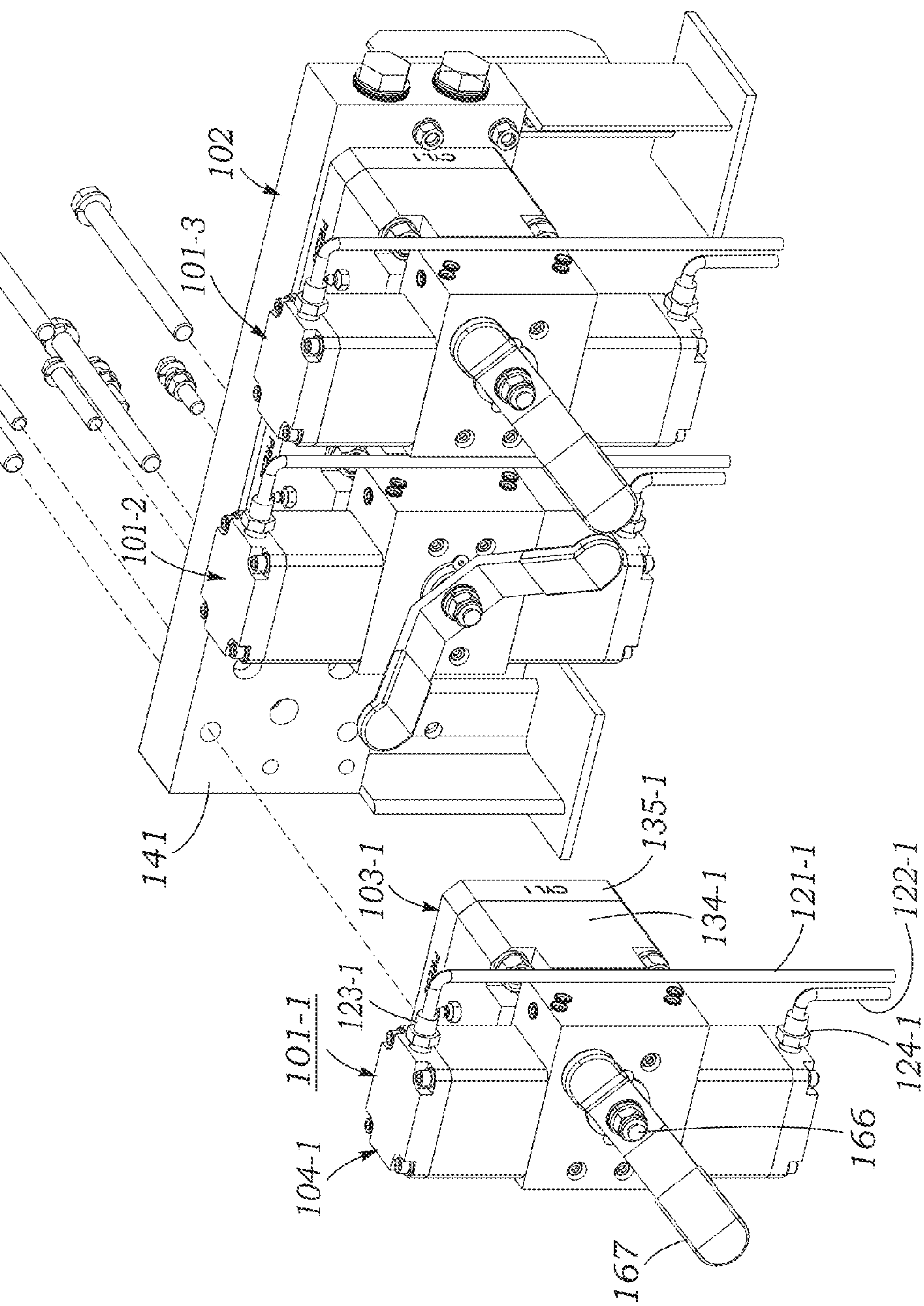
105
114
130C
118A
120B
107
117A

Fig. 10C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101-3
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134-1
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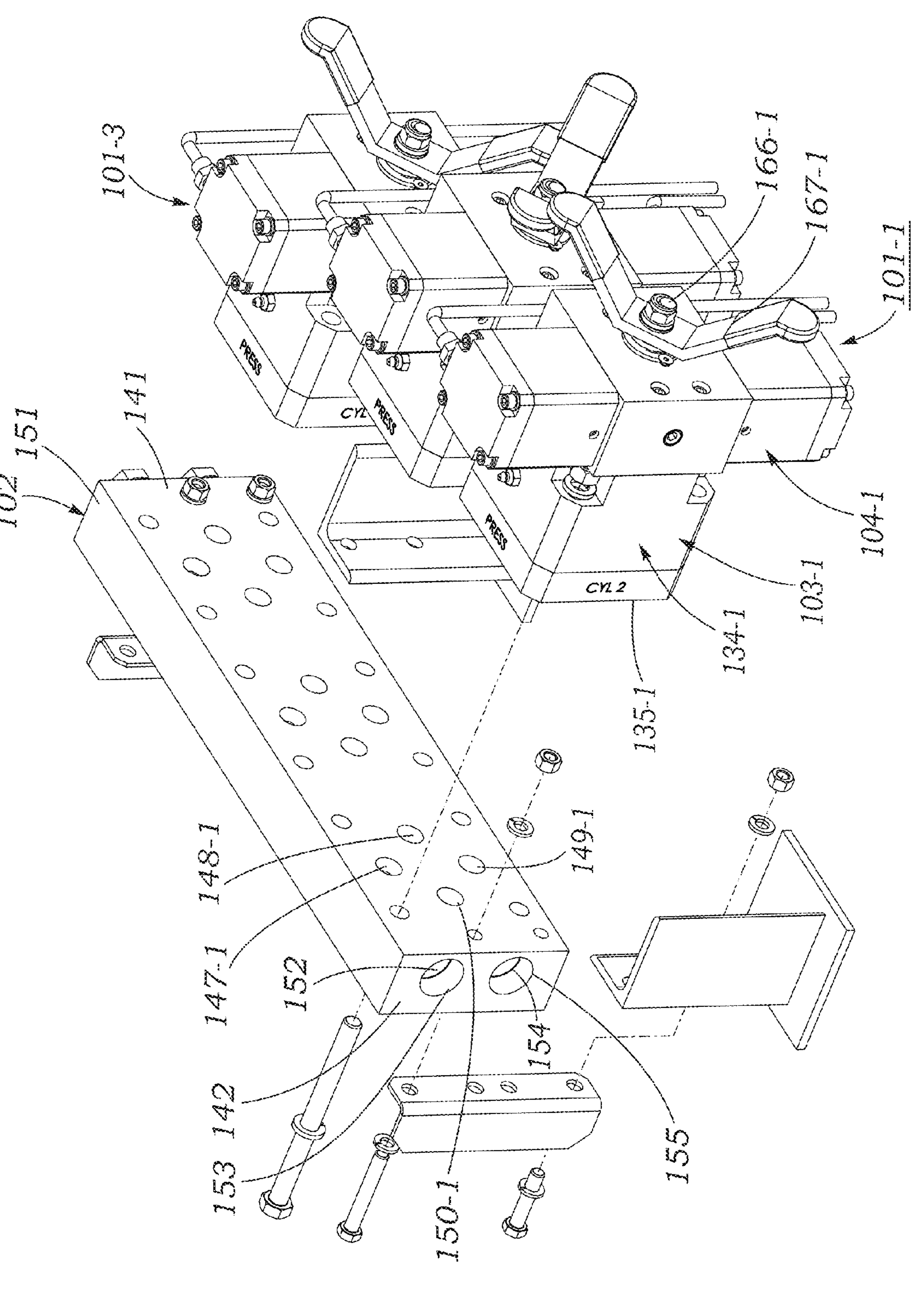
101-1
123-1
124-1
104-1
166
167

Fig. 11A



101-3
166-1
167-1
101-1
102
151
141
PRESS
PRESS
PRESS
CYL
CYL 2
104-1
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149-1
147-1
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153
150-1
155

Fig. 11B

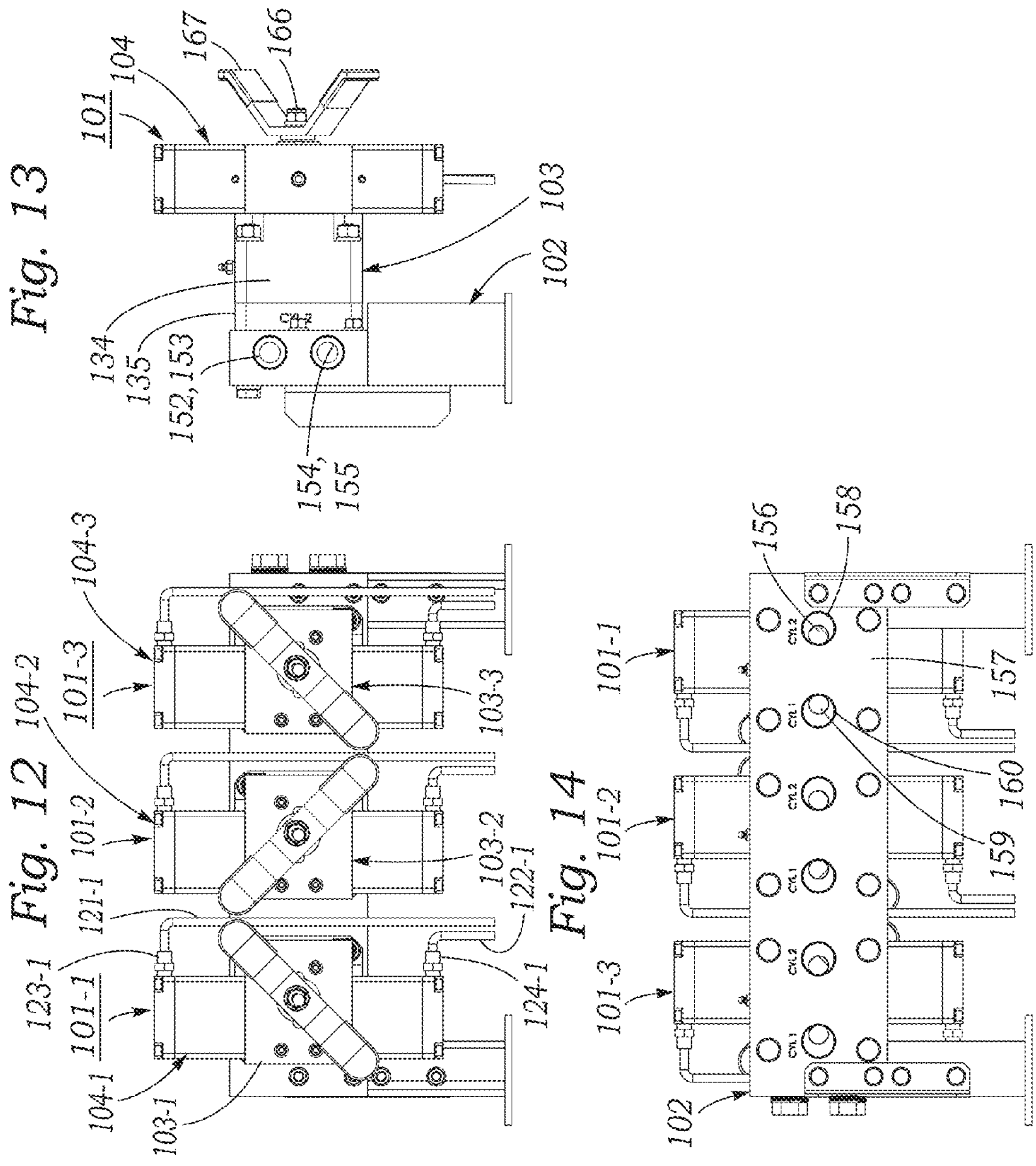


Fig. 12

Fig. 13

Fig. 14

Fig. 15A

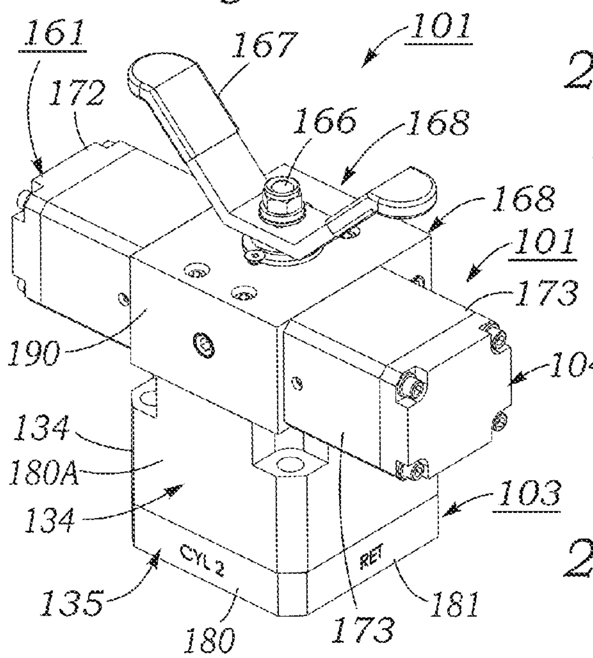


Fig. 16

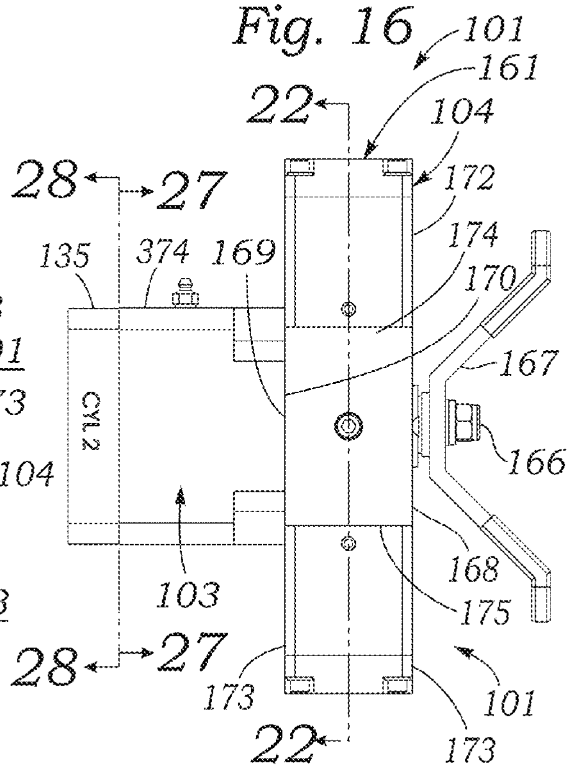


Fig. 17

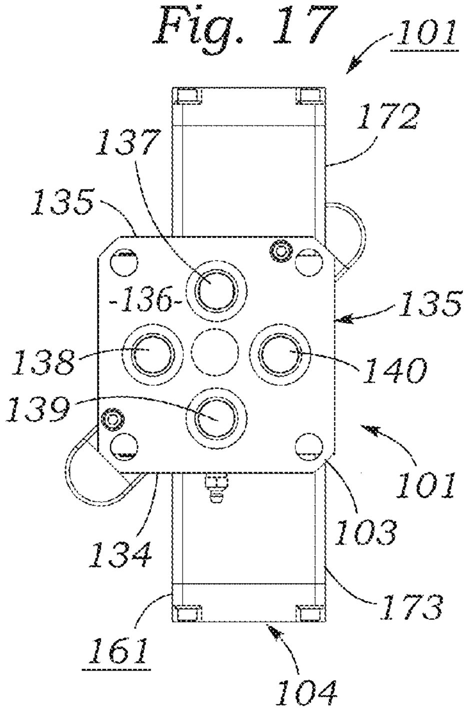
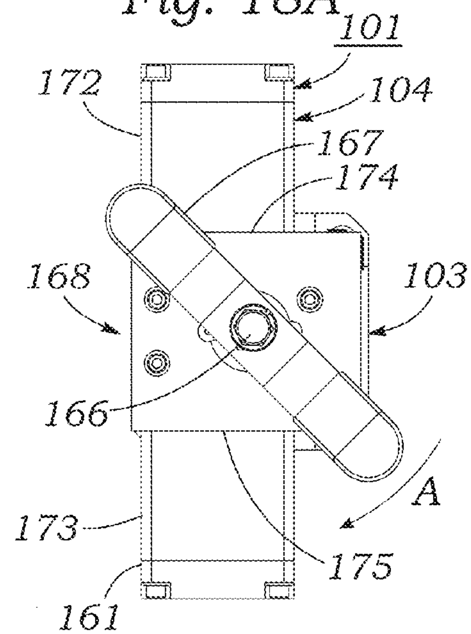
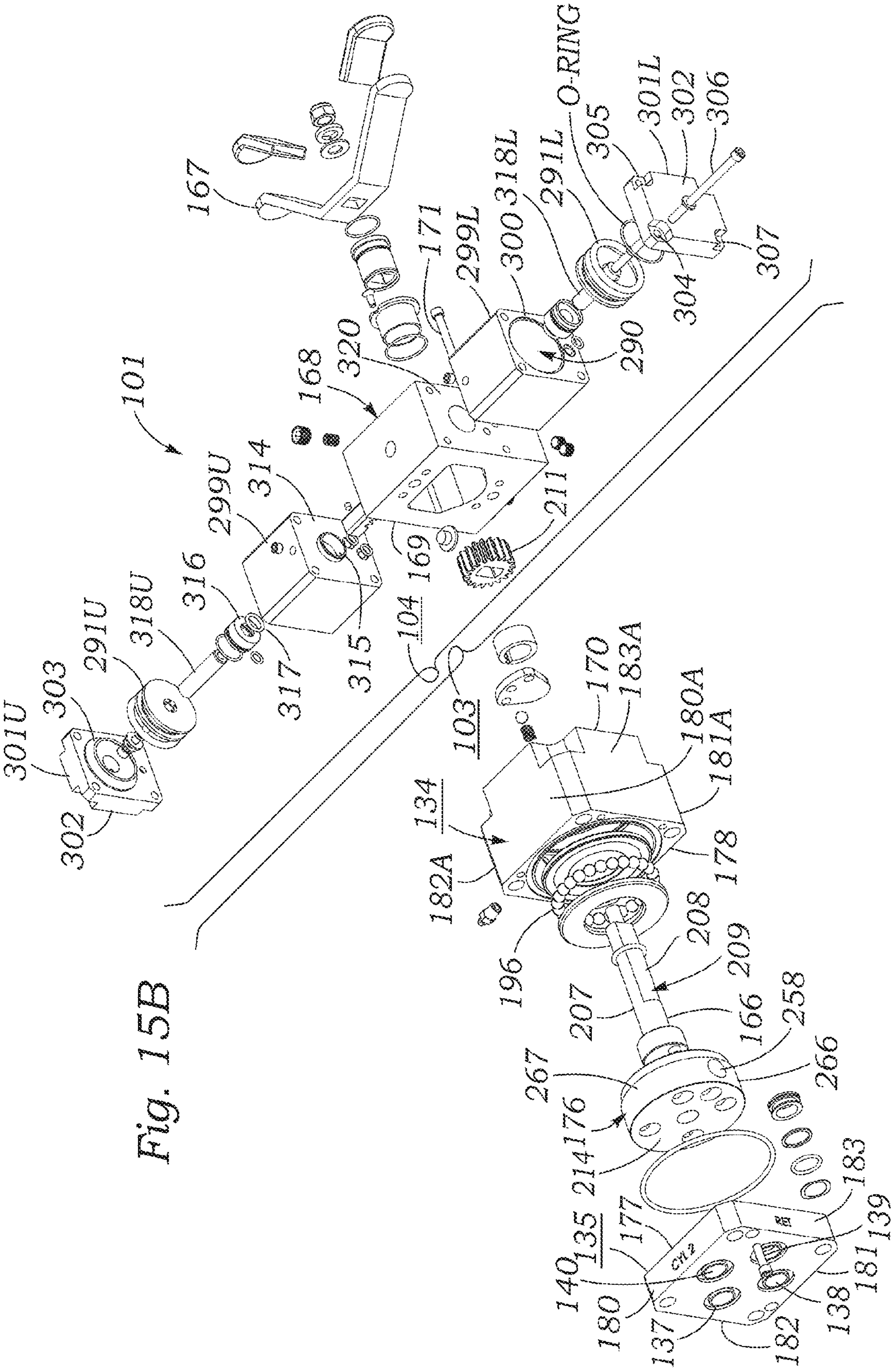


Fig. 18A

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211
169
316
318U
291U
303
301U
302
317
315
104
103
170
183A
180A
181A
134
182A
178
196
208
209
207
166
258
266
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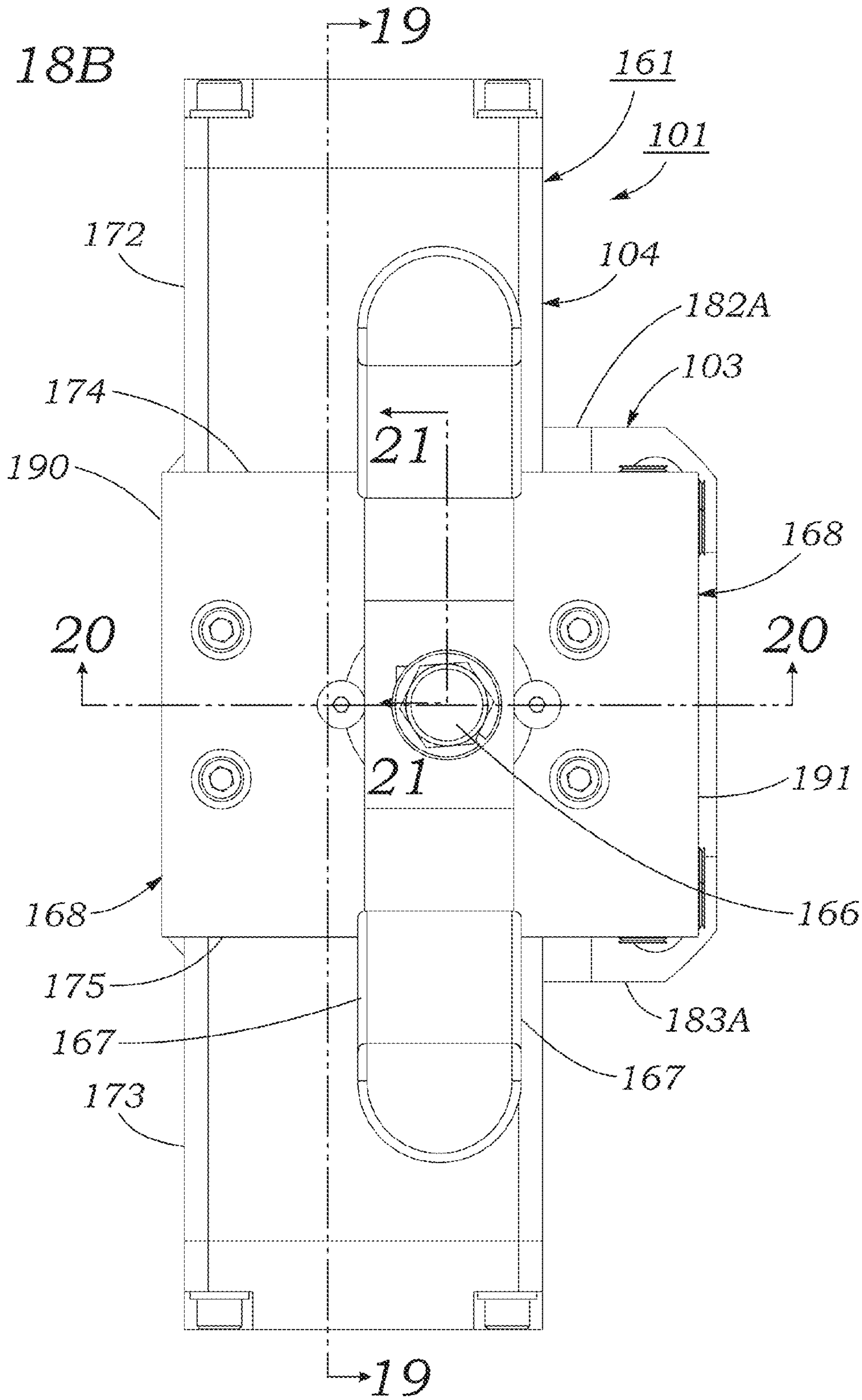
182
138
181
139
183
CYL 2
Fig. 15B

Fig. 18B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183A
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167
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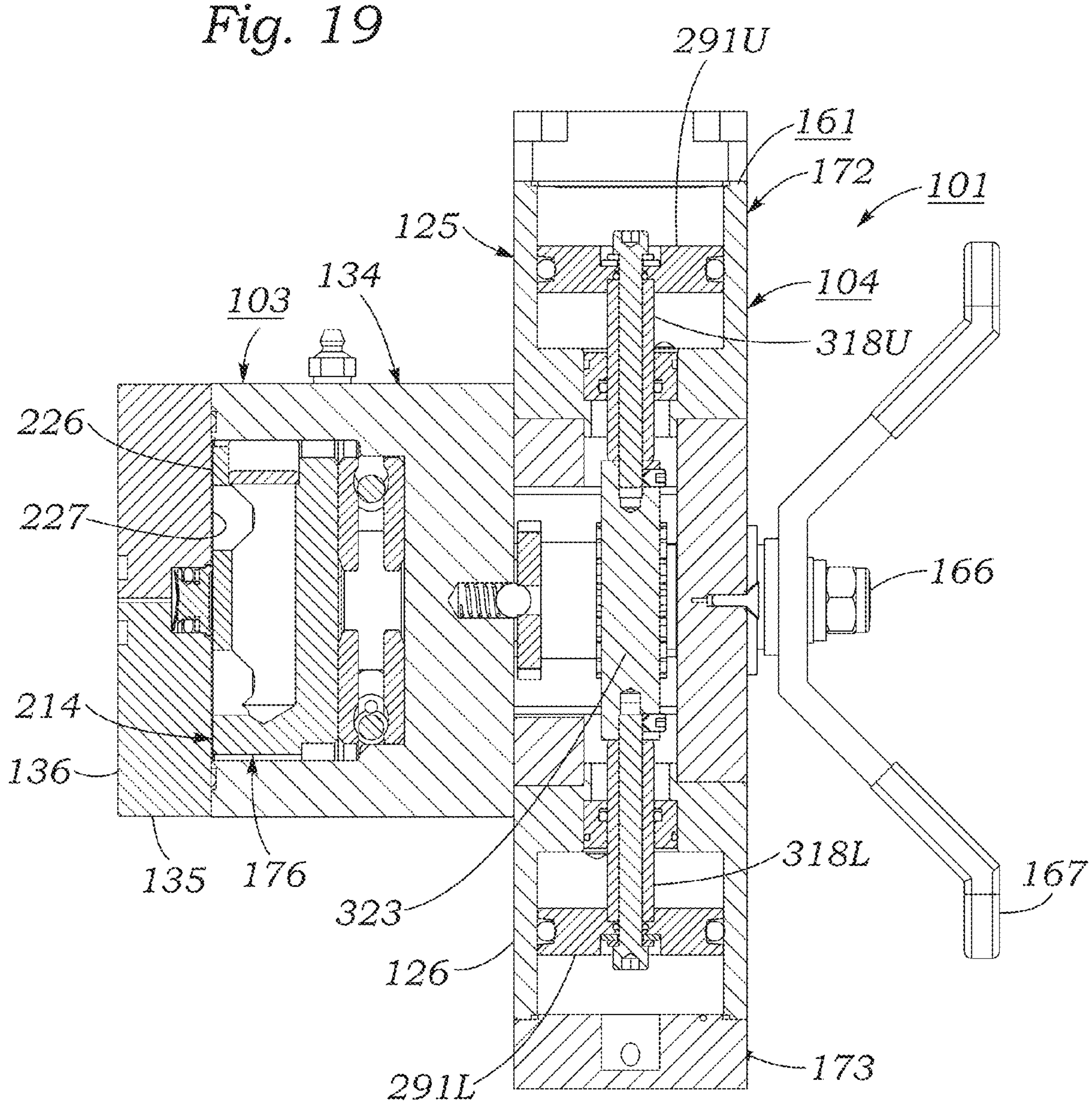
19

Fig. 19



291U
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291L

Fig. 20

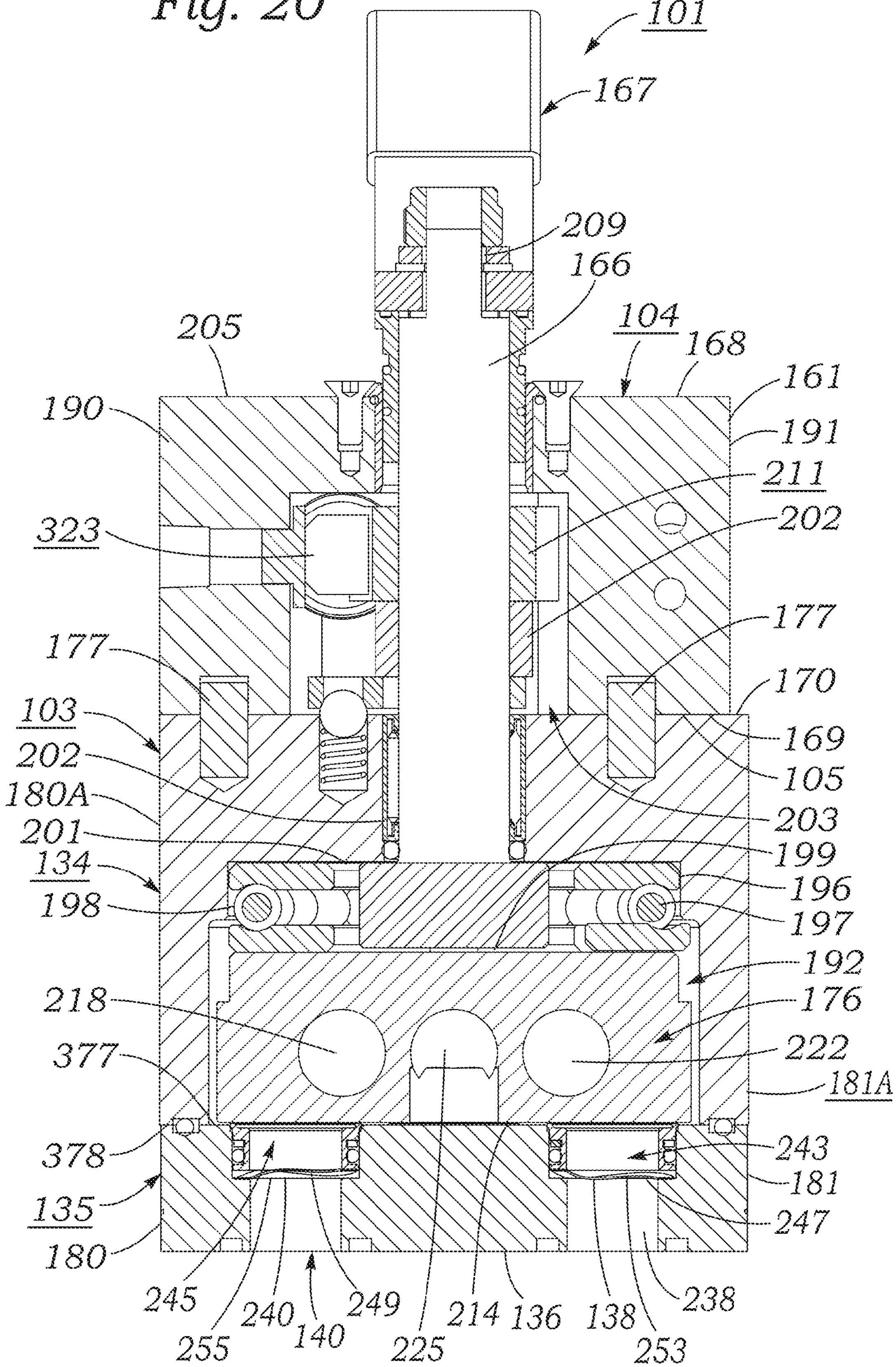

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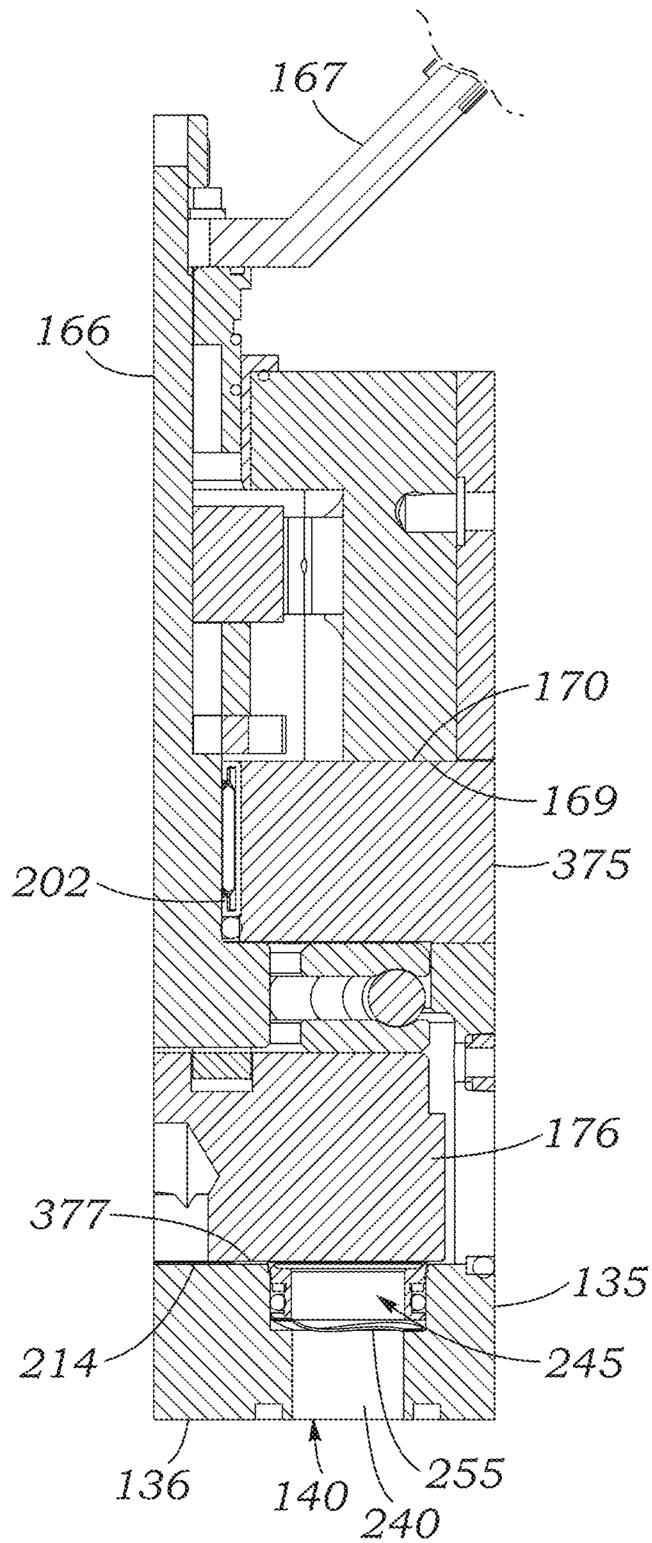
Fig. 21



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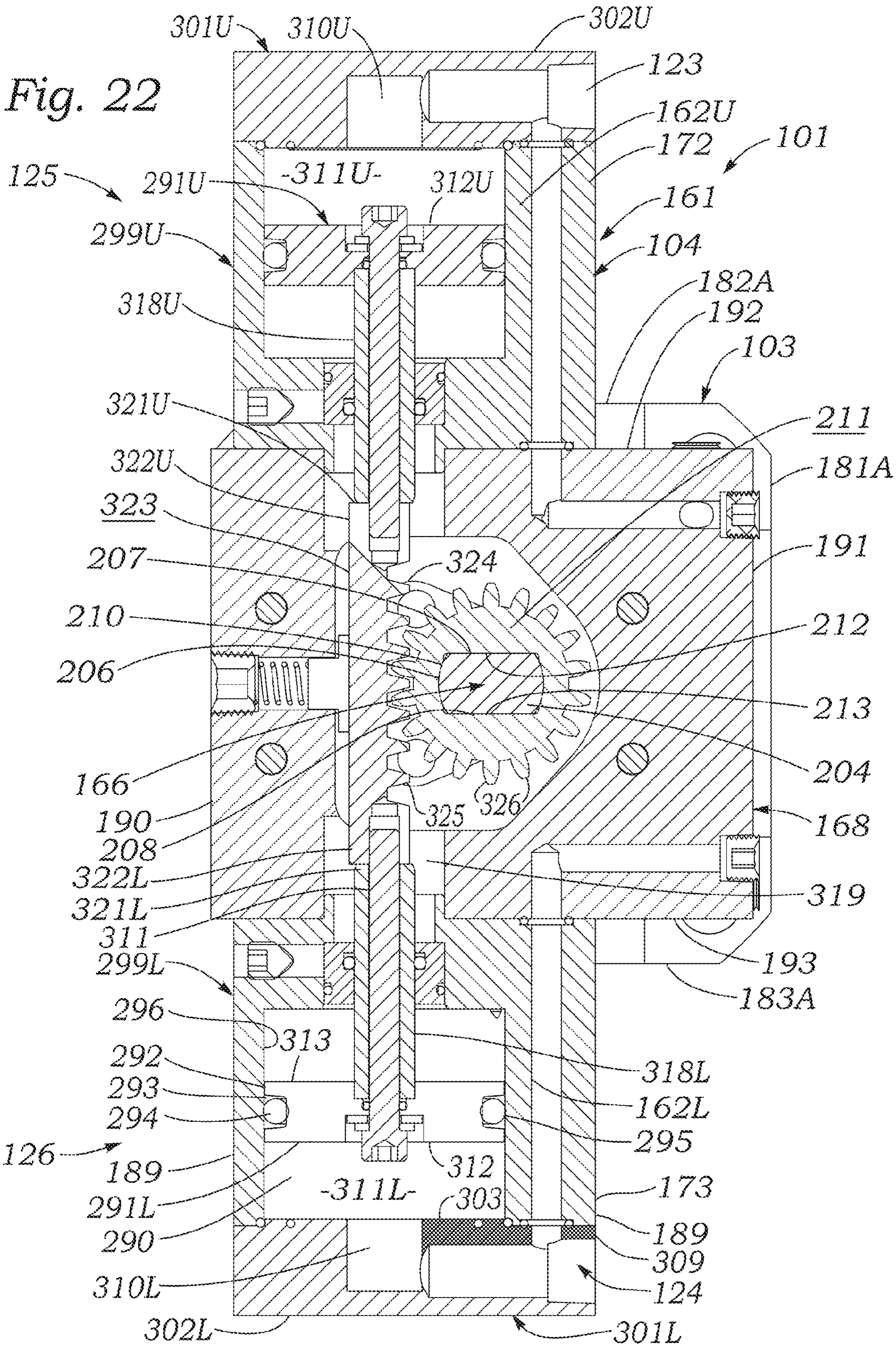
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321U
211
322U
181A
323
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324
191
210
212
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213
166
204
190
325
326
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208
322L
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321L
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193
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Fig. 23

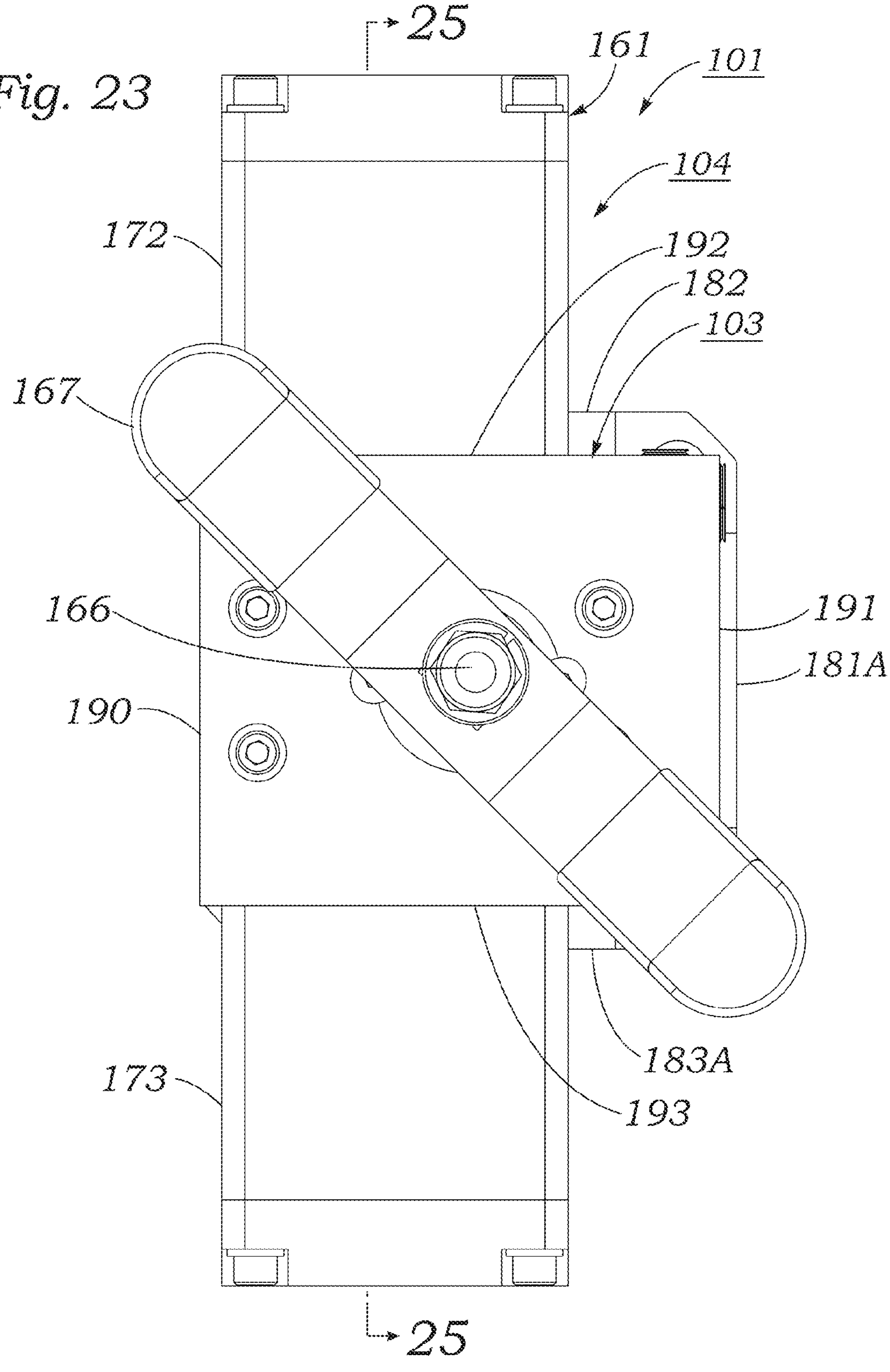

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Fig. 24

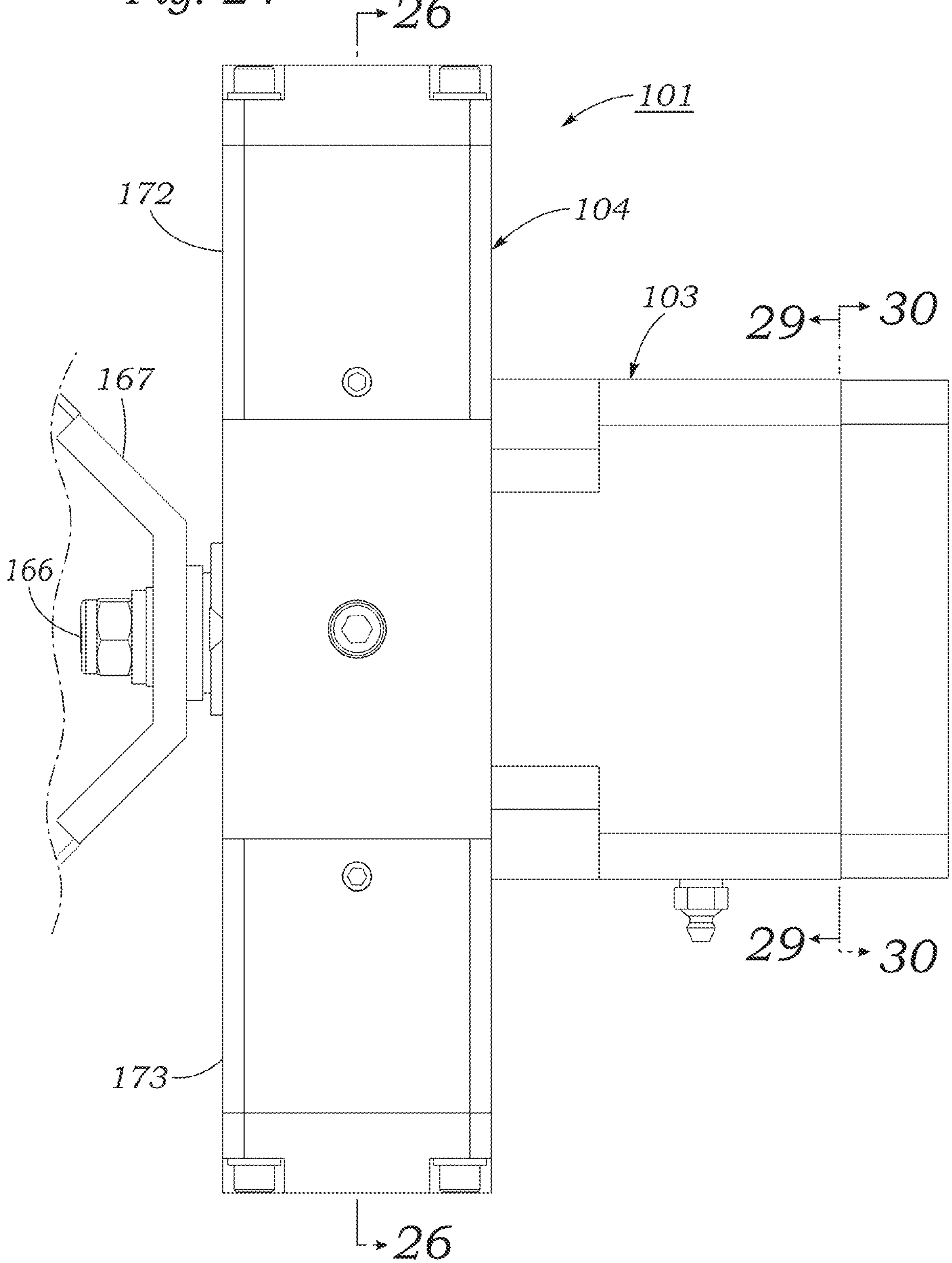
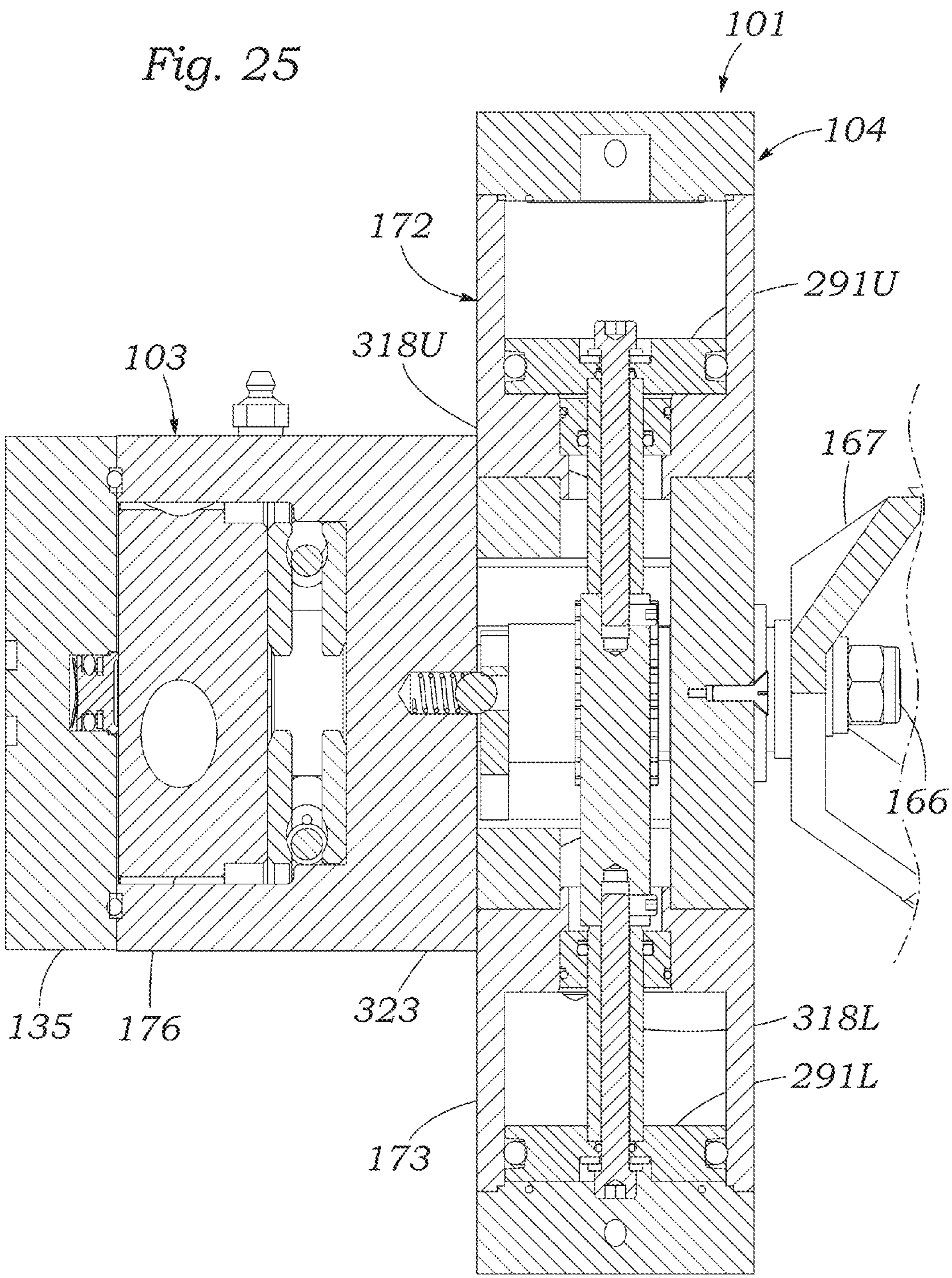


Fig. 25



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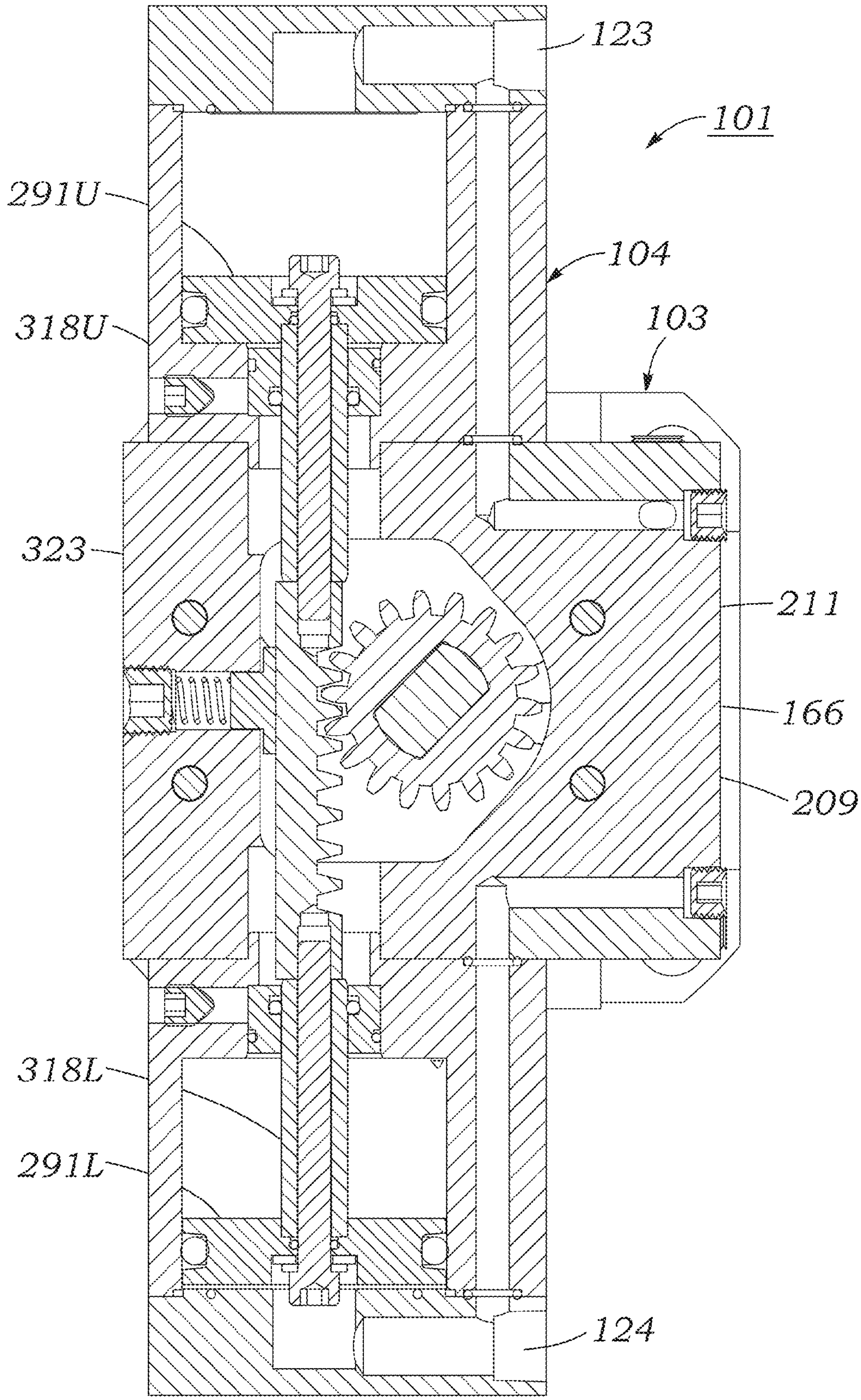

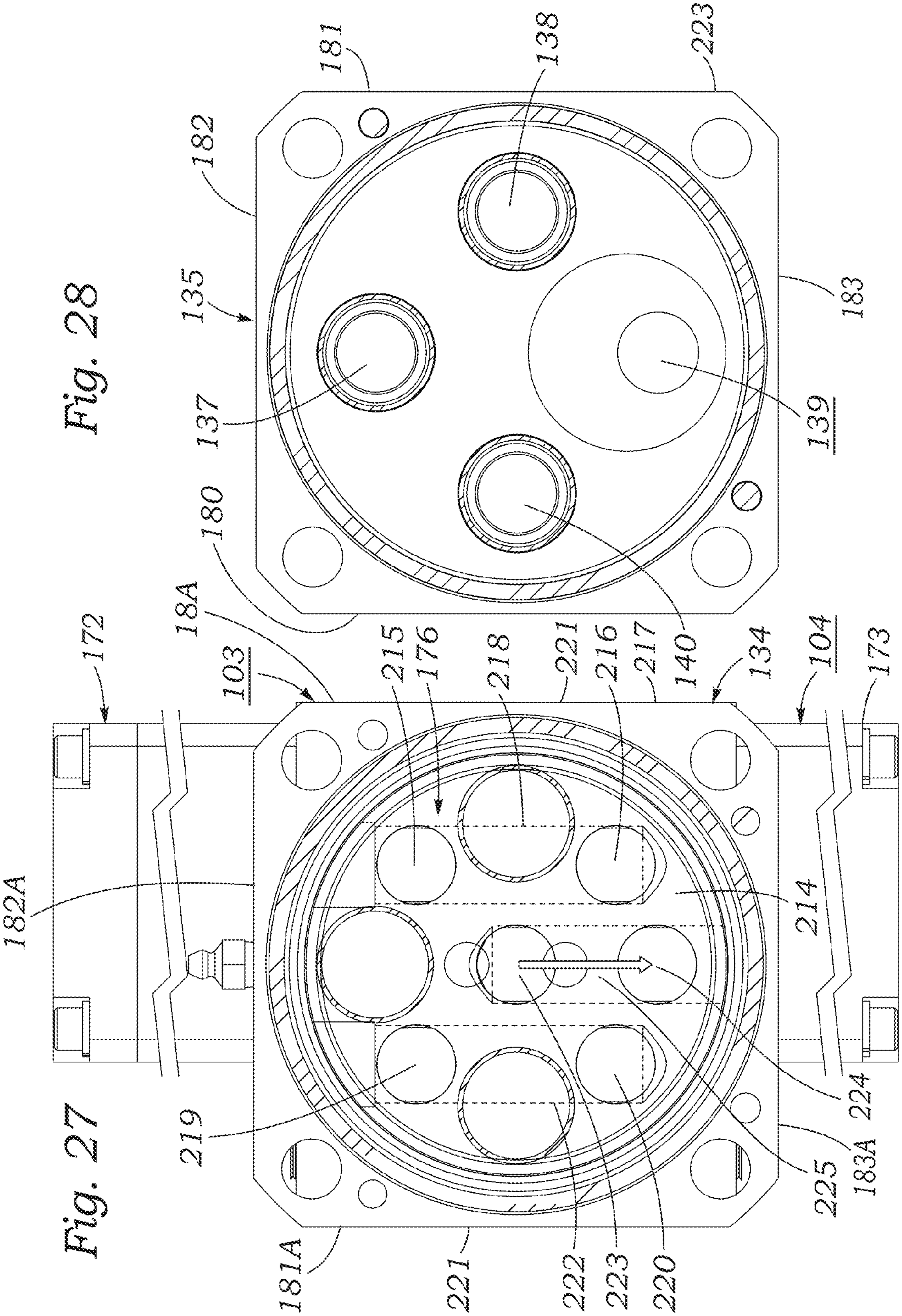
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183A
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181A
221
222
223
220

Fig. 28

Fig. 27

Fig. 30

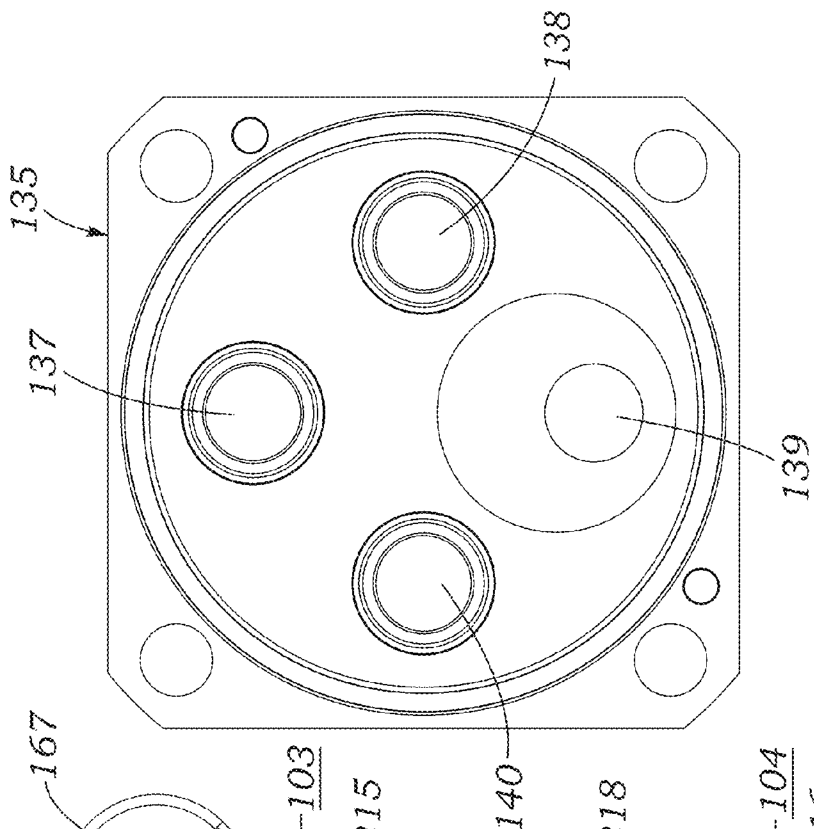
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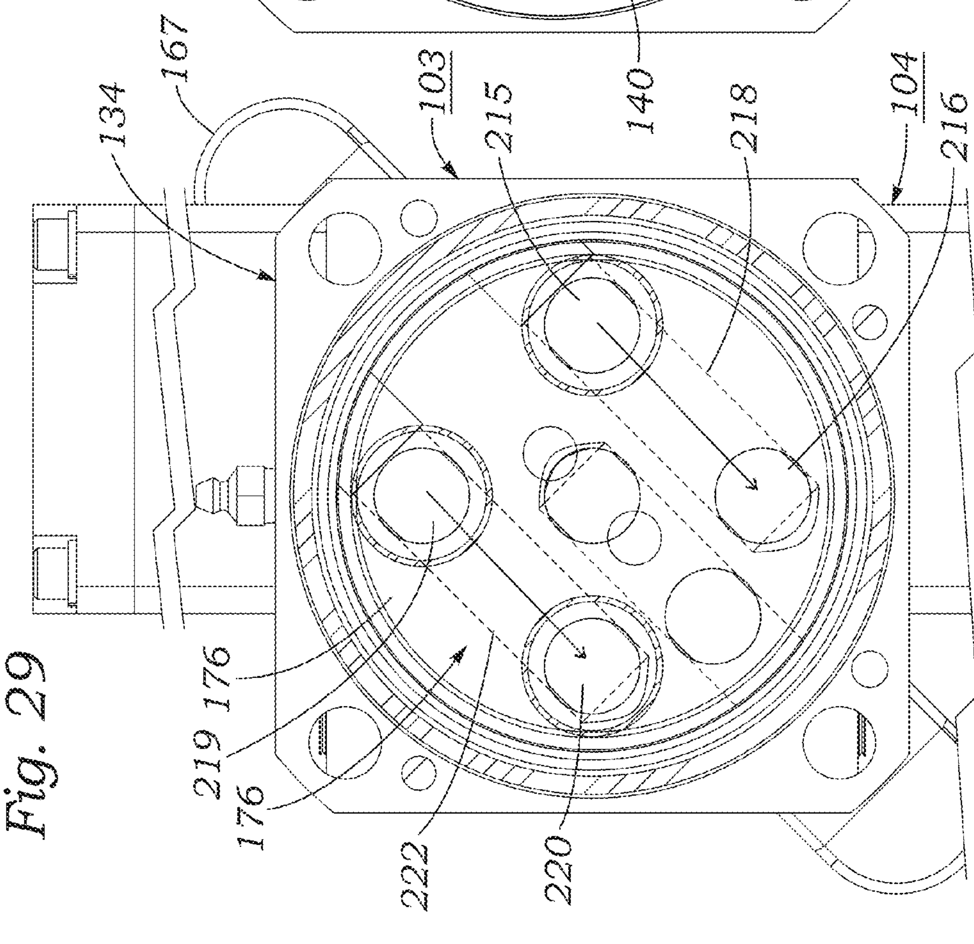
Fig. 29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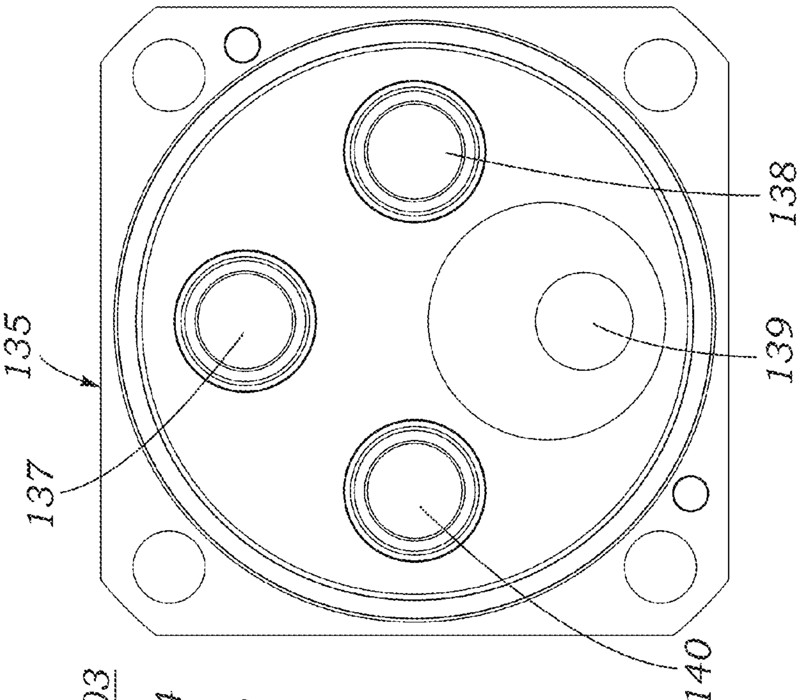

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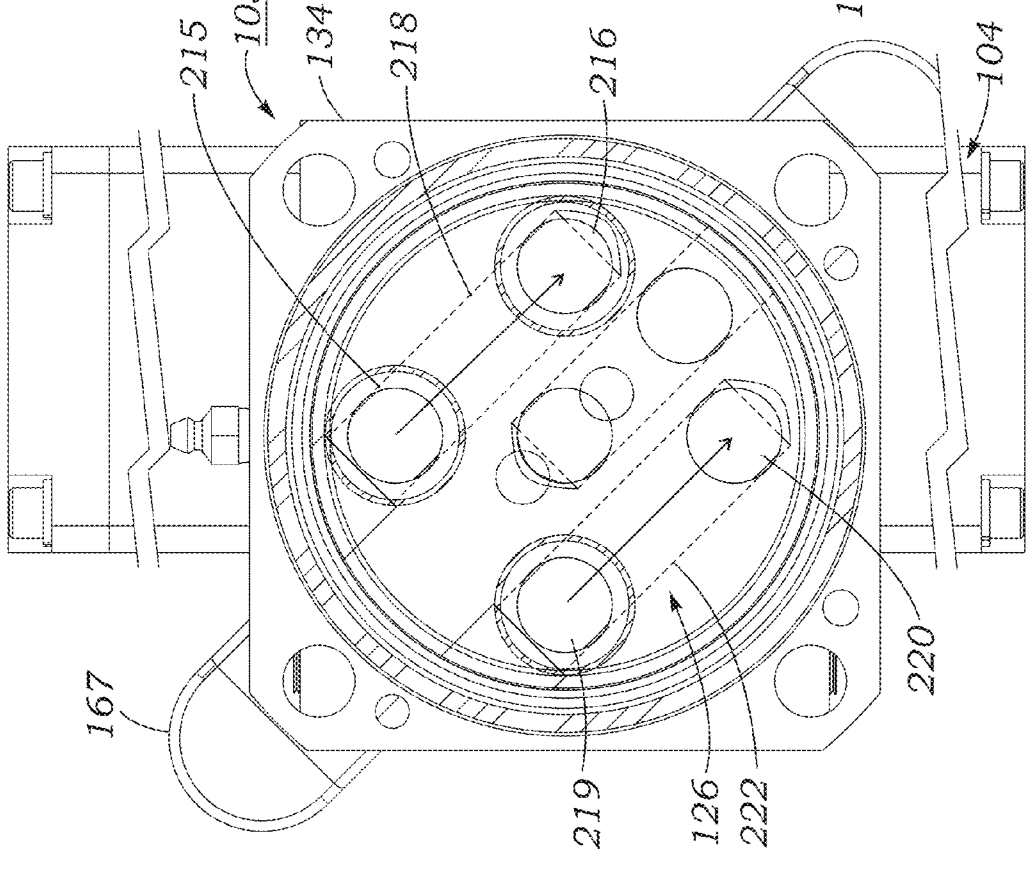
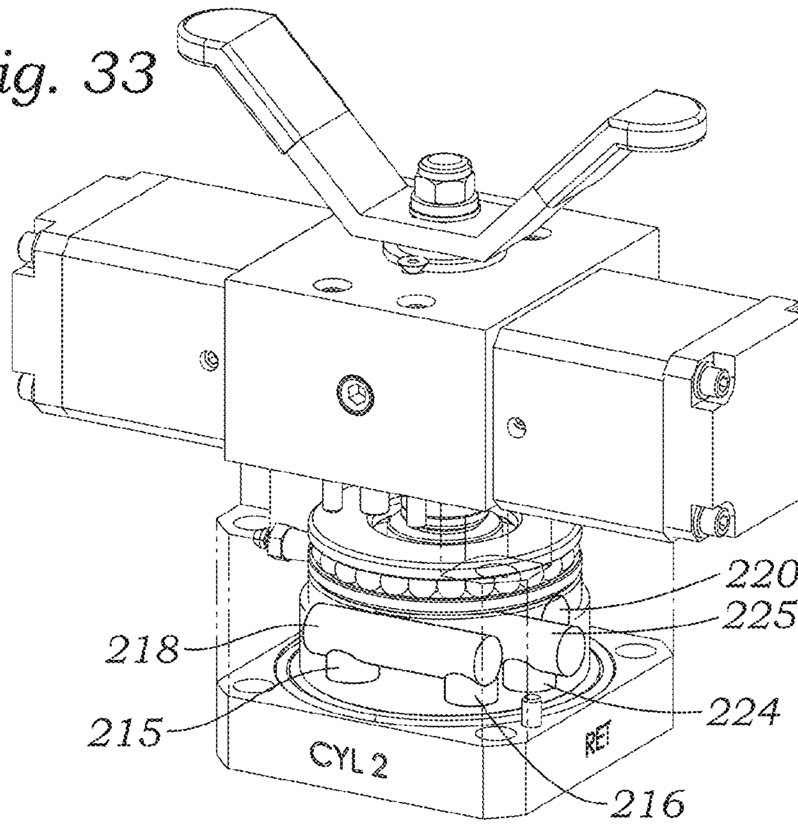


Fig. 31

Fig. 33



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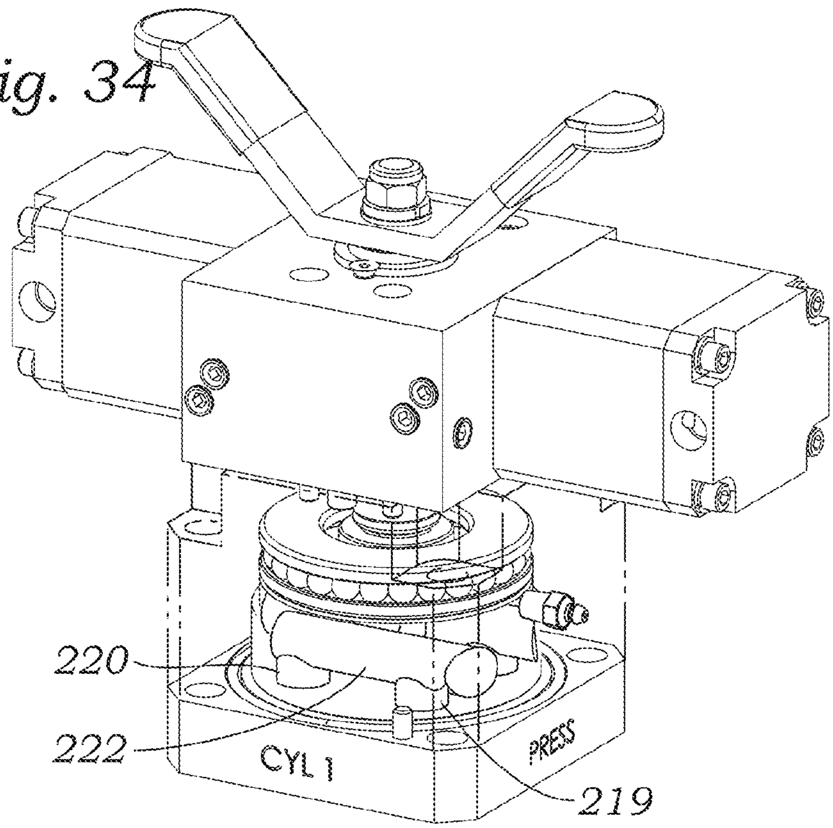

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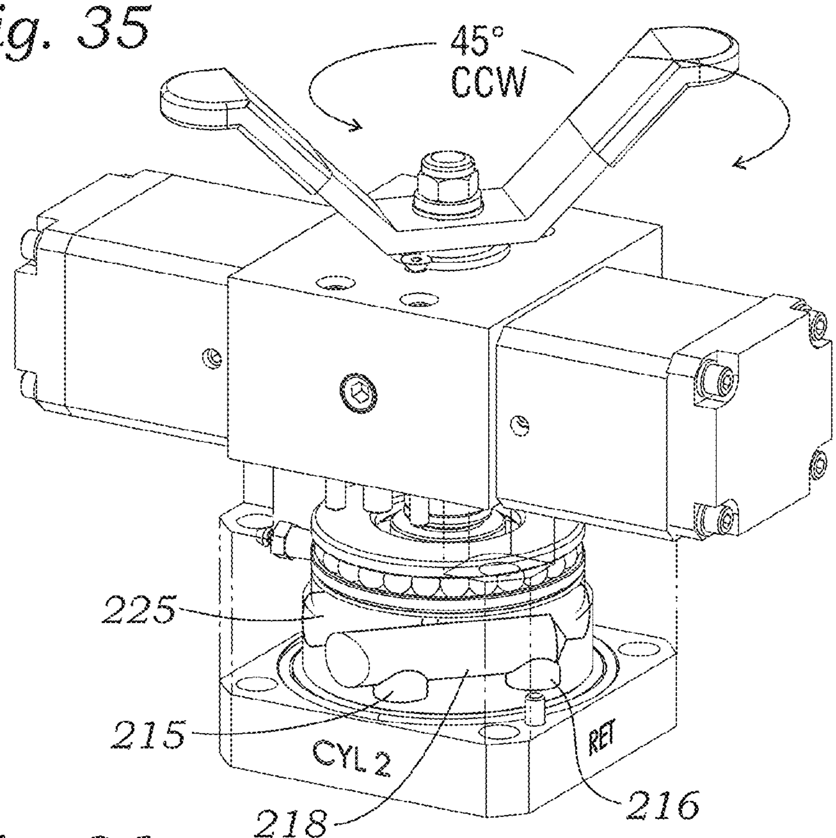
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225
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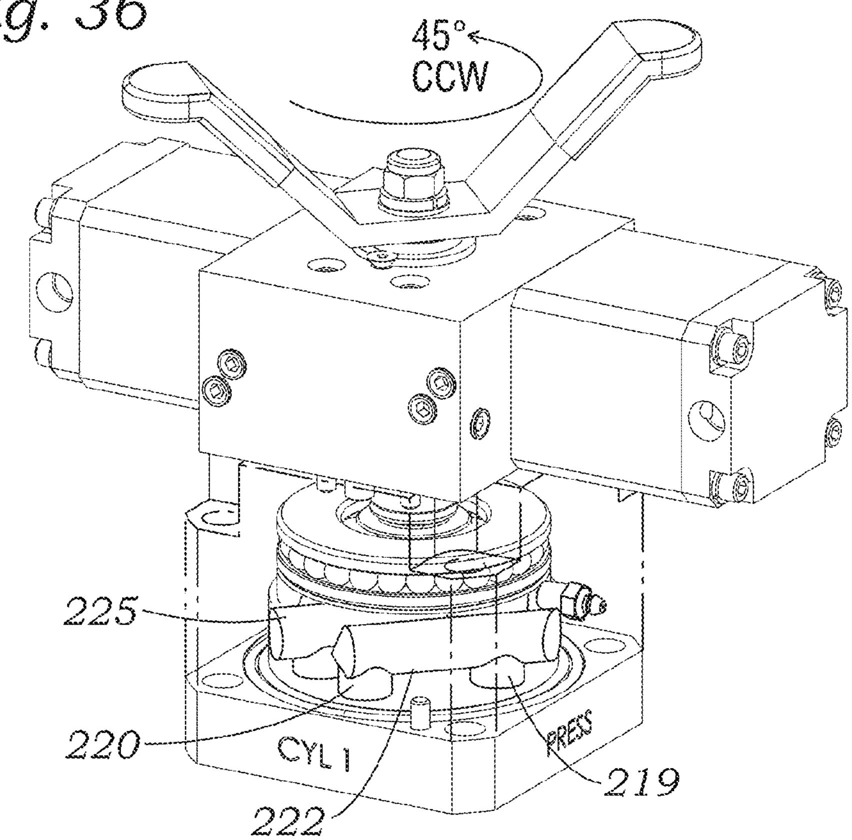
CYL 2
RET
218
216

Fig. 36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225
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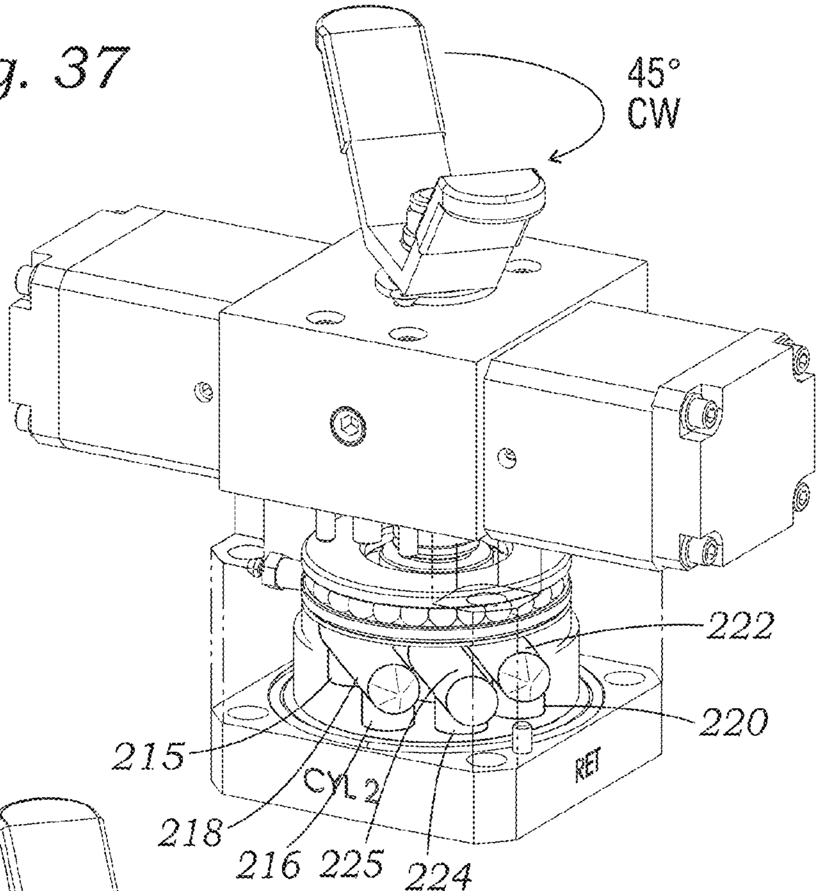
CYL 1
PRESS
222
219

Fig. 37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CYL 2
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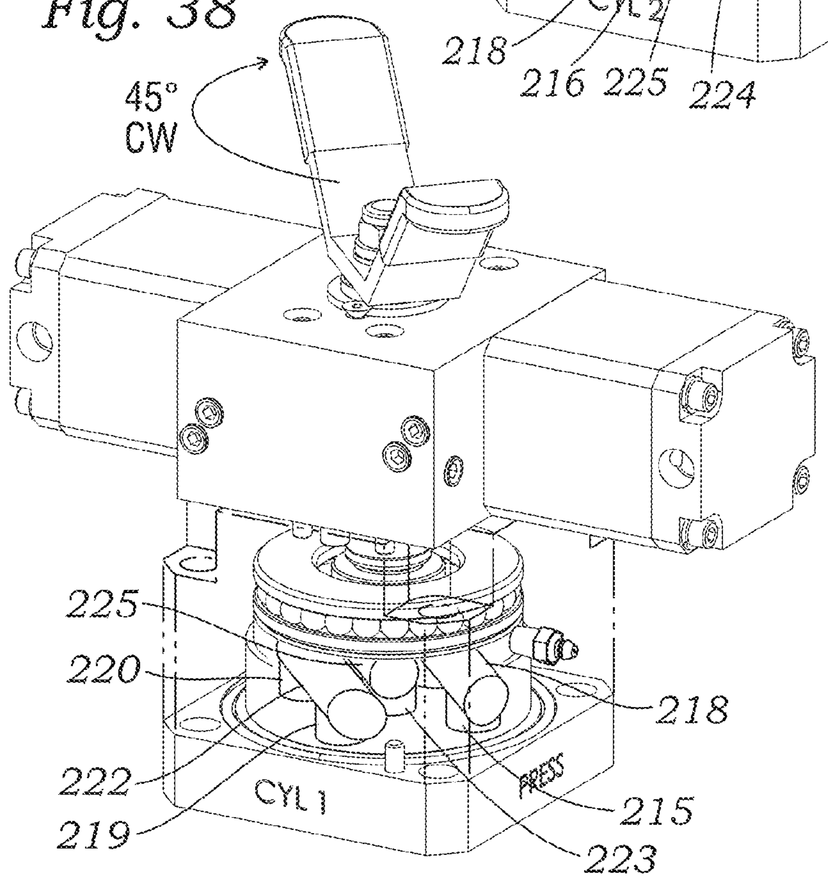
224

Fig. 38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218
222
CYL 1
PRESS
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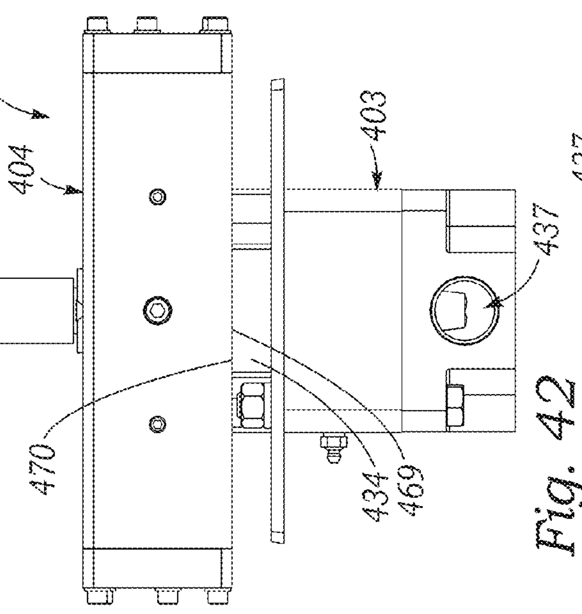
219
223



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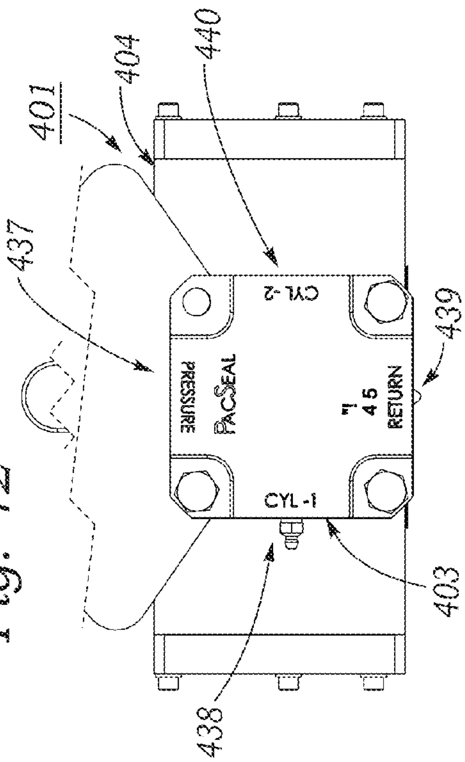

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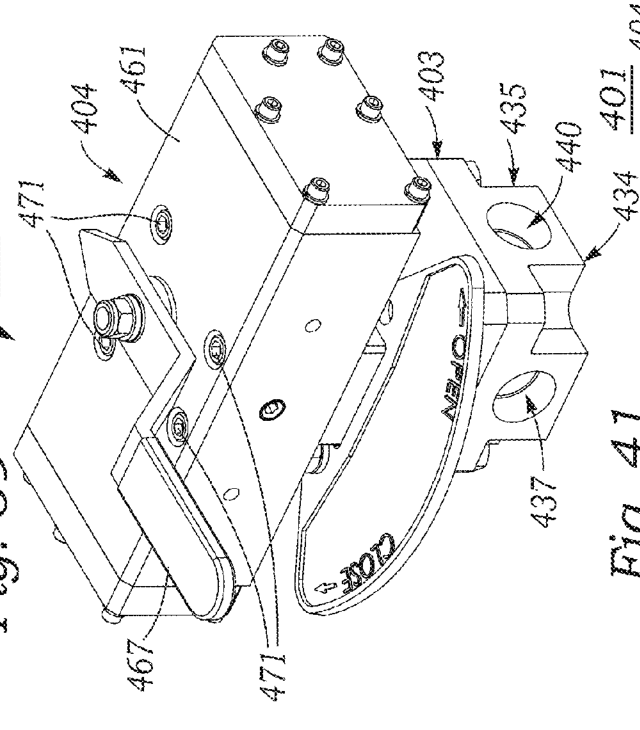

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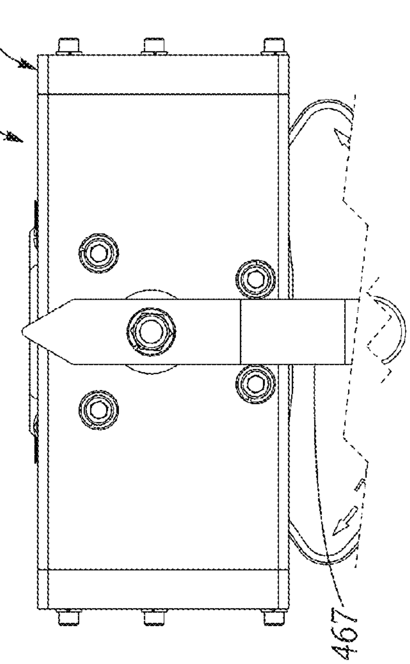
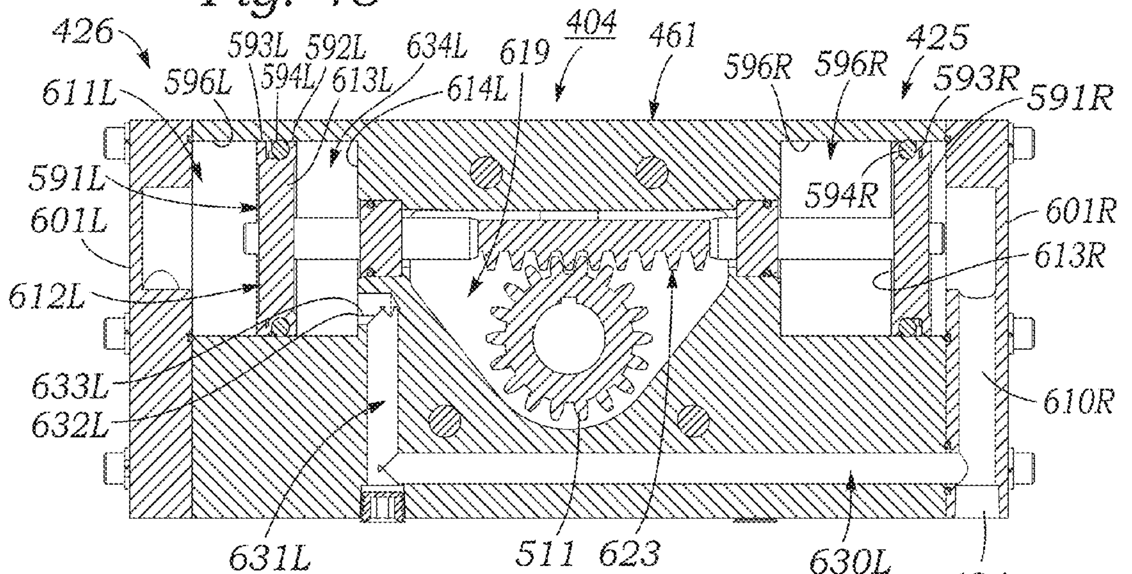


Fig. 41

Fig. 45



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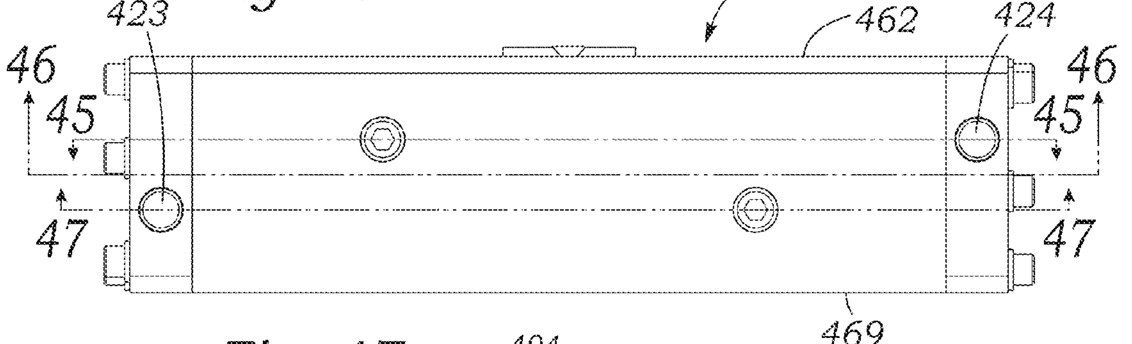

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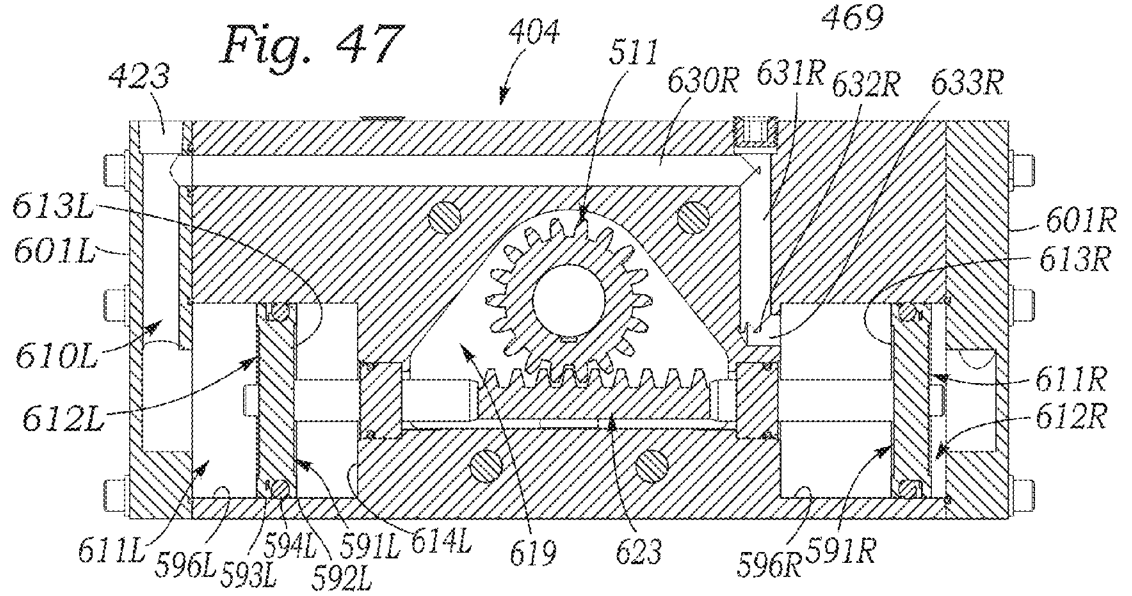

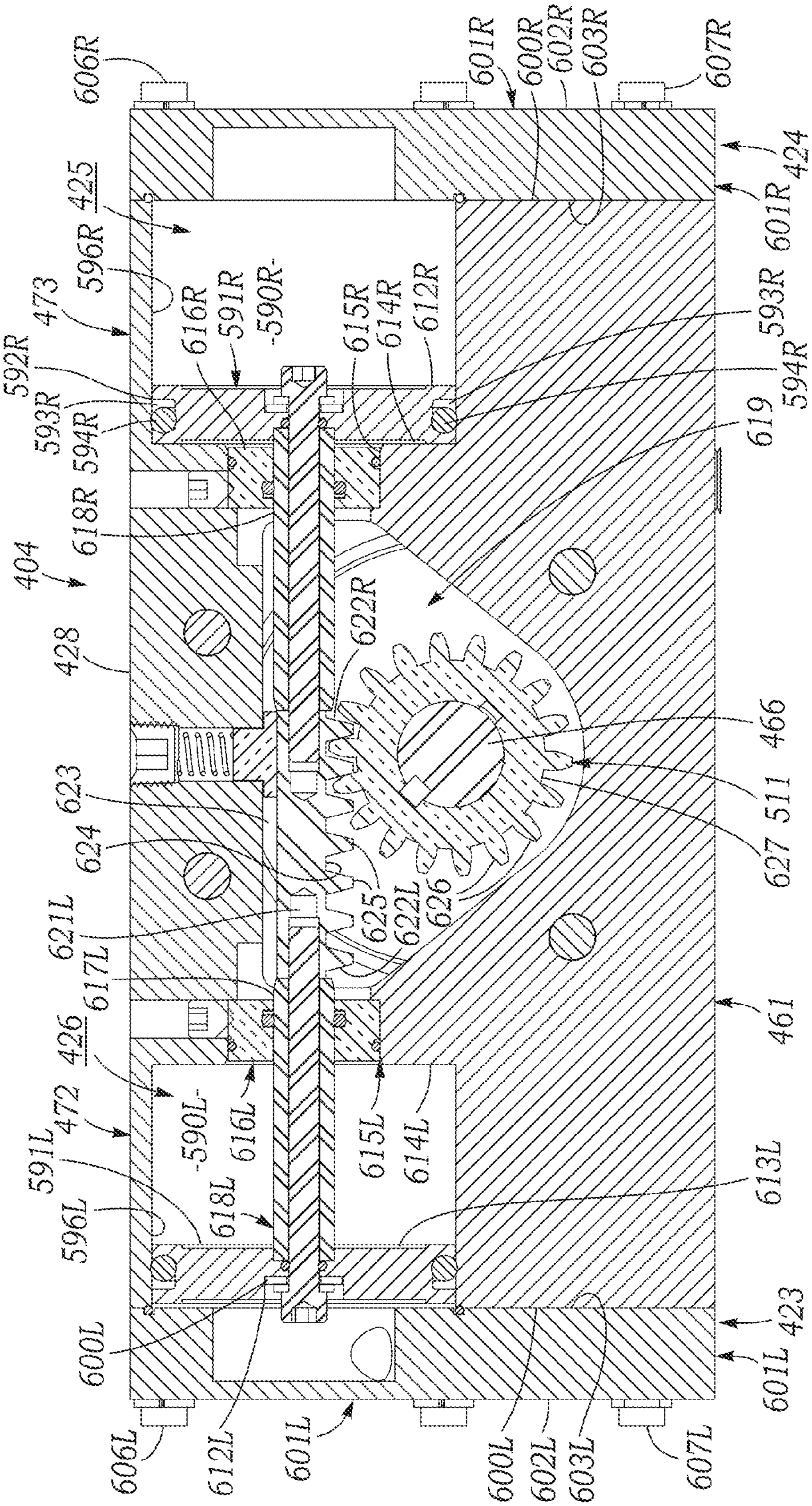
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607R
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593R
594R
619
618R
404
622R
428
466
623
511
627
624
625
622L
626
621L
617L
461
426
472
591L
590L
616L
615L
614L
613L
596L
618L
600L
423
601L
606L
612L
601L
600L
602L
603L
607L
601L

Fig. 46

Fig. 49

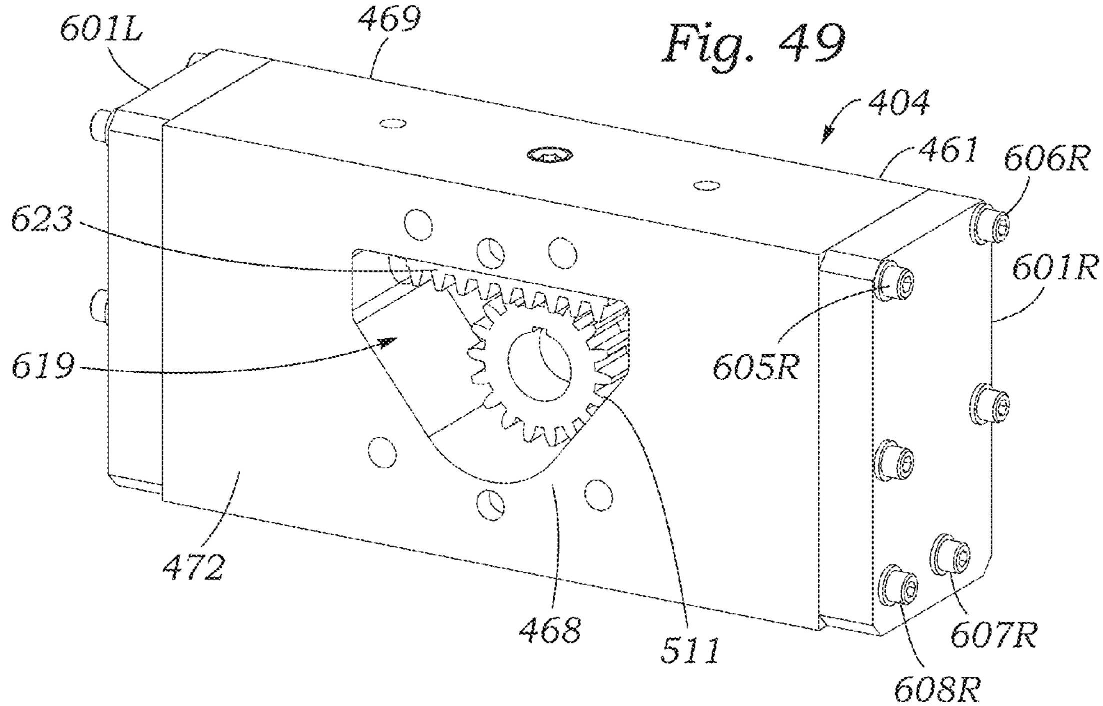

601L
469
404
461
606R
623
601R
619
605R
472
468
511
607R
608R

Fig. 44

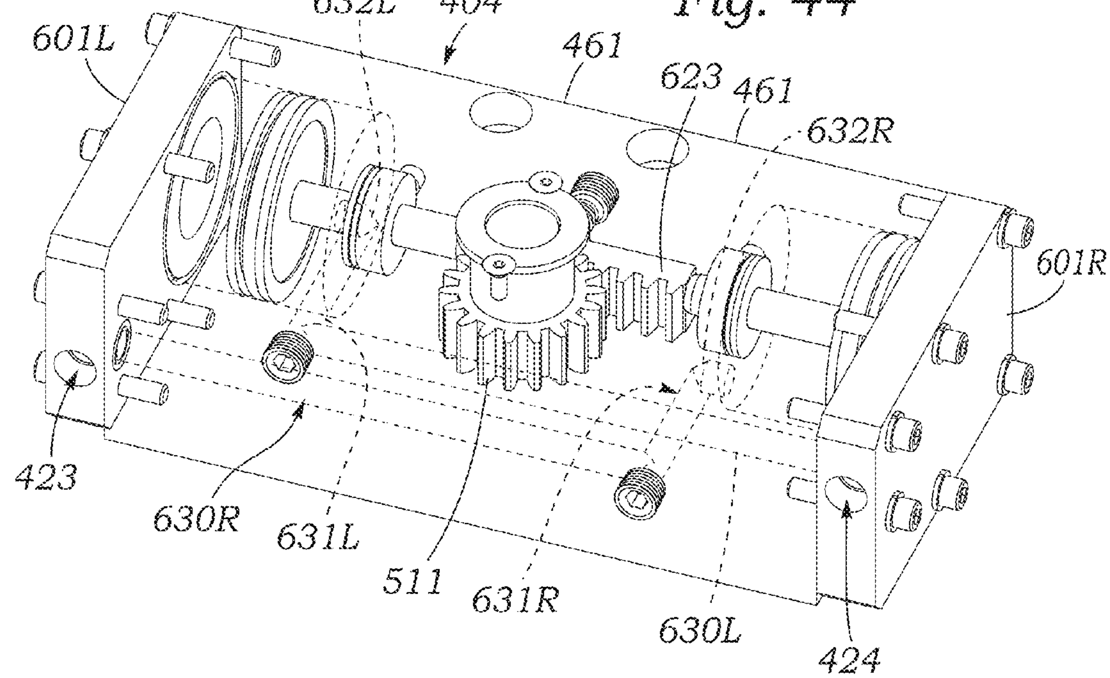
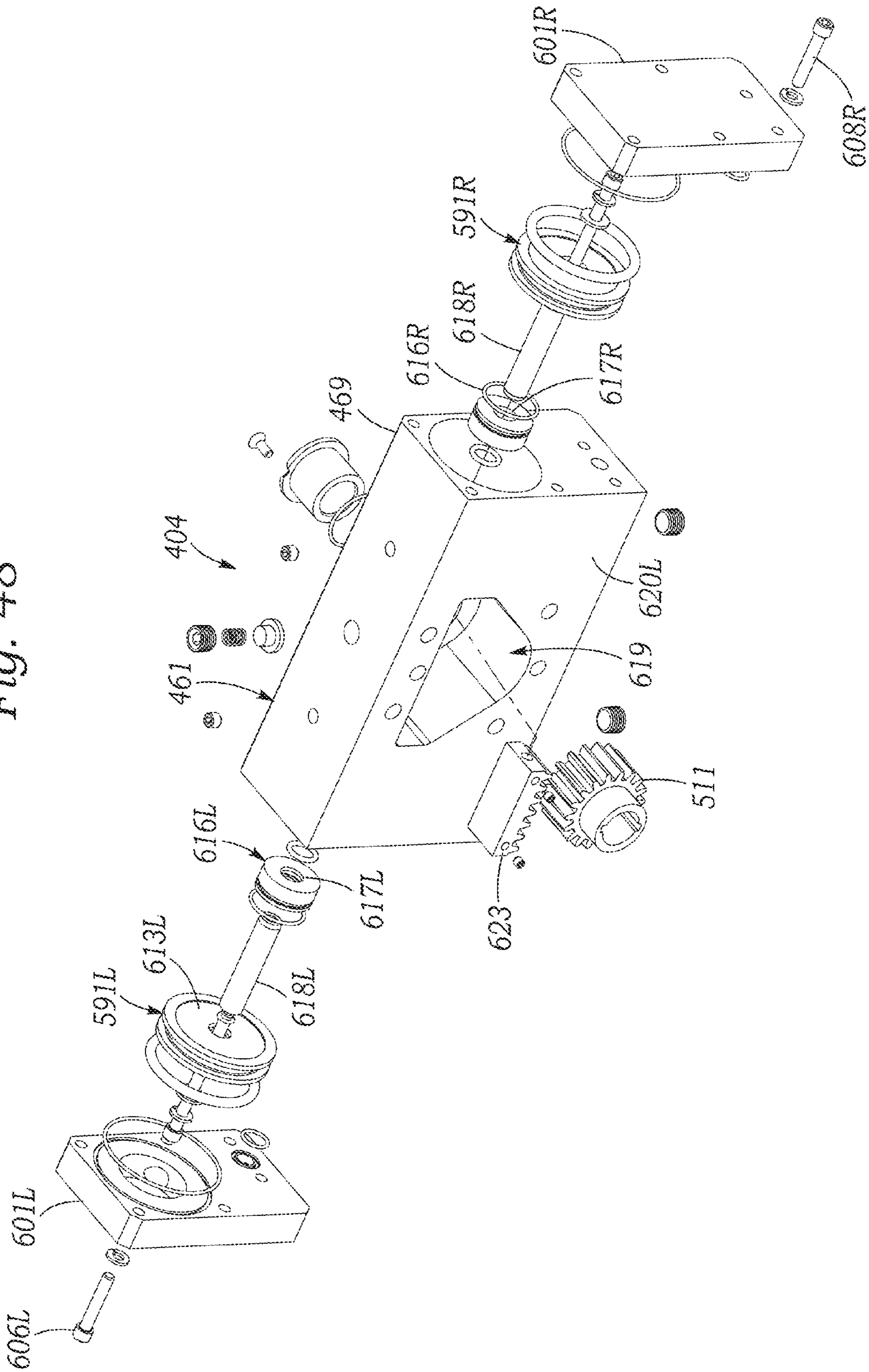

632L
404
601L
461
623
461
632R
601R
423
630R
631L
511
631R
630L
424

Fig. 48


601R
608R
591R
618R
616R
617R
469
404
461
620L
619
511
616L
617L
623
613L
591L
618L
601L
606L

MODULAR ACTUATOR AND HYDRAULIC VALVE ASSEMBLIES AND CONTROL APPARATUS FOR OIL WELL BLOW-OUT PREVENTERS

BACKGROUND OF THE INVENTION

A. Field of the Invention

The present invention relates to apparatus for use in the drilling and operation of wells, particularly oil wells and geothermal wells. More particularly, the invention relates to novel modular actuator and hydraulic assemblies and a novel control apparatus for use with existing oil well blow-out preventers of the type used to prevent pressurized subterranean liquids or gases from blowing out and upwards through a well hole

B. Description of Background Art

In drilling for natural gas or liquid petroleum, a drill string consisting of many lengths of threaded pipes screwed together and tipped with a drill bit head is used to bore through rock and soil. The drill bit head has a larger diameter than the pipes forming the drill string above it. A rotary engine coupled to the upper end of the drill string transmits a rotary boring action to the drill bit head.

During the drilling operation, a specially formulated mud is introduced into an opening in an upper drill pipe. This mud, which typically is selected to have a high specific gravity, flows downwards through the hollow interior of the pipes in the drill string and out through small holes or jets in the drill bit head. Since the drill bit head has a larger diameter than the drill string above it, an elongated annular space is created between the drill string pipes and the bore hole wall during the drilling process. The annular space permits the mud to flow upwards to the surface. Mud flowing upwards carries drill cuttings, primarily rock chips, to the surface. The mud also lubricates the rotating drill string, and provides a downward hydrostatic pressure which counteracts pressure which might be encountered in subsurface gas pockets. A steel tubular well casing is inserted into the bore hole when the drilling operation has been completed.

In normal oil well drilling operations, it is not uncommon to encounter subsurface gas pockets whose pressure is much greater than could be resisted by the hydrostatic pressure of the elongated annular column of drilling mud. To prevent the explosive and potentially dangerous and expensive release of gas and/or liquid under pressure upwards out through the drilling hole, Blow-Out Preventers (BOP's) are used. Blow-out preventers are usually mounted to a drill pipe or well casing near the upper end of the bore hole. The blow-out preventers are mounted to drill string components such as a drill pipe or well casing tubes, and function by shutting off upward movement of a gas, liquid or drill string components which could be forced upwardly in response to pressure encountered in an oil or gas reservoir.

Typical oil or gas well drilling or production operations utilize a vertical stack of blow-out preventers of various types. The stack usually includes an annular type of blow-out preventer which is located at the upper end of a stack, located near a well-head.

Annular blow-out preventers have a resilient sealing means which can be forced by hydraulic cylinders into compressive sealing contact with the outer circumferential surface of various diameter drill string components or well casings, preventing pressure from subterranean gas pockets from blowing out material along the drill string and up the bore hole. Usually, the resilient sealing means of a blow-out preventer is so designed as to permit abutting contact of a plurality of sealing elements, when all elements of a drill string are removed from the casing. This permits complete shutoff of the well, even with all drill string elements removed. Most oil well blow-out preventers are remotely operable, as, for example, by a hydraulic pressure source near the drill hole opening having pressure lines running down to hydraulic actuator cylinders of the blow-out preventer.

Most blow-out preventer stacks also include a series of longitudinally spaced apart blow-out preventers of various types, located below an upper annular blow-out preventer. Other types of blow-out preventers include pipe ram, blind ram and shear ram. Construction and operation of blow-out preventers of the types identified above are described at http://en.wickipedia.org/wiki/blowout-preventer.

The present invention was conceived of in part to provide a modular control apparatus for oil well blow-out preventers, the apparatus including novel air actuator/hydraulic valve assemblies which are mounted to a compact hydraulic manifold, and including a novel actuator air control panel for remotely energizing pneumatic air cylinder-actuators which operate an integral hydraulic valve of each actuator/valve assembly.

OBJECTS OF THE INVENTION

An object of the present invention is to provide a modular control apparatus for controlling flow of pressurized hydraulic fluid to hydraulic actuator cylinders of oil well blow-out preventers used to control upward pressure from an oil or gas well reservoir

Another object of the invention is to provide novel modular pneumatic actuator/hydraulic valve assemblies which have a small footprint that enables various numbers of the assemblies to be mounted in a close side-by-side arrangement to a hydraulic manifold and thus enable construction of compact blow-out preventer control apparatuses.

Another object of the invention is to provide a novel double-action linear pneumatic actuator for exerting torque on a rotatable shaft.

Another object of the invention is to provide a novel modular air control panel for controlling flow of pressurized air to remotely located pneumatic actuator/hydraulic valve assemblies, in which various numbers of manually operated air valves are mounted to an air manifold and used to transmit pressurized air to a pair of air actuator cylinders of individual remotely located actuator/hydraulic valve assemblies, which in turn provide pressurized hydraulic fluid to opening and closing double-action hydraulic actuator cylinders of blow-out preventers located near a well head.

Various other objects and advantages of the present invention, and its most novel features, will become apparent to those skilled in the art by perusing the accompanying specification, drawings and claims.

It is to be understood that although the invention disclosed herein is fully capable of achieving the objects and providing the advantages described, the characteristics of the invention described herein are merely illustrative of the preferred embodiments. Accordingly, we do not intend that the scope of our exclusive rights and privileges in the invention be limited to details of the embodiments described. We do intend that equivalents, adaptations and modifications of the invention reasonably inferable from the description contained herein be included within the scope of the invention as defined by the appended claims.

SUMMARY OF THE INVENTION

Briefly stated, the present invention comprehends an improved control apparatus for oil well blow-out preventers, of the type variously referred to as hydraulic power units or BOP (Blow-Out Preventer) closing units and used to remotely actuate closing and opening hydraulic actuator cylinders of blow-out preventers mounted to a drill string or well casing of an oil or gas well. The invention includes a novel double-action pneumatic actuator and integral rotatable hydraulic valve assembly, a modular hydraulic manifold assembly for mounting various numbers of actuator and valve assemblies in a smaller space than prior-art control units, and a novel remote air panel and air manifold for remote manual operational control of pairs of air cylinders of individual air actuator and valve assemblies.

Each hydraulic valve and pneumatic actuator assembly according to the present invention includes an hydraulic valve that has rectangular block-shaped hydraulic valve housing which has in a flat valve port interface base plate at the base of the valve housing inlet, outlet and return ports for pressurized hydraulic fluid. The fluid ports, which are disposed perpendicularly through the valve port interface base plate at the base of the valve housing, facilitate mounting a selected number of valve and actuator assemblies on the flat front surface of a hydraulic manifold plate which has therein complementary manifold ports that are used to make fluid pressure-tight connections to the ports in the valve port interface base plate. Optionally, the hydraulic valve ports may be located in sides of a modified valve port interface base plate bolted to the valve housing, for in-line applications in which hydraulic lines are threadingly tightened into the in-line, side ports.

According to the invention, each hydraulic valve has within its housing a circular cylindrically-shaped rotor which is rotatably supported within the housing by an annular ring-shaped bearing race and ball bearings in an outer circumferential wall surface of the rotor. The rotor is fixed to the lower end of a shaft which protrudes perpendicularly upwards from the center of the rotor. The shaft is rotatably supported within a bearing located in an upper part of the valve housing, and protrudes upwardly from the upper surface of the valve housing.

A novel double-action linear pneumatic air actuator for the hydraulic valve includes a housing which has a central block-shaped part that has a flat lower mounting surface that seats on the flat upper surface of the valve housing. The actuator housing encloses a pair of collinear, diametrically opposed air cylinders located within a pair of rectangular outer cross-section housing extensions which extend equal distances outwards from the central block-shaped part of the housing and from the valve rotor shaft. The actuator housing is secured to the valve housing with bolts, and extends equal distances outwards from opposite sides of the valve housing.

According to the invention, ports of a manifold used to mount various numbers of valve and actuator assemblies in a side-by-side relation are arranged so that the pneumatic actuator cylinders are oriented in a parallel, side-by-side configuration. For example, for a manifold which has a vertically oriented, flat front ported face, the ports in the valve port interface base plate at the base of the valve housing are arranged so that the pneumatic actuator housing bases of adjacent actuator/valve assemblies are oriented in a side-by-side arrangement in a vertical plane, with upper and lower parts of each actuator which contain the upper and lower actuator air cylinders, respectively, extending above and below the upper and lower surfaces, respectively, of the valve housing, in a side-by-side, parallel arrangement. This arrangement enables valve and actuator assemblies to be arranged so that the width of a manifold on which the assemblies are mounted can be reduced from that required by prior-art control units in which adjacent actuator cylinders are arranged in-line on a single horizontal axis.

The novel pneumatic actuator according to the present invention includes a rotor shaft bore which is disposed perpendicularly through upper and lower surfaces of the actuator housing. The bore through the actuator cylinder housing has bearings which receive and rotatably support an upper part of the valve rotor shaft, which protrudes upwardly from the upper surface of the actuator cylinder housing and has attached thereto a handle for manual rotational operation of the valve. The handle is provided for emergency manual back-up operation of the valve.

According to the invention, the central axis of the rotor shaft bore through the actuator housing for the valve rotor shaft is centered in the block-shaped central portion of the actuator housing which is offset laterally, e.g., to the right, of the common longitudinal center lines of the upper and lower actuator cylinders. Thus, the rotor shaft axis is offset laterally from a longitudinal center line of the pneumatic actuator housing, e.g., closer to a right-hand vertical side of the housing than the left hand side. The lateral offset is provided to enable an inner, e.g., left hand side of a spur gear, which receives through a central flatted bore thereof a flatted portion of the valve rotor shaft, to mesh with a linear rack gear which is laterally centered within the pneumatic actuator housing. The rack gear is joined at opposite ends, e.g., upper and lower ends for a vertically oriented actuator cylinder housing, to upper and lower actuator piston rods. The upper and lower piston rods extend downwardly and upwardly, respectively, from upper and lower air pistons. The pistons are slidably mounted in air pressure-tight seals within the upper and lower air cylinders within the actuator housing extensions.

With the foregoing construction, when the upper cylinder is pressurized with air, the upper piston and piston rod, and the rack gear are forced downwards, thus rotating the spur gear, valve rotor shaft, and valve rotor in a counterclockwise sense. In a counterclockwise limit position, hydraulic fluid-flow channels within the body of the cylindrical valve rotor align with ports in the valve port interface base plate and manifold to thus permit flow of pressurized hydraulic fluid from a pressure source through a hydraulic line to an OPENING hydraulic actuator cylinder of a remote blow-out preventer, which retracts blow-out preventer seals from sealing contact with a drill string component.

Conversely, when the lower pneumatic actuator cylinder is pressurized with air, the lower piston and piston rod, and rack gear are forced upwardly, thus rotating the spur gear, valve rotor shaft and valve rotor to a clockwise limit position. In this position, ports of hydraulic fluid-flow channels within the body of the cylindrical valve rotor align with ports in the valve port interface base plate and manifold to thus permit flow of pressurized hydraulic fluid from a pressure source through a hydraulic line to a CLOSING hydraulic actuator cylinder of a remote blow-out preventer, which extends blow-out preventer seals into sealing contact with a drill string component.

Manually operating the hydraulic valve control handle to a central neutral position causes the valve rotor shaft and attached spur gear to be rotatably centered in a NEUTRAL position between counterclockwise and clockwise limit positions. This NEUTRAL position causes ports and channels of the valve rotor to align with valve port interface base plate and manifold ports in a manner which enables flow of hydraulic fluid which may have accumulated within the valve housing during a previously pressurized BOP hydraulic opening or closing operation to return to a reservoir.

According to the invention, the pneumatic actuators for the hydraulic valves are preferably operated by a remotely located air control remote panel and station. The air control remote panel and station includes a pair of separate manually operated push-button air valves for each of the two cylinders of each pneumatic actuator of an actuator/valve assembly. Each air valve has an inlet port connected through a flexible tube to a source of pressurized air, and an outlet port connected through a separate flexible tube to an inlet port of either the upper or lower cylinder of a pneumatic valve actuator. Thus, a first OPEN push-button operated air valve is connected to the upper, opening air cylinder of an actuator, and the second, CLOSE push-button operated air valve is connected to the lower, closing air cylinder of that actuator.

According to the invention, the push-button air valves are mounted on the front vertical surface of an air manifold. The air manifold has a multiplicity of control ports which are connected at one end to outlet ports of individual push-button air valves. The air manifold also has a multiplicity of pressurized air ports which mate with inlet ports of individual push-button air valves. The air manifold air valve air pressure source ports are in turn connected to a source of pressurized air such as an air compressor by a single pressurized air supply tube. An opposite end of each air valve control port is connected by a separate air tube to a remotely located upper or lower cylinder of the pneumatic actuator of an actuator/hydraulic valve assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front elevation view of a prior-art hydraulic closing unit for oil well blow-out preventers showing each of the hydraulic control valves thereof in a counterclockwise limit position in which hydraulic fluid may be conducted through the valve to an opening hydraulic actuator cylinder of an oil well Blow-Out Preventer (BOP).

FIG. **2** is a fragmentary view of the prior-art apparatus of FIG. **1**, showing a valve thereof in a clockwise limit position in which hydraulic fluid may be conducted through the valve to a closing hydraulic actuator cylinder of a blow-out preventer.

FIG. **3** is a lower plan view of a prior-art hydraulic valve and pneumatic actuator air cylinder of the apparatus of FIG. **1**.

FIG. **4** is a rear elevation view of the prior-art valve and actuator of FIG. **3**.

FIG. **5**A is a front perspective view of the prior-art valve and actuator of FIG. **4**.

FIG. **5**B is a longitudinal sectional view of the prior-art valve and actuator of FIG. **5**A, taken in the direction **5**B-**5**B.

FIG. **6** is a fragmentary perspective view of a modular pneumatic actuator and hydraulic control valve apparatus for oil well blow-out preventers according to the present invention, showing novel components of the apparatus including a rear view of a remote air controller component of the apparatus and a front view of a manifold and a single hydraulic valve and pneumatic actuator mounted on the manifold.

FIG. **7** is a rear perspective view of the apparatus of FIG. **6**.

FIG. **8** is a fragmentary view of the apparatus of FIG. **6**, showing a remote air controller component of the apparatus.

FIG. **9** is a right side perspective view of the remote air controller of FIG. **8**.

FIG. **10**A is an exploded front perspective view of the air controller of FIG. **8**.

FIG. **10**B is an exploded right rear perspective view of the air controller of FIG. **10**A.

FIG. **10**C is an exploded left rear perspective view of the air controller of FIG. **10**A.

FIG. **11**A is a right side front perspective view of a manifold, hydraulic valve and pneumatic actuator assembly of the control apparatus of FIG. **6**, showing one valve and actuator module thereof removed from the manifold.

FIG. **11**B is a left perspective view similar to that of FIG. **11**A, showing three valve actuators assemblies removed from the manifold.

FIG. **12** is a front elevation view of the assembly of FIG. **11**.

FIG. **13** is a right side elevation view of the assembly of FIG. **11**.

FIG. **14** is a rear elevation view of the assembly of FIG. **11**.

FIG. **15**A is a left side perspective view of a single manifold-ported hydraulic valve and pneumatic actuator according to the present invention.

FIG. **15**B is an exploded view of the valve and actuator of FIG. **15**A.

FIG. **16** is a left side elevation view of the valve and actuator of FIG. **15**A.

FIG. **17** is a rear elevation view of the valve and actuator of FIG. **15**A.

FIG. **18**A is a front elevation view of the valve and actuator of FIG. **15**A, showing the valve in a counterclockwise limit position.

FIG. **18**B is a front elevation view of the valve and actuator of FIG. **15**A, on an enlarged scale, showing the valve in a centered, NEUTRAL position.

FIG. **19** is a vertical longitudinal sectional view of the valve and actuator of FIG. **18**, taken in the direction of line **19**-**19**, and showing the valve in a NEUTRAL position.

FIG. **20** is a horizontal longitudinal sectional view of the valve and actuator of FIG. **18**, taken in the direction of line **20**-**20**.

FIG. **21** is another vertical longitudinal sectional view of the valve and actuator of FIG. **18**, taken in the direction of line **21**-**21**.

FIG. **22** is a transverse sectional view of the valve and actuator of FIG. **16**, taken in the direction of line **22**-**22**.

FIG. **23** is a front elevation view of the valve and actuator of FIG. **18**B, showing the valve in an OPEN counterclockwise limit position in which hydraulic fluid may be routed through the valve to the opening hydraulic actuator cylinder of a BOP.

FIG. **24** is a right-side elevation view of the valve and actuator of FIG. **23**.

FIG. **25** is a vertical longitudinal sectional view of the valve and actuator of FIG. **23**, taken in the direction of line **25**-**25**.

FIG. **26** is a transverse sectional view of the valve and actuator of FIG. **24**, taken in the direction of line **26**-**26**.

FIG. **27** is a forward-looking transverse sectional view of the valve and actuator in the NEUTRAL position of FIG. **16**, taken in the direction of line **27**-**27**.

FIG. **28** is a rearward-looking transverse sectional view of the valve of FIG. **16**, taken in the direction of line **28-28**.

FIG. **29** is a forward-looking transverse sectional view of the valve and actuator in the open position shown in FIGS. **23** and **24**, taken in the direction of line **29-29**.

FIG. **30** is a rearward-looking transverse sectional view of the valve of FIGS. **23** and **24**, taken in the direction of line **30-30**.

FIG. **31** is a forward-looking transverse sectional view similar to that of FIG. **27**, but showing a rotor of the valve turned to a CLOSED clockwise limit position, in which hydraulic flow can be conducted through the valve to the closing hydraulic actuator cylinder of a blow-out preventer.

FIG. **32** is a rearward-looking transverse sectional view similar to that of FIG. **28** but showing the valve rotor turned to the clockwise limit position as in FIG. **31**.

FIG. **33** is a partly diagrammatic skeletal left side view of the valve and actuator of FIG. **15**, showing the valve rotor in a NEUTRAL position in which both cylinder **1** and cylinder **2** ports of the valve are blocked.

FIG. **34** is a right side perspective view of the valve and actuator of FIG. **33**.

FIG. **35** is a view similar to that of FIG. **33**, but showing the valve and actuator in a counterclockwise, OPEN position.

FIG. **36** is a right side perspective view of the valve and actuator of FIG. **35**.

FIG. **37** is a view similar to that of FIG. **33**, but showing the valve and actuator in a clockwise, CLOSED position.

FIG. **38** is a right side perspective view of the valve and actuator of FIG. **37**.

FIG. **39** is a perspective view of a modified valve and actuator assembly according to the present invention, which includes a side-ported hydraulic valve and a modified pneumatic actuator that has a monolithic construction in which opposed cylinder bores and air passageways thereof are machined from a single aluminum block.

FIG. **40** is a front elevation view of the valve and actuator assembly of FIG. **39**.

FIG. **41** is an upper plan view of the valve and actuator assembly of FIG. **39**.

FIG. **42** is a lower plan view of the valve and actuator assembly of FIG. **39**.

FIG. **43** is a fragmentary rear view of the valve and actuator assembly of FIG. **39**, showing the actuator disassembled from the valve.

FIG. **44** is an upper broken-away phantom view of the pneumatic actuator of FIG. **43**.

FIG. **45** is an upper longitudinal sectional view of the actuator of FIG. **43**, taken in the direction of line **45-45**.

FIG. **46** is a medial longitudinal sectional view of the actuator of FIG. **43** showing the actuator in a leftward limit position.

FIG. **47** is a lower sectional view of the actuator of FIG. **43**, taken in the direction of line **47-47**.

FIG. **48** is an exploded view of the actuator of FIG. **43**.

FIG. **49** is a perspective view of the actuator of FIG. **48**, with an upper cover plate thereof removed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Novel features and advantages of a Modular Actuator And Hydraulic Valve Assemblies And Control Apparatus For Oil Well Blow-Out Preventers (BOP's) according to the present invention may best be understood by considering briefly the construction and function of a typical prior-art blow-out preventer control apparatus, of the type shown in FIGS. **1-5**B.

Referring to FIG. **1**, it may be seen that an example of a prior-art hydraulic power unit or control apparatus **50** for oil well blow-out-preventers (BOP's) includes various mechanical components which are mounted on a skid **51** that is transportable to a location near an oil well head. The apparatus **50** includes a hydraulic pump **52** which is driven by an electric, pneumatic, or hydraulic motor **53** which provides pressurized hydraulic fluid through various pressure regulators and conduits **54**A, **54**B, **55** to a multiplicity of individual hydraulic pressure accumulators **56**, e.g., accumulators **56**-I through **56**-N. Typically, apparatus **50** includes a bank of hydraulic pressure accumulators **56**-I through **56**-N connected to a common manifold. The accumulators provide pressurized hydraulic fluid for the OPENING hydraulic actuator and the CLOSING hydraulic actuator of each one of a multiplicity of separate blow-out preventers (not shown) which are mounted to an oil well drill string at a well head located some distance from the control apparatus **50**.

As shown in FIG. **1**, blow-out preventer control apparatus or hydraulic power unit **50** includes a multiplicity of hydraulic control valves **57**. As shown in FIG. **5**B, each hydraulic control valve **57** is typically a rotary, three-position type valve which has an internal rotor **58**, coupled to a shaft **59** which protrudes forward from the valve housing **60**. The outer end of valve rotor shaft **59** is fastened to a lever arm **61** which has a handle bar **62** that extends radially outwards from the shaft and serves as a manually operable handle for rotating the shaft. Lever arm **61** also has a short flat bar-shaped actuator lever extension **63** that extends radially outwards from the valve rotor shaft **59**, in a direction diametrically opposed to handle bar **62**.

As may be seen best by referring to FIGS. **2**, **5**A and **5**B, a radially outwardly located end of valve actuator lever extension **63** is received in a gap **64** between the sheaves **65**, **66** of a clevis **67**, and is pivotably joined to the sheaves by a pivot pin **68** disposed perpendicularly through aligned holes **69**, **70**, **71** in the upper sheave, actuator lever extension, and lower sheave, respectively.

As shown in FIG. **5**B, clevis **67** is fastened at an outer end thereof to the outer end of a piston rod **72**. Piston rod **72** extends outwardly from the bulkhead **73** of a pneumatic air actuator **74**. The inner end of piston rod **72** is fastened to the base **75** of a piston **76** which is longitudinally slidable in pneumatically sealing contact with the inner cylinder wall surface **77** of an air cylinder **78** within pneumatic actuator **74**.

As may be envisioned by referring to FIGS. **1**, **2** and **5**B, when pressurized air is introduced through a port **80** through cylinder head **81** of actuator cylinder **78** into the head space **82** between the inner surface **83** of the cylinder head and the head **84** of piston **76**, the piston **76** and piston rod **72** are forcibly extended away from cylinder head **81**. In turn, outward motion of piston rod **72** and clevis **67** forces counterclockwise orbital motion of valve actuator lever **63** and counterclockwise rotation of valve rotor shaft **59** from a CLOSED position shown in FIG. **2** to an OPEN position shown in FIG. **1**.

In the CLOSED position of a valve **57** shown in FIG. **2**, pressurized hydraulic fluid is conducted from the outlet port of a manifold supplied with pressurized hydraulic fluid from a bank of accumulators **56**-I through **56**-N to a PRESSURE inlet port in body **85** of the valve, and through rotor **58** and an output port of the valve to a hydraulic pressure line which is connected to the CLOSING hydraulic actuator cylinder of a distant blow-out preventer.

Similarly, pneumatic actuator cylinder **78** is used to orbit turn control lever **59** to a clockwise-limit, CLOSED position by retracting piston **76** and piston rod **72**. Retraction of piston **76** and piston rod **72** is accomplished by introducing pressurized air through a port **86** through bulkhead **73** of actuator cylinder **78** into a space **87** between the bulkhead and base **75** of piston **76**. In this configuration of valve **57**, pressurized hydraulic fluid is conducted from the output port of a manifold connected to a bank of accumulators, **56**-I, through **56**-N, to the pressure inlet port in valve body **85**, and through valve rotor **58** to an OPENING outlet port which is connected to a hydraulic pressure line which is in turn connected to the OPENING hydraulic actuator cylinder of a distant blow-out preventer.

Although it is not shown in FIGS. **1**-**5**B, each hydraulic control valve **57** has a third, NEUTRAL position in which valve handle lever **62** is oriented in an upright vertical position, midway between the counterclockwise OPEN limit position and clockwise CLOSED limit position.

As may be seen by referring to FIGS. **5**A and **5**B, each valve **57** has a spring loaded detent ball **91** which lodges under spring tension into one of three circumferentially spaced apart detent depressions **92**A, **92**B, **92**C in an upper cover plate **93** of the valve body **85**. In this NEUTRAL position, the pressure inlet port and opening and closing outlet ports are blocked.

As shown in FIG. **1**, the prior-art arrangement of multiple hydraulic valves in which a pneumatic actuator cylinder for each valve lies along a common laterally disposed axis, combined with the relatively long handle lever arms **62**, which are required for manual backup operability of the valves required by safety standards, results in a substantially wide, and correspondingly heavy control apparatus. The design and construction of various components of a modular actuator and hydraulic valve and control apparatus according to the present invention affords, among other advantages, a reduction in the size and weight of the control apparatus, as will now be described.

FIGS. **6**-**38** illustrate details of a novel Modular Actuator And Hydraulic Valve Assemblies And Control Apparatus For Oil Well Blow-Out Preventers according to the present invention. Certain standard components of the apparatus which are known to those skilled in the art, and/or which have been described above in the discussion of the prior-art, are omitted for clarity of the ensuing description.

FIGS. **6** and **7** are fragmentary views showing major components of a Modular Actuator And Hydraulic Valve Assemblies And Control Apparatus for Oil Well Blow-Out Preventers according to the present invention, in which major components of the apparatus which in actual use may be separated by substantial distances, are mounted close together on a demonstration bench or test bench B.

As shown in FIGS. **6** and **7**, a Modular Actuator And Hydraulic Valve Assemblies And Control Apparatus For Oil Well Blow-Out Preventers **100** according to the present invention includes one or more pneumatic actuator and hydraulic valve assemblies **101** mounted on a hydraulic manifold **102**. Each actuator/valve assembly **101** consists of an hydraulic valve **103** to which is mounted an integral double-action pneumatic actuator **104**. Both the valve and actuator are described in detail below. Apparatus **100** includes a remotely locatable air control panel unit **105** which is connectable to individual pneumatic actuators **104** by separate air tubes **121**, **122**, **128** that are contained in a larger diameter flexible coaxial tubular jacket **107**.

As shown in FIGS. **6**-**10**C, air panel control unit **105** includes pairs of manually operable OPENING and CLOSING push-button valves **108-1** through **108-4**, and **109-1** through **109-4**, respectively. Opening valves **108** are arranged in a left-hand vertical column in horizontal alignment with closing valves **109**, which are located in a right-hand vertical column.

Each valve **108**, **109** has a push-button **110**, **111** which protrudes through a panel **112** of the air panel control unit. Each valve **108**, **109** has a rectangular block-shaped rear housing **113**, **114** which has in an inner vertical side thereof a valve outlet port. Valves **108**, **109** are mounted to opposite vertical sides of a valve manifold **120**A, with valve outlet ports and in hermetic sealing contact with aligned ports in the valve manifold.

FIGS. **10**B and **10**C illustrate how a typical push-button valve, such as the upper right-hand CLOSING valve **109-1**, is attached in pneumatic sealing contact to the right-hand vertical side of valve manifold **120**A. As shown in FIGS. **10**B and **10**C, valve **109-1** has in an inner, left vertical side thereof an air outlet port **116**A which fastens in hermetically sealing contact to port **116**B in the right side of valve manifold **120**A. Valve **109-1** also has an air inlet port **133**A which fastens in hermetically sealing contact to port **133**B in the right side of valve manifold **120**A. As may be best understood by referring to FIG. **10**C, left-hand OPENING valves, such as the upper left OPENING valve **108-1**, are fastened in hermetically sealing contact with a portion of the left-hand vertical side of valve manifold **120**A in an exactly analogous fashion.

Valve manifold **120**A has internal air passageways (not shown) which connect a valve ports (not shown) in its left side wall and **116**B in its right side wall with rear valve manifold ports **117**A, **118**A located in the rear face of valve manifold **120**A.

As may be understood by referring to FIGS. **10**A-**10**C, valve manifold outlet ports **117**A, **118**A in the rear face of valve manifold **120**A are longitudinally aligned with inlet ports **117**B, **118**B in the front face of an air manifold **120**B located rearward of valve manifold **120**A. Air manifold **120**B has internal air passages, such as the elbow **121**A shown in FIG. **10**A, which connect each inlet port **117**B, **118**B to a separate air outlet tube **121**, **122**. The distal ends of each pair of air outlet tubes **121**, **122** are in turn connected to input ports **123**, **124** of upper and lower air cylinders **125**, **126** of a pneumatic actuator **104**.

When front valve manifold **120**A is bolted to rear air manifold **120**B with rear and front faces thereof in hermetic sealing contact, aligned outlet-inlet port pairs **117**A-**117**B, **118**A-**118**B provide paths for pressurized air conducted through valves **108**, **109** to air outlet tubes **121**, **122**.

As shown in FIGS. **6**, **9**, and **10**A-C, apparatus **100** also includes a source of pressurized air such as an air compressor **127** which supplies pressurized air through a tube **128** to a pressurized air source inlet port **129** located in a side wall of valve manifold **120**A.

As shown in FIGS. **10**A and **10**B, air panel control unit **105** includes a master air valve **129**A which has an air inlet port **129**B located in a bottom wall of a housing of the master air valve. Master air valve **129**A also has an air outlet port **129**C located in the bottom wall of the valve housing. The two ports in the housing of master air inlet valve **129**A are vertically alignable with, and hermetically sealable to, corresponding ports in the upper wall of valve manifold **120**A, when the master air valve **129**A is bolted to the valve manifold. Thus valve manifold **120**A has located in its upper wall a first, air supply inlet port **130**B which is alignable with air inlet port **129**B of master air valve **129**A. Air inlet port **130**B is connected through an internal passageway (not shown) within valve manifold **120**A to pressurized air inlet" port **129** of the valve manifold.

Valve manifold **120**A also has located in its upper wall a second, air supply outlet port **130**C which is alignable with air outlet port **129**C of master valve **129**A. As may be understood by referring to FIGS. **19**B and **10**C, air outlet port **130**C is connected through internal passageways (not shown) within valve manifold **120**A through outlet ports **132**B (not shown) and **133**B to inlet ports **132**A (not shown) and **133**A of push button valves **108**, **109**. With this construction, pressurized air may be conducted through outlet ports **115**A, **116**A of push button valves **108**, **109** and thence through valve manifold/air manifold port pairs **117**A-**117**B, **118**A-**118**B to air outlet tubes **121**, **122** only when master air valve **129**A is manually actuated to an ON position.

The example embodiment of air panel control unit **105** shown in FIGS. **10**A-**10**C has in left and right, OPENING and CLOSING columns four OPENING valves **108-1** through **108-4** and four CLOSING valves **109-1** through **109-4**. However, the modular design of air panel control unit may use fewer valves, in which case unused ports of valve manifold **120**A would be plugged.

FIGS. **11**A through **18** illustrate certain external structural features which determine form-factors, i.e., geometrical shapes, of the novel pneumatic actuator and hydraulic valve assemblies **101** according to the invention. Those figures also show how the novel construction of the actuator/valve assembles **101** facilitates mounting various numbers of the assemblies to a hydraulic manifold **102** in close proximity to thus construct a compact modular blow-out control apparatus **100**.

Referring to FIGS. **11**A-**18**, it may be seen that each actuator and hydraulic valve assembly **101** includes an hydraulic valve **103** which has a rectangular block-shaped housing **134**. As shown in FIGS. **16** and **17**, a base end of hydraulic valve housing **134** is fixed to a relatively thin, square cross-section valve port interface base plate **135**. As shown in FIG. **17**, a lower flat mounting surface **136** of valve port interface base plate **135** is penetrated by four hydraulic fluid ports which are spaced circumferentially apart at 90-degree intervals. The hydraulic fluid ports include a first, PRESSURE inlet port **137** for receiving pressurized hydraulic fluid. Inlet port **137** located at a 0-degree, twelve o'clock or top position.

As viewed from the front of valve **103**, rather than from the rear view of FIG. **17**, valve port interface base plate **135** of hydraulic valve **103** also has at a 90-degree, three-o'clock, or right-side position a second, Cylinder **1** (OPENING) hydraulic fluid outlet port **138** for connection to the OPENING hydraulic actuator cylinder of a blow-out preventer.

As is also shown in FIG. **17**, mounting surface **136** of valve port interface base plate **135** is penetrated by a third, hydraulic fluid RETURN outlet port **139**, which is located at a 180-degree, six-o'clock or bottom position relative to pressurized hydraulic fluid inlet port **137**. The RETURN port is provided for connection through a RETURN hydraulic line to a hydraulic fluid reservoir.

Valve port interface base plate **135** has a fourth, Cylinder **2** CLOSING hydraulic fluid outlet port **140** which is located at a 270-degree, nine-o'clock or left-side position relative to the first, pressurized fluid inlet port **137**. The Cylinder **2**, CLOSING port **140** is provided for connection to the CLOSING hydraulic actuator cylinder of a blow-out preventer.

As may be understood by referring to FIGS. **11**A-**13** and **17**, the hydraulic fluid ports **137**, **138**, **139** and **140** in valve port interface base plate **135** of valve housing **134** facilitate mounting hydraulic valve **103** on the flat front surface **141** of hydraulic manifold **102**.

As may be seen best by referring to FIG. **11**B, manifold **102** has hydraulic fluid ports which are alignable with the hydraulic fluid ports **137-140** in valve port interface base plate **135** of the housing of a hydraulic valve **103**. Thus, for example, as shown in FIG. **11**B, manifold **102** has in a front surface **141** thereof near a left-hand side **142** of the manifold a first set of four ports, **147-1**, **148-1**, **149-1**, **150-1**, which are alignable with ports **137-1**, **138-1**, **139-1** and **140-1**, respectively, of a first, left-hand valve and actuator assembly **101-1**.

As may be envisioned by referring to FIG. **11**B, manifold port **147-1**, which is located at a twelve o'clock position, is connectable in a fluid pressure-tight connection to aligned port **137-1** of hydraulic valve **103-1** when the housing **134-1** of that valve is bolted onto manifold **102**. Within the block-shaped body **151** of manifold **102** is located a first, upper manifold runner tube channel **152** which has an inlet port **153** that is connectable to a source of pressurized hydraulic fluid, such as a single hydraulic accumulator or a bank of accumulators.

Referring still to FIG. **11**B, it may be understood that manifold port **149-1**, which is located at a six-o'clock position is connectable in a fluid pressure-tight connection to aligned port **139-1** of hydraulic valve **103-1** when the housing **134-1** of that valve is bolted onto manifold **102**. Within the body **151** of manifold is located a second, lower manifold runner tube **154** which has an outlet port **155** that is connectable to a reservoir for hydraulic fluid.

Referring to FIGS. **11**B and **17**, it may be seen that manifold port **148-1**, which is located at a three-o'clock position, is connected in a fluid pressure-tight connection to aligned port **138-1** of hydraulic valve **103-1** when the housing **134-1** of that valve is bolted onto manifold **102**. As shown in FIG. **14**, body **151** of manifold **102** has disposed therethrough a passageway **159** which penetrates the rear surface **157** of the body and has a CYLINDER **1**, OPENING port **160** which is connectable by a hydraulic pressure line to the OPENING hydraulic actuator of a blow-out preventer. When handle **167** and rotor **166** of valve **103** are rotated 45 degrees counterclockwise from a center NEUTRAL position to an OPEN position, pressurized hydraulic fluid inlet to PRESSURE inlet port **137** is conducted through valve **103** to OPENING outlet port **160**.

As may also be understood by referring to FIGS. **11**B and **17**, manifold port **150-1**, which is located at a nine-o'clock position, is connected in a fluid pressure-tight connection to aligned port **140-1** of hydraulic valve **103** when the housing **134-1** of that valve is bolted onto manifold **102**. Body **151** of manifold **102** has disposed therethrough a passageway **156** which penetrates the rear surface **157** of the body and has a CYLINDER **2**, CLOSING port **158** which is connectable by a hydraulic pressure line to the CLOSING hydraulic actuator of a blow-out preventer. When handle **167** and rotor **166** of valve **103** are rotated 45 degrees clockwise from a center NEUTRAL position to a CLOSED position, pressurized hydraulic fluid inlet to PRESSURE inlet port **137** in conducted through valve **103** to CLOSING outlet port **158**.

As shown in FIGS. **11**A-**18**B and is described in detail below with reference to FIGS. **19**-**26**, the pneumatic actuator

104 of each actuator/valve assembly **101** has within a longitudinally elongated rectangular cross-section prism-shaped housing **161** thereof upper and lower air cylinders **125**, **126**, which are pressurizable by upper and lower air inlet lines **121**, **122**, respectively. As is described below, air cylinders **125**, **126** are contained within upper and lower housings **172**, **173** that extend upwardly and downwardly, respectively from a central block-shaped section **168** of housing **161** of actuator **104**.

As will be described in detail below, actuator/valve assembly **101** is constructed in a manner which causes a valve rotor shaft **166** and manual control handle **167** of valve **103** to rotate to a counterclockwise OPEN position when upper air cylinder **125** is pressurized with air through upper actuator air inlet line **121**, as shown in FIG. **18**A.

Conversely, when lower air cylinder **173** is pressurized with air through lower actuator air inlet line **122**, valve rotor shaft **166** and manual control handle **167** are rotated to a clockwise CLOSED position, as shown for actuator/valve assembly **101-1** in FIGS. **11**A, **11**B and **12**.

As shown in FIGS. **15**A and **16**, valve handle **167** may be manually operated to orient valve rotor **176** to a NEUTRAL position parallel to the longitudinal axes of the upper and lower cylinders.

As shown in FIGS. **15**A-**18**B, the housing **161** of actuator **104** of each actuator/valve assembly **101** has a flat, square rear face **169** that seats on and is bolted to the square, flat, front face **170** of valve housing **134** by bolts **171**.

The construction and function of upper and lower pneumatic actuator air cylinders **125**, **126**, in upper and lower housing extensions **172**, **173**, respectively, of actuator **104** are described in detail below.

Referring still to FIGS. **15**A-**18**B, it may be seen that valve housing **134**, which extends congruently upwards from relatively thin, square cross-section valve port interface base plate **135**, contains a valve rotor **176**. As shown in the figures, valve port interface base plate **135** has a flat, square upper face **177** which is fastened in abutting contact to a lower flat, square face **178** of valve housing **134**.

As is also shown in the figures, valve port interface base plate **135** has through lower flat surface **136** thereof the hydraulic fluid ports **137**, **138**, **139**, **140** which were described previously. Also, valve port interface base plate **135** has depending perpendicularly upwards from lower flat surface **136** thereof a left side **180** inscribed with CYLINDER **2**, a right side **181** inscribed with CYLINDER **1**, and upper side **182** inscribed with PRESSURE, and a lower side **183** inscribed with RETURN. As shown in FIGS. **15-18**B, valve housing **134** has sides **180**A, **181**A, **182**A and **183**A which are co-planar extensions of corresponding sides **180**, **181**, **182** and **183** of valve port interface base plate **135**.

As may be seen best by referring to FIGS. **15**A-**18**B and **23**, central square cross-section block-shaped section **168** of actuator housing **161** has a left side wall **190** which is approximately co-planar with left side **180**A of valve housing **134**. Central block-shaped section **168** of actuator housing **161** also has a right side **191** which is parallel to but recessed inwardly slightly from right side **181**A of valve housing **134**. Also, central block-shaped housing section **168** of actuator housing **161** has an upper side face **174** and a lower side face **175** which are parallel to but recessed inwardly from upper and lower sides **182**A and **183**A, respectively, of valve housing **134**.

FIGS. **15**B and **19-38** illustrate in further detail the construction and function of a novel pneumatic actuator and hydraulic valve assembly **101** according to the present invention, consisting of a pneumatic actuator **104** and hydraulic valve **103**.

As shown in FIGS. **15**B, **19-21** and **27**, rotor **176** of valve **103** has generally the shape of a relatively thick circular disk or short right-circular cylinder. Rotor **176** is rotatably located within a cylindrically-shaped well **192** which extends perpendicularly inwards from lower square face **178** of valve housing **134**, and is supported by a ring-shaped ball bearing race **196** which holds therein a multiplicity of spherical ball bearings **197** that rollingly contact a circular annular ring-shaped groove **198** formed in the upper end portion of well **192**.

As shown in FIGS. **20-22**, valve rotor **176** has extending perpendicularly upwards from upper surface **199** thereof an elongated circular cross section coaxial rotor shaft **166**. Rotor shaft **166** is disposed through a vertically disposed bore **201** through valve housing **134**, and is rotatably supported within the bore by a sleeve bearing or bushing **202**. As shown in FIG. **20**, valve rotor shaft **166** extends upwardly through upper face **170** of valve housing **134**, and through a bore **203** disposed upwardly into lower face **169** of actuator housing center section **168** and extends upwardly from upper face **205** of the actuator housing center section.

As may be seen best by referring to FIGS. **20-22**, an upper part of valve rotor shaft **166** has formed in opposite sides of the outer circumferential wall surface **206** of the shaft a pair of parallel, diametrically opposed flats **207**, **208** that form an upper flatted or keyed shaft section **209**. The upper keyed section **209** of valve rotor shaft **166** is received in a central keyed hole **210** through a spur gear **211** located in actuator **104**. Keyed hole **210** through spur gear **211** has the shape of a circle which has indented flat, parallel diametrically opposed sides **212**, **213**, and thus comprises a keyway which has a shape complementary to the outer transverse cross-sectional shape of the keyed section **209** of valve rotor shaft **166**. The flat inner sides **212**, **213** of the keyed hole **210** conformally receive the flat sides **207**, **208** of the valve rotor shaft. Optionally, shaft **166** may have a circular cross-section which has a slot for receiving a key that fits into a keyway in spur gear **211** to facilitate transmission of torque from the rack gear to valve rotor shaft **166**.

Referring to FIGS. **20**, **21**, **27**, **33** and **34**, it may be seen that valve rotor **176** has disposed perpendicularly upwards from lower circular face **214** thereof a series of circular cross-section bores which are rotatably alignable with bores **137**, **138**, **139** and **140** through valve port interface base plate **135** of valve **103**.

FIG. **27** is a lower plan view of valve housing **134**, which shows the various ports and passageways for hydraulic fluid within the valve rotor **176**, with the rotor oriented at a zero-degree, NEUTRAL rotation angle relative to valve housing **134**. Thus, as shown in FIG. **27**, rotor **176** has in a lower face **214** thereof a first, left-side pair of ports **215**, **216** which are located on a chord of the rotor near the left side **217** of valve housing **134**, equidistant from a horizontal diameter of the rotor disposed perpendicularly to the chord. Left-side ports **215**, **216** are located at upper and lower ends, respectively, of a first, left-side tubular passageway **218** within valve rotor **176**.

Referring still to FIG. **27**, valve rotor **176** has in lower face **214** thereof a second, right-side pair of ports **219**, **220** which are mirror symmetric, through a longitudinal vertical plane of valve housing **134**, with left-side ports **215**, **216**. Thus, right-side ports **219**, **220** are located on a chord of rotor **176** near the right side **221** of valve housing **134**, equidistant from a horizontal diameter of the rotor disposed perpendicularly to the chord. Ports **219**, **220** are located at upper and lower ends, respectively, of a second, right-side tubular passageway **222** within valve rotor **176**.

As is also shown in FIG. **27**, valve rotor **176** has in lower face **214** thereof a third, center-line pair of upper and lower ports **223**, **224**, located at upper and lower ends of a third, center-line tubular passageway **225** through the rotor. Upper port **223** of center-line passageway **225** is coaxially centered on the longitudinal axis of rotor **176**, and port **224** is located near the lower end of a vertical radius of the rotor.

Left, right and center-line passageways **218**, **222** and **225** within rotor **176** are used to conduct hydraulic fluid between various ports **137**, **138**, **139** and **140** for various rotational orientations of valve rotor **176**, as will now be described. Thus, as shown in the figures, with valve rotor **176** oriented at a zero-degree, NEUTRAL rotation angle, center-line passageway **225** provides a path for excess hydraulic fluid which may be trapped between the lower surface **214** of valve rotor **176** and upper surface **227** of valve port interface base plate **135**. In this position of the valve rotor **176** relative to the valve port interface base plate **135**, excess hydraulic fluid is conducted from upper, inlet port **223** to lower, outlet port **224**, out through lower port **139** through valve port interface base plate **135** and into a RETURN port **149** in front face **141** of hydraulic manifold **102**.

When valve rotor **176** is rotated 45 degrees counterclockwise relative to valve port interface base plate **135**, as shown in FIGS. **29**, **35**, and **36**, upper port **219** of right-side valve rotor passageway **222** becomes aligned with fluid PRESSURE inlet ports **137** and **147** of valve port interface base plate **135** and hydraulic manifold **102**, respectively. In this position, pressurized hydraulic fluid may be introduced into upper port **219** of right-side passageway **222**, conducted through that passageway to lower, outlet port **220** of the right-side passageway, and conducted through CYLINDER **1**, OPENING cylinder valve outlet port **138** and an aligned port **148** of the hydraulic manifold **102**, and thence through a hydraulic line to the OPENING inlet port of a hydraulic actuator cylinder of a remote blow-out preventer.

In the 45-degree counterclockwise orientation of valve rotor **176**, upper port **215** of left-side valve rotor passageway **218** is aligned with CYLINDER **2** ports **140**, **150** of valve port interface base plate **135** and manifold **102**, respectively. Also in this 45-degree counterclockwise orientation, lower outlet port **216** of left-side passageway **218** aligns with RETURN outlet ports **139**, **149** of the valve port interface base plate **135** and manifold **102**, allowing fluid flow from CYLINDER **2** to a fluid reservoir.

In an exactly analogous fashion, when valve rotor **176** is rotated 45 degrees clockwise from the NEUTRAL position shown in FIGS. **33** and **34** to the CLOSED position shown in FIGS. **31**, **37** and **38**, upper port **215** of left-side valve rotor passageway **218** becomes aligned with fluid PRESSURE inlet ports **137** and **147** of valve port interface base plate **135** and hydraulic manifold **102**. In this position, pressurized hydraulic fluid may be introduced into left-side passageway **218** and conducted through that passageway to lower, outlet port **216** of the left-side passageway, conducted through CYLINDER **2**, CLOSING valve outlet port **140** and an aligned port **150** of hydraulic manifold **102**, and thence through a hydraulic line to the CLOSING inlet port of a hydraulic actuator cylinder of a remote blow-out preventer.

In the 45-degree clockwise orientation of valve rotor **176** upper port **219** of right-side valve rotor passageway **222** is aligned with CYLINDER **1** ports **138**, **148** of valve port interface base plate **135** and manifold **102**, respectively. Also in this 45-degree clockwise orientation, lower outlet port **220** of right-side passageway **222** aligns with RETURN outlet ports **139**, **149** of the valve port interface base plate **135** and manifold **102**, respectively, allowing return of hydraulic fluid to the fluid reservoir

As may be seen best by referring to FIGS. **20** and **21**, each hydraulic fluid port which extends inwardly from lower face **136** of valve port interface base plate **135** has a cylindrically-shaped entrance bore. Thus, port **137** has an entrance bore **237**, port **138** has an entrance bore **238**, port **139** has an entrance bore **239**, and port **140** has an entrance bore **240**. As shown in the figures, the upper end of each entrance bore which penetrates upper face **377** of valve port interface port, base plate **135** is penetrated by a circular cross-section counter-bore **242**, **243**, **244**, **245**. Each counterbore through which hydraulic fluid under high pressure is conducted receives conformally therein a cylindrically-shaped metal sealing ring **246**, **247** and **249** which has a beveled upper surface. The beveled upper surface of each sealing ring is urged into sealing contact with lower surface **214** of rotor **176** by individual annular ring-shaped wave springs **252**, **253**, **255**, located in counter-bores **242**, **243** and **245**, respectively.

As may be seen best by referring to FIGS. **15**B, **20** and **33-38**, each fluid passageway **218**, **222**, **225** through valve rotor **176** includes a transverse bore **258**, **262**, **265** which is made through the outer circumferential wall surface **266** of valve rotor body **267**. The entrance openings of transverse bores **258** and **262** are plugged after the bores are made. Each fluid passageway **218**, **222**, **225** also has at opposite ends of transverse bores **258**, **262**, **265** end sections which extend downwardly into axially disposed tubular end sections.

Details of the construction and function of pneumatic actuator **104** may be further understood by referring to FIGS. **15**B, **19-22**. As shown in FIG. **22**, the center of block-shaped central section **168** of actuator housing **161** is offset laterally, e.g., to the right, of the common longitudinal center-line of upper actuator cylinder **125** in housing extension **172** and lower actuator cylinder **126** in lower cylinder housing extension **173**. Thus, as shown in FIG. **22**, the common axial center-line of valve rotor shaft **166** and attached spur gear **211** is offset to the right of the cylinders' center-line.

As shown in FIGS. **15**B, **19** and **22** and stated above, upper and lower housing extensions **172**, **173** of pneumatic actuator **104** contain therein identically constructed actuator air cylinders **125**, **126**, respectively. Each air cylinder **125**, **126** includes a circular cross-section cylinder bore **290**U, **290**L which holds longitudinally slidably therewithin a piston **291**U, **291**L. Each piston **291**U, **291**L has generally the shape of a short right-circular cylinder or disk which has an outer circumferential wall surface **292** in which is formed an annular ring-shaped groove **293** that holds therein an elastically deformable O-ring type piston ring **294**. The outer circumferential wall surface **295** of piston ring **294** longitudinally slidably contacts in hermetically sealing contact the inner cylindrical wall surface **296** of air cylinder bore **290**.

As shown in FIGS. **15**B and **22**, each air cylinder **125**, **126** has generally the shape of a longitudinally elongated rectangular cross-section cylinder block **299** which has a flat outer transversely disposed end face **300** that is penetrated by cylinder bore **290**. Each cylinder **125**, **126** also has a thin rectangular plate-shaped cylinder head **301** which has an outer flat face transversely disposed face **302** and a parallel inner transversely disposed face **303**. Cylinder head **301** is secured to cylinder block **299** of cylinder **162** with inner face

303 of the cylinder head in flat, pneumatically sealing abutting contact with outer end face **300** of cylinder block **299** by bolts **304**, **305**, **306**, **307** at the corners of the cylinder block and cylinder head **301**.

As may be seen best by referring to FIG. **22**, upper and lower cylinder heads **301**U, **301**L have radially disposed inlet ports **123**, **124**, respectively, for pressurized air which penetrates a side wall **309** of the cylinder head. Each inlet port **123** or **124** communicates at a radially inwardly located end thereof with longitudinally disposed air passageway **310** that is coaxial with and communicates with an outer portion of cylinder bore **290** that forms a head space **311**. Head space **311** is located between the head face **312** of piston **291** and the inner face **303** of cylinder head **301**.

Referring still to FIGS. **15**B and **22**, it may be seen that cylinder block **299** has at an inner end thereof a flat, rectangular cross-section bulkhead web **314**. Cylinder block bulkhead **314** has through its thickness dimension an axially disposed piston rod bore **315** which is coaxial with cylinder bore **290**. Piston rod bore **315** receives therein a cylindrically-shaped piston rod bearing bushing **316**. Piston rod bearing bushing **316** holds longitudinally slidably through a central coaxial bore **317** therethrough a piston rod **318** which extends coaxially outwards from the inner transverse face **313** of piston **291**.

As may be seen best by referring to FIG. **22**, an inner axial end of piston rod **318** extends inwardly through piston rod bearing bushing **316** into an enlarged, triangular cross-section bore **319** which is disposed through upper and lower outer faces **320**U, **320**L of central block-shaped section **168** of actuator housing **161**.

As shown in FIG. **22**, opposed inner ends **321**U, **321**L of piston rods **318**U, **318**L are fastened to opposite ends **322**U, **322**L of a linear rack gear **323**. Rack gear **323** has on a longitudinally disposed right-side **324** thereof gear teeth **325** which mesh with gear teeth **326** in the outer circumferential wall surface **327** of spur gear **211**.

From the foregoing description of the construction of actuator **104**, it should be clear that when pressurized air is introduced into upper air inlet port **123** of upper cylinder **125**, upper piston **291**U is forced downwardly within the bore **290**U of upper cylinder housing **172**U, from the NEUTRAL position shown in FIG. **22**, to a downward limit position as shown in FIGS. **25** and **26**. It should also be clear that downward motion of upper piston **291**U causes upper piston rod **318**U and rack gear **323** to be forced downwardly. Downward motion of rack gear **323** in turn causes spur gear **211** to be rotated to a counterclockwise limit position, and thus also cause valve rotor shaft **166** and valve rotor **176** to be rotated to counterclockwise limit positions in which hydraulic valve **103** is in an OPEN position.

Conversely, when pressurized air is introduced into lower air inlet port **124** of lower cylinder **126**, lower piston **291**L is forced upwardly, causing rack gear **323** to be forced upwardly. Upward motion of rack gear **323** in turn causes spur gear **211** to rotate to a clockwise limit position, and thus also rotate valve rotor shaft **166** and valve rotor **176** to a clockwise limit position. In this position valve **103** is in a CLOSED position.

As those skilled in the art of oil well blow-out preventers will know, the hydraulic pressures required for operating blow-out preventers are quite large, ranging up to 2,000 to 3,000 psi or more. Also, as has been described above, hydraulic valve **103** according to the present invention must be capable of conducting hydraulic fluid through mating parts on the lower surface of the valve rotor **176** and upper surfaces of sealing rings **246**, **247**, **248** in valve port interface base plate **135**. Consequently, it can be readily appreciated that rotating, sliding contact forces between the lower surface of valve rotor **176** and the upper surfaces of sealing rings **246**, **247** and **249** protruding from the upper surface of valve port interface base plate **135** must be relatively high to minimize leakage of highly pressurized hydraulic fluid in radial directions from aligned ports in the rotor base and valve port interface base plate **135**.

Thus, contacting pressures required between the face of the valve rotor **176** and the upper faces of sealing rings **246**, **247**, **249** in valve interface base plate **135** can be as high as 3000-4000 psi. Therefore, the torque required to turn valve rotor shaft **166** between open, closed and neutral positions can be as high as 45 foot pounds, for a shaft diameter of ⅞ inch, and correspondingly higher torque values for larger shaft diameters used for larger capacity valves. In view of the foregoing facts, it can be readily appreciated that the linear forces between contacting teeth of the rack gear **323** and spur gear **211** can be as high as 64 pounds. And it can also be appreciated that each time rotor **176** of valve **103** is rotated, there can be a certain degree of surface wear caused by ablation of contact surfaces of the rack gear **323** and spur gear **211**. Eventually, such wear of the meshing teeth of the rack gear and spur gear will result in an unacceptably large amount of free-play, or gear-train back-lash.

Advantageously, the novel design and construction of actuator **104** according to the present invention can essentially double the useful service life of spur gear **211**, by utilizing the following procedure. Spur gear **211** is mirror symmetric about a plane perpendicular to its flat, upper and lower surfaces and centered between and parallel to the flats bordering the rotor shaft bore through the spur gear. Therefore, when wear-caused gear train back lash reaches a pre-determined value, valve **103** may be disassembled sufficiently far for spur gear **211** to be removed from valve rotor shaft **166** rotated 180 degrees or "flipped" about a diameter of the spur gear located midway between parallel flats of the spur gear rotor shaft bore, and replaced on the rotor shaft, thus placing a new half of the spur gear in meshing contact with the rack gear.

Although actuator/valve assemblies **101** are preferably oriented with the long axis of each actuator **104** vertically oriented as shown in FIGS. **11** and **14**, the actuators may optionally be oriented with the long axis horizontally oriented. Also, actuator body **161** may optionally have a unitary, single piece construction in which central square block-shaped housing section **168** and upper and lower cylinder housing extensions **172**, **173** are integrated into a single body **161**.

Also, actuator assemblies **101** may optionally utilize pressurized hydraulic fluid rather than pressurized air to achieve larger actuation forces.

FIGS. **39-49** illustrate a modification of the pneumatic actuator and valve assembly **101** used in modular control apparatus **100** described above. Modified modular pneumatic actuator and hydraulic valve assembly **401** includes a modified pneumatic actuator **404**, which has a unitary, monolithic housing body **461** in which opposed air cylinders and air passageways for supplying pressurized air to the cylinders are machined from a single block of a durable material such as aluminum or other metal.

As shown in FIGS. **39-44**, modified actuator/valve assembly **401** includes a modified pneumatic actuator **404** which is attached to a hydraulic valve **403**. As shown in FIGS. **39-44**, hydraulic valve **403** has hydraulic fluid ports located in the sides of the valve base **435**, rather than in the lower surface of the manifold-mount valve **103** described above.

Thus as shown in FIGS. **39-44**, hydraulic valve **403** has four hydraulic fluid ports **437**, **438**, **439** and **440** located in side walls of base **435** of the valve. Those ports are exactly analogous in structure and function to ports **137**, **138**, **139** and **140** of hydraulic valve **103** described above. Optionally, modified pneumatic actuator may optionally be attached to and used with a manifold-mount valve **103**.

FIGS. **45-49** illustrate details of the construction and function of modified pneumatic actuator **404**.

As shown in FIGS. **45-49**, modified pneumatic actuator **404** has a construction and function similar to that of pneumatic actuator **104** described above. However, actuator **404** has a monolithic construction in which a single rectangularly shaped metal block which has a longitudinally elongated rectangular prism shape is machined to form a housing **461** that includes a central section **468** analogous to central section **168** of actuator **104**. Housing **461** also has left and right housing sections **472** and **473** which extend left-ward and right-ward from central housing section **468**, which are analogous to upper and lower housing sections **172**, **173** of pneumatic actuator **104**.

As shown in FIGS. **46-49**, left and right housing sections **472**, **473** contain therewithin left and right air cylinders **425**, **426**, respectively, which are pressurizable by left and right inlet ports **423**, **424**, respectively.

In a manner exactly analogous to that described above for actuator/valve assembly **101**, actuator/valve assembly **401** is constructed in a manner which causes a valve rotor shaft **466** and manual control handle **467** of hydraulic valve **403** to rotate to a counterclockwise OPEN position when right-hand air cylinder **426** is pressurized with air through right-hand air inlet port **424**, as shown in FIG. **47**.

Conversely, when left-hand air cylinder **472** is pressurized with air through left-hand actuator air inlet port **423**, valve rotor shaft **466** and manual control valve **467** are rotated to a clockwise CLOSED position.

As shown in FIGS. **39-43**, housing **461** of actuator **404** of actuator/valve assembly **401** according to the present invention includes a central square cross-section, block-shaped section **468** which has a flat, square lower face **469** that seats on and is bolted to square, flat upper face **470** of valve housing **434** by bolts **471**, as shown in FIGS. **39** and **40**.

As shown in FIGS. **43** and **46**, central block-shaped section **468** of pneumatic actuator housing **461** has formed therein a cavity **619** in which is located a spur gear **511**. Spur gear **511** is pinned to the upwardly protruding end of rotor shaft **466** of hydraulic valve **403**, as shown in FIG. **46**.

As shown in FIGS. **46**, **47**, and stated above, left and right housing sections **472**, **473** of housing **461** of pneumatic actuator **404** contain therein identically constructed left and right actuator air cylinders **425**, **426**, respectively. Each air cylinder **425**, **426** includes a circular cross-section cylinder bore **590**R, **590**L machined into housing block **461**.

The cylinder bores **590**R, **590**L of left and right air cylinders **425**, **426** each hold longitudinally slidably therewithin a piston **591**L, **591**R, respectively. Each piston **591**L, **591**R has generally the shape of a short right-circular cylinder or disk which has an outer circumferential wall surface **592** in which is formed an annular ring-shaped groove **593** that holds therein an elastically deformable O-ring type piston ring **594**. The outer circumferential wall surface **595** of piston ring **594** longitudinally slidably contacts in hermetically sealing contact the inner cylindrical wall surface **596** of air cylinder bore **590**.

As shown in FIGS. **45-48**, the bore **590**L, **590**R of each air cylinder **425**, **426** penetrates one of a pair of opposed parallel transverse outer end faces **600**L, **600**R of housing **461**. Each cylinder **425**, **426** also has a thin rectangular block-shaped cylinder head **601**L, **601**R which has an outer flat transversely disposed face **602**L, **602**R and a parallel inner transversely disposed face **603**L, **603**R. Each cylinder head **601**L, **601**R is secured to housing **461** with inner face **603**L, **603**R of the cylinder head in flat, hermetically sealing abutting contact with outer face **600**L, **600**R of the housing **461** by bolts **604**L, **605**L, **606**L, **607**L; **604**R, **605**R, **606**R, **607**R at the corners of the housing and cylinder heads **601**L, **601**R, respectively.

As may be seen best by referring to FIGS. **43-45** and **47-51**, left and right cylinder heads **601**L, **601**R include inlet ports **423**, **424**, respectively, for receiving pressurized air. The ports penetrate short sides **609**L, **609**R of cylinder heads **601**L, **601**R, respectively. Each air inlet port **423**, **424** communicates at a radially inwardly located end thereof with a transversely disposed air passageway **610**L, **610**R. Each air passageway **610**L, **610**R communicates at an inner end thereof with an outer portion of a cylinder bore **590**L, **590**R that forms a cylinder head space **611**L, **611**R. Cylinder head space **611**L, **611**R is located between the head face **612**L, **612**R of piston **591**L, **591**R and the inner face **603**L, **603**R of a cylinder head **601**L, **601**R.

Referring now to FIGS. **45-47**, it may be seen that each cylinder bore **590**L, **590**R terminates at an inner end thereof in a flat, transversely disposed web that forms a bulkhead **614**L, **614**R which is part of unitary housing block **461**. Each bulkhead **614**L, **614**R has through its thickness dimension a central circular cross-section bore **615**L, **615**R. Each bore **615**L, **615**R receives conformally therein a cylindrically shaped piston rod bearing bushing **616**L, **616**R. Each piston rod bearing bushing **616**L, **616**R holds longitudinally slidably through a central coaxial bore **617**L, **617**R therethrough a piston rod **618**L, **618**R which extends coaxially outward from the inner or lower transverse faces **613**L, **613**R of pistons **591**L, **591**R, respectively.

As may be seen best by referring to FIGS. **45-47** and **48**, the inner axial end of each piston rod **618**L, **618**R extends inwardly through a piston rod bearing bushing **616**L, **616**R into an enlarged, triangular cross-section cavity **619** which is disposed through upper and lower outer faces **462**, **469** of central block-shaped section **468** of actuator housing **461**.

As shown in FIGS. **46** and **47**, opposed inner ends **621**L, **621**R of piston rods **618**L, **618**R are fastened to opposite ends **622**L, **622**R of a linear rack gear **623**. Rack gear **623** has on a longitudinally disposed rear side **624** thereof gear teeth **625** which mesh with gear teeth **626** in the outer circumferential wall surface **627** of spur gear **511**.

From the foregoing description of the construction of actuator **404**, it should be clear that when pressurized air is introduced through left-hand air inlet port **423** into bore **590**L of left-hand cylinder **425**, left-hand piston **591**L is forced rightwardly within the bore **590**L of left-hand cylinder housing **572**L, from a neutral position to a right-hand limit position. It should also be clear that rightward motion of left-hand piston **591**L causes left-hand piston rod **618**L and rack gear **623** to be forced rightward. Rightward motion of rack gear **623** in turn causes spur gear **511** to be rotated to a clockwise limit position and thus also causes valve rotor shaft **466** and valve rotor **476** to be rotated to a clockwise limit position in which hydraulic valve **403** is in a CLOSED position.

Conversely, when pressurized air is introduced through right-hand air inlet port **424** into bore **590**R of right-hand cylinder **425**, right-hand piston **591**R and rack gear **623** are forced leftwards. Leftward motion of rack gear **623** in turn causes spur gear **511** to be rotated to a counterclockwise limit position and thus also rotate valve rotor shaft **466** and valve rotor **476** to a counterclockwise limit position, as shown in FIG. **46**. In this position, hydraulic valve **403** is in an OPEN position.

As may be seen best by referring to FIGS. **44**, **45**, and **47**, modified pneumatic actuator **404** includes a novel arrangement of auxiliary conduits for pressurized air which nearly double the force exertable by either piston **591**L, **591**R from a value of P×A, where P is the pressure of pressurized air introduced into the head space of a cylinder, and A is the area of the piston head.

Thus as shown in FIGS. **44**, **45**, and **47**, there is connected to transversely disposed air passageway **610**R that carries pressurized air from air inlet port **424** of right-hand air cylinder **426** to head space **611**R of the right-hand air cylinder bore **590**R a longitudinally disposed auxiliary conduit **630**L for pressurized air. Auxiliary conduit **630**L extends leftwards within housing block **461** to a location in approximate transverse alignment with bulkhead **614**L of left-hand cylinder **426**. Auxiliary conduit **630**L has at a lefthand end thereof a shorter transversely disposed right-angle elbow extension **631**L. Elbow extension **631**L extends inward to a location on a side of cylinder bulkhead **614**L opposite that of cylinder bore **590**L, and has a short L-shaped nozzle section **632**L which penetrates right-hand cylinder bulkhead **614**L. An air output orifice **633**L of nozzle section **632**L communicates with a downstroke part **634**L of left-hand cylinder bore **590**R, which is located below lower or downstroke face **613**L of left-hand piston **591**L.

The force exerted on right-hand piston **591**R and hence on piston rod **618**R and spur gear **511** by air at pressure P in cylinder bore **590**L is P×A, where A is the area of the head face **612**R of piston **591**R. However, the addition of auxiliary air conduit **630**L results in a force P×B being exerted simultaneously on the downstroke side of left-hand piston **591**L, where B is the area of the downstroke side face **613**L of the piston. As may be envisioned by viewing FIGS. **44** and **47**, the area of downstroke face **613**L of piston **591**L is equal to the area of piston head face **612**L minus the cross-sectional area of piston rod **618**L. Since the ratio between piston rod area and piston face area would typically be less than about one-tenth, the force exerted by rack gear **623** with the addition of auxiliary air conduit **630**L is about 90 percent greater than could be produced by pressurizing only the head space **611**R of right-hand cylinder **590**R.

As shown in FIGS. **44**, **45**, and **47**, the novel construction of modified pneumatic actuator **404** which increase the leftward force exerted on rack gear **623** when pressurizing right-hand cylinder **590**R has analogous components which increase rightward force when left-hand cylinder **590**L is pressurized.

Thus as shown in FIGS. **44**, **45**, and **47**, there is connected to transversely disposed air inlet passageway **610**L that carries pressurized air from air inlet port **423** of left-hand air cylinder **425** to head space **611**L of the left-hand air cylinder bore **590**L a longitudinally disposed auxiliary conduit **630**R for pressurized air. Auxiliary conduit **630**R extends rightward within housing block **461** to a location in approximate transverse alignment with bulkhead **614**R of right-hand cylinder **426**. Auxiliary conduit **630**R has a a right-hand end thereof a shorter transversely disposed right-angle elbow extension **631**R. Elbow extension **631**R extends inward to a location on a side of cylinder bulkhead **614**R opposite that of cylinder bore **590**R, and has a short L-shaped nozzle section **632**R which penetrates right-hand cylinder bulkhead **614**R. An air output orifice **633**R of nozzle section **632**R communicates with a downstroke part **634**R of right-hand cylinder bore **590**R, which is located below lower or downstroke face **613**R of right-hand piston **591**R.

The force exerted on left-hand piston **591**L and hence on piston rod **618**L and spur gear **511** by air at pressure P in cylinder bore **590**L is P×A, where A is the area of the head face **612**L of piston **591**L. However, the addition of auxiliary air conduit **630**R results in a force P×B being exerted simultaneously on the downstroke side of right-hand piston **591**R, where B is the area of the downstroke side face **613**R of the piston. As may be envisioned by viewing FIGS. **44** and **47**, the area of downstroke face **613**R of piston **591**R is equal to the area of piston head face **613**R minus the cross-sectional area of piston rod **618**R. Since the ratio between piston rod area and piston face area would typically be less than about one-tenth, the force exerted on rack gear **623** with the addition of auxiliary air conduit **630**R is about 90 percent greater than could be produced by pressurizing only the head space **611**L of left-hand cylinder **590**L.

What is claimed is:

1. A modular oil well blow-out preventer (BOP) control apparatus for controlling flow of pressurized hydraulic fluid to hydraulic actuator cylinders of a BOP, said apparatus comprising;

a. at least a first multiple-position rotary hydraulic valve which has a rotor rotatable between a closed position and at least a first open position for controlling flow of pressurized hydraulic fluid between a source of pressurized hydraulic fluid and an hydraulic line connected to said valve and an hydraulic actuator cylinder of a BOP, said valve having protruding from a housing thereof a rotor shaft having a manually operable handle to open and close said valve,

b. a linear actuator operably connected to said valve shaft for reversibly opening and closing said valve, said linear actuator including at least a first cylinder which holds therein a piston slidably movable in response to pressurization of said cylinder,

c. a force coupling mechanism for converting linear motion of said piston in said cylinder into rotary motion of said valve rotor, said force coupling mechanism including in combination a curved gear fastened coaxially to said rotor shaft of said valve, said curved gear having teeth on an outer convex surface thereof, and a single linear gear which has teeth which mesh with said teeth of said curved gear, said linear gear being reciprocally translatable in response to linear motion of said piston in said first cylinder, said curved gear being a circular gear which is reversibly attached to said rotor shaft to thereby interchangeably engage opposite sides of said curved gear with said linear gear, said linear gear being a rack gear coupled at a first end to a piston rod extendible from said first cylinder, and

d. said linear actuator including a second cylinder, said second cylinder having a piston rod extendible therefrom coupled to a second end of said rack gear, said first and second piston rods of said linear actuator extending outwards from first and second opposed ends of said rack gear, and co-linearly aligned along a common action axis, said linear actuator having a central block-shaped central housing section which has a rear wall that receives rotatably therethrough said rotor shaft of said valve, said rotor shaft being received fixedly through the center of said curved gear and extending through a front wall of said central housing section, said first and second pistons of said linear actuator being linearly slidably located within first and second cylinder bores located in first and second cylinder housing sections which extend perpendicularly from upper and lower sides, respectively, of said central housing section of said linear actuator, said linear actuator including a first inlet port for pressurized fluid which communicates with a head space of said first cylinder bore located adjacent to the head of said first piston, and a second inlet port for pressurized fluid which communicates with a head space of said second cylinder bore located adjacent to the head of said second piston, said linear actuator further including a first auxiliary pressurized fluid conduit which communicates with said first inlet port and a downstroke part of said second cylinder bore located adjacent to the skirt side of said second piston.

2. The apparatus of claim **1** wherein said linear actuator further includes a second auxiliary pressurized fluid conduit which communicates with said second inlet port and a downstroke part of said first cylinder bore located adjacent to the skirt side of said first piston.

3. The apparatus of claim **2** wherein said linear actuator is pressurized by air.

4. The apparatus of claim **2** wherein said linear actuator is pressurized by hydraulic fluid.

5. The apparatus of claim **2** wherein said linear actuator is constructed from a single block of material in which are formed said first and second cylinder bores, first and second inlet ports, and first and second auxiliary pressurized fluid conduits.

6. The apparatus of claim **1** wherein said rotor shaft extending from said curved gear through a front wall of said central housing section of said linear actuator and has attached thereto a handle for manual rotation of said valve rotor.

7. The apparatus of claim **1** wherein said hydraulic valve is further defined as being a multiple position hydraulic valve having a pressure inlet port for connection to a source of pressurized hydraulic fluid, a Cylinder **1** opening outlet port, and a return outlet port connectable to a fluid reservoir, said valve having a first, opening configuration effective in conducting pressurized hydraulic fluid from said pressure port through said Cylinder **1** opening port to an opening hydraulic actuator cylinder of a BOP, and hydraulic fluid returned from a closing hydraulic actuator cylinder to a Cylinder **2**, closing port through said valve to said return port, a second, closing configuration effective in conducting pressurized hydraulic fluid from said pressure port through said Cylinder **2**, closing port to a closing hydraulic actuator cylinder of a BOP, and hydraulic fluid returned from said opening hydraulic actuator cylinder to said Cylinder **1** opening port through said valve to said return port, and a third, neutral configuration effective in blocking both said opening and closing ports.

8. The apparatus of claim **7** further including a pressurized fluid control panel for providing pressurized fluid to said linear actuator in response to a discrete configuration command to cause said linear actuator to configure said hydraulic valve into a selected one of said configurations.

9. The apparatus of claim **8** wherein said pressurized fluid control panel is further defined as comprising in combination;

a. at least a first manually operable opening, pressurized fluid control valve for conducting pressurized fluid from a source of pressurized fluid to a first opening pressure tube connected to a first, upper opening cylinder of a first linear actuator, and

b. at least a first, manually operable closing pressurized fluid control valve for conducting pressurized fluid from a source of pressurized fluid to a first closing pressure tube connected to a second, closing lower cylinder of said first linear actuator.

10. The apparatus of claim **9** wherein said pressurized fluid control panel includes at least a second set of manually operable opening and closing pressurized fluid control valves for connecting to a second linear actuator/hydraulic valve assembly.

11. The apparatus of claim **10** wherein said pressurized fluid control panel includes an actuator valve manifold, said actuator valve manifold having at least first and second sets of actuator valve manifold ports for pressure-tight mating with first and second sets of valve air ports of opening and closing actuator control valves, said actuator valve manifold having connected to each port a conduit for fluid pressure-tight connection to separate pressure tubes connected to a separate ones of said cylinders of said linear actuator.

12. The apparatus of claim **11** wherein said pressurized fluid control panel includes a pressurized fluid manifold positioned between said actuator valve manifold and said pressure tubes, said pressurized fluid manifold having an obverse face fastened in sealing contact with a reverse face of said actuator valve manifold, said pressure manifold having internal pressurized fluid conduits having at front ends thereof in said obverse face pressure manifold ports for pressure-tight mating with said actuator valve manifold air ports, and at rear ends thereof fluid pressure-tight connections to said pressure tubes.

13. The apparatus of claim **8** wherein said pressurized fluid is a pressurized gas.

14. The apparatus of claim **8** wherein said pressurized fluid is a pressurized hydraulic fluid.

15. The apparatus of claim **7** wherein said pressure inlet port, said Cylinder **1**, opening outlet port, and said Cylinder **2**, closing outlet port and said return are located in a valve port interface base plate at the base of said valve housing.

16. The apparatus of claim **15** wherein said four ports penetrate a rear wall of said valve port interface base plate.

17. The apparatus of claim **16** further including an hydraulic manifold, said hydraulic manifold having a first set of four manifold ports connectable in fluid pressure-tight sealing contact with said four ports in said valve port interface base plate of said first valve when said base plate is bolted to said hydraulic manifold, said manifold including a first, pressure conduit connectable to a source of pressurized hydraulic fluid, a second, Cylinder **1**, opening conduit connectable to an opening cylinder of a BOP, a third, Cylinder **2**, closing conduit connectable to a closing cylinder of a BOP, and a fourth, return conduit connectable to a hydraulic fluid reservoir.

18. The apparatus of claim **17** wherein said hydraulic manifold is further defined as including at least a second set of four manifold ports alignable in fluid pressure-tight sealing contact with corresponding ports of the valve port interface base plate of a second valve and actuator assembly.

19. The apparatus of claim **18** wherein said first and second set of four manifold ports are further defined as being oriented relative to one another so as to facilitate positioning of said first and second valve and actuator assemblies in a close side-by-side arrangement with said axes of said actuator cylinders mutually parallel.

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