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Bowen et al.

[11] **3,816,029**
[45] **June 11, 1974**

[54] **PUMPING UNIT FOR CONSTANT PULSELESS FLOW**

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[73] Assignee: **The Duriron Company, Inc.**, Dayton, Ohio

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[52] **U.S. Cl.** **417/223,** 417/339, 417/533, 417/539, 92/13.51, 92/86.5, 417/569
[51] **Int. Cl.** .. **F04b 49/00,** F04b 17/00, F04b 21/02
[58] **Field of Search** 417/521, 533, 534, 535, 417/536, 319, 223, 539; 92/13.8, 13.51, 13.5

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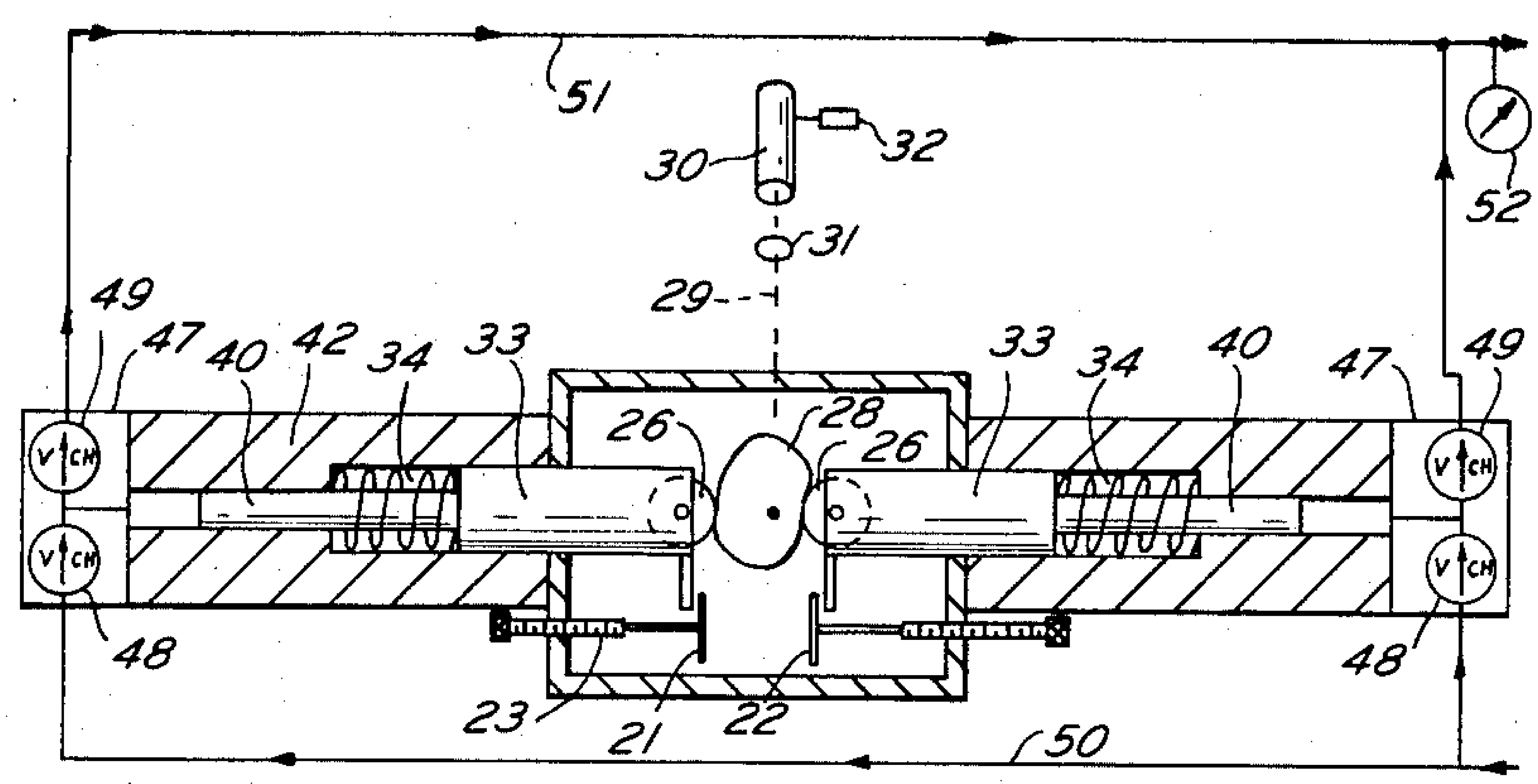
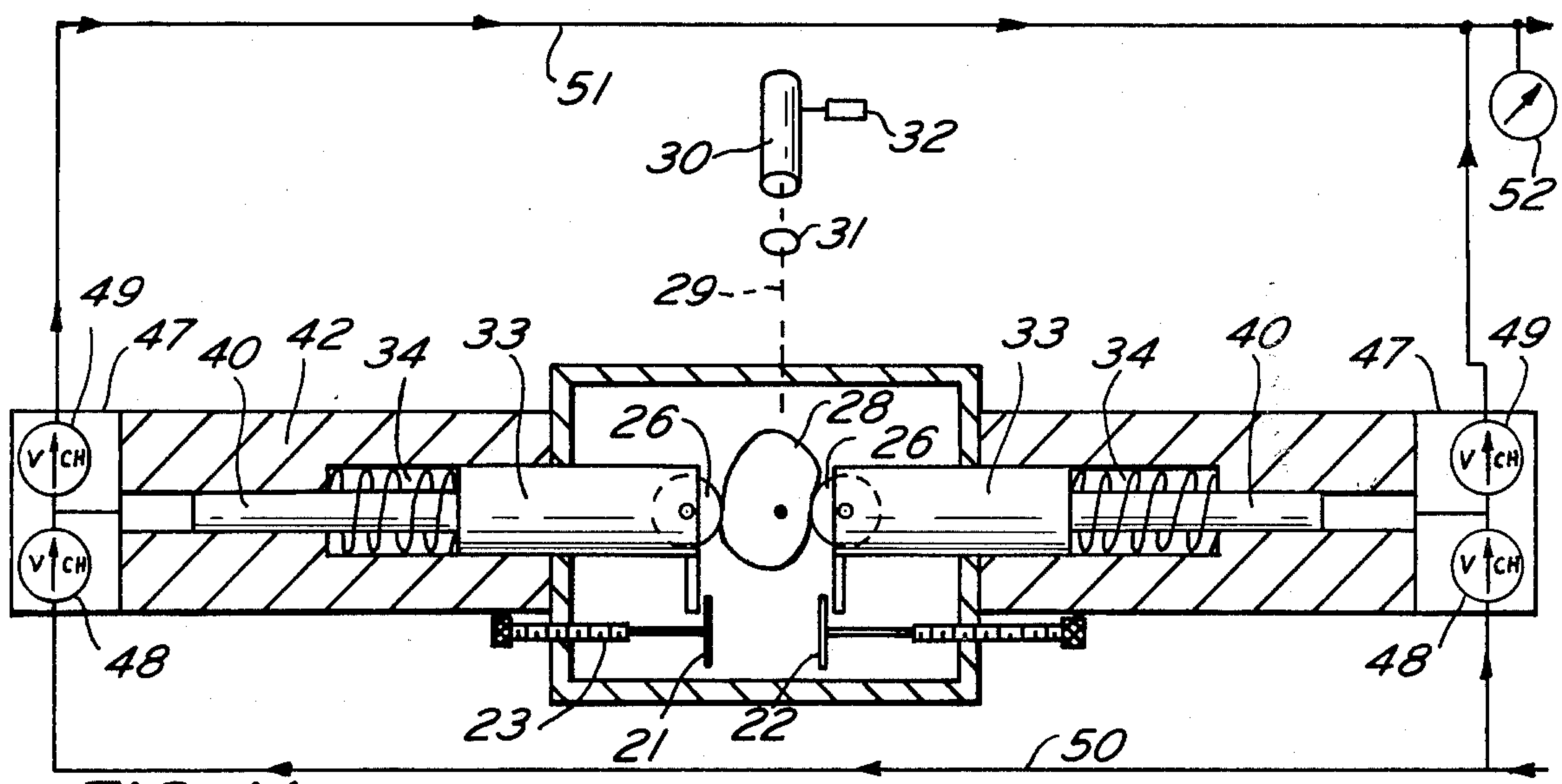
Primary Examiner—Carlton R. Croyle
Assistant Examiner—Richard E. Gluck
Attorney, Agent, or Firm—Zachary T. Wobensmith, 2nd

[57] **ABSTRACT**

A pumping unit for high pressure operation of the order of 10,000 psi or greater including upwards of 150,000 to 200,000 psi is disclosed which is essentially pulseless in its discharge, has no packing but utilizes plungers with hydrostatic supports and seals, and for this purpose two pumps and/or intensifiers are employed actuated by a cam directly or through fluid actuators for each cylinder. The cam has a constant rate of rise with a faster return rate. The return position is adjustable by a variably positioned stop or pick-off so that one cylinder will overcome compressibility and commence discharging fluid when the other cylinder finishes thereby providing a steady discharge flow rate. A simple low pressure hydraulic circuit and an air actuating circuit are described.

13 Claims, 12 Drawing Figures




51
30
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34
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26
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V CH
48
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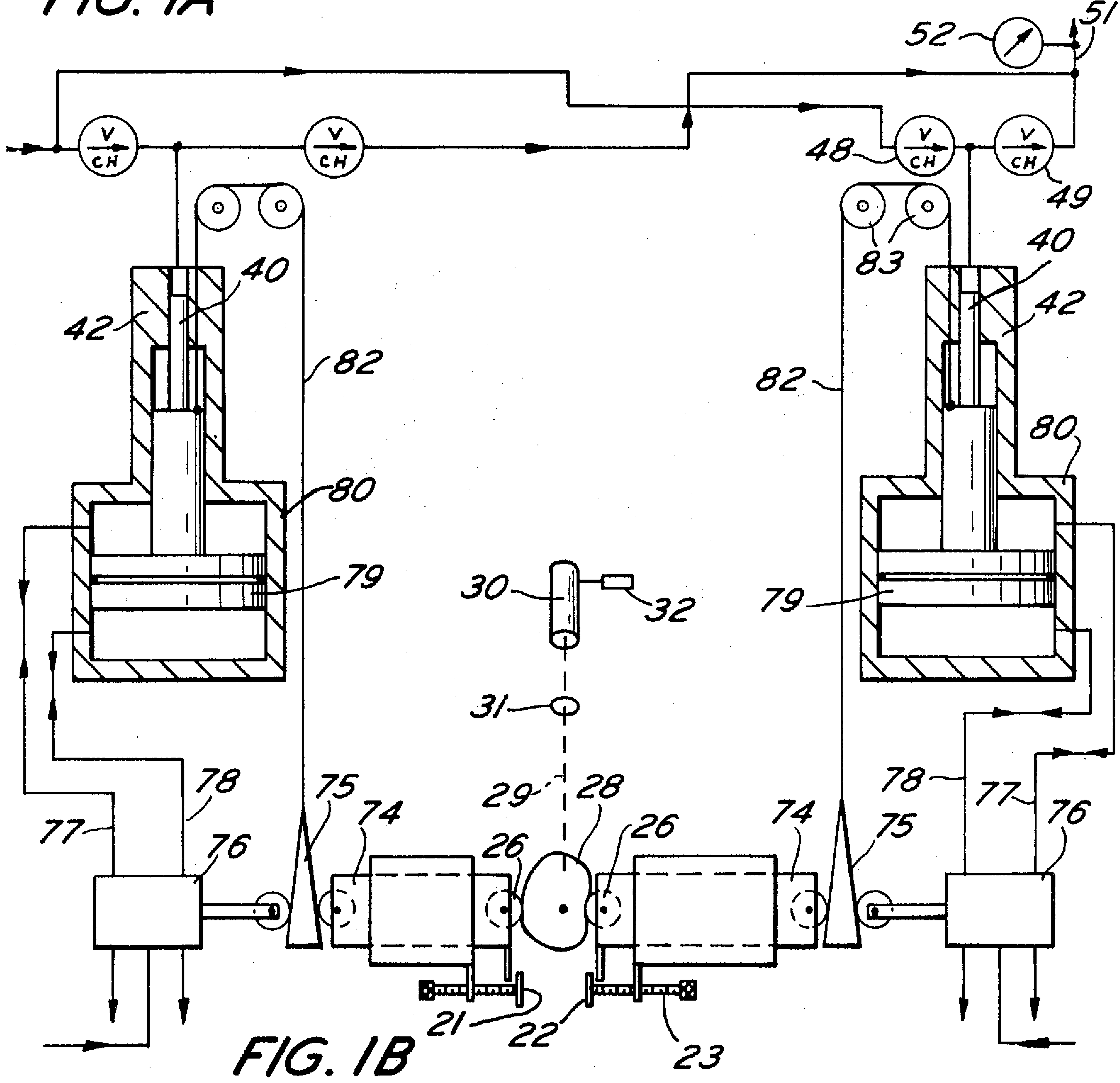
22
50

FIG. 1A


52
51
V CH
48
49
83
40
42
82
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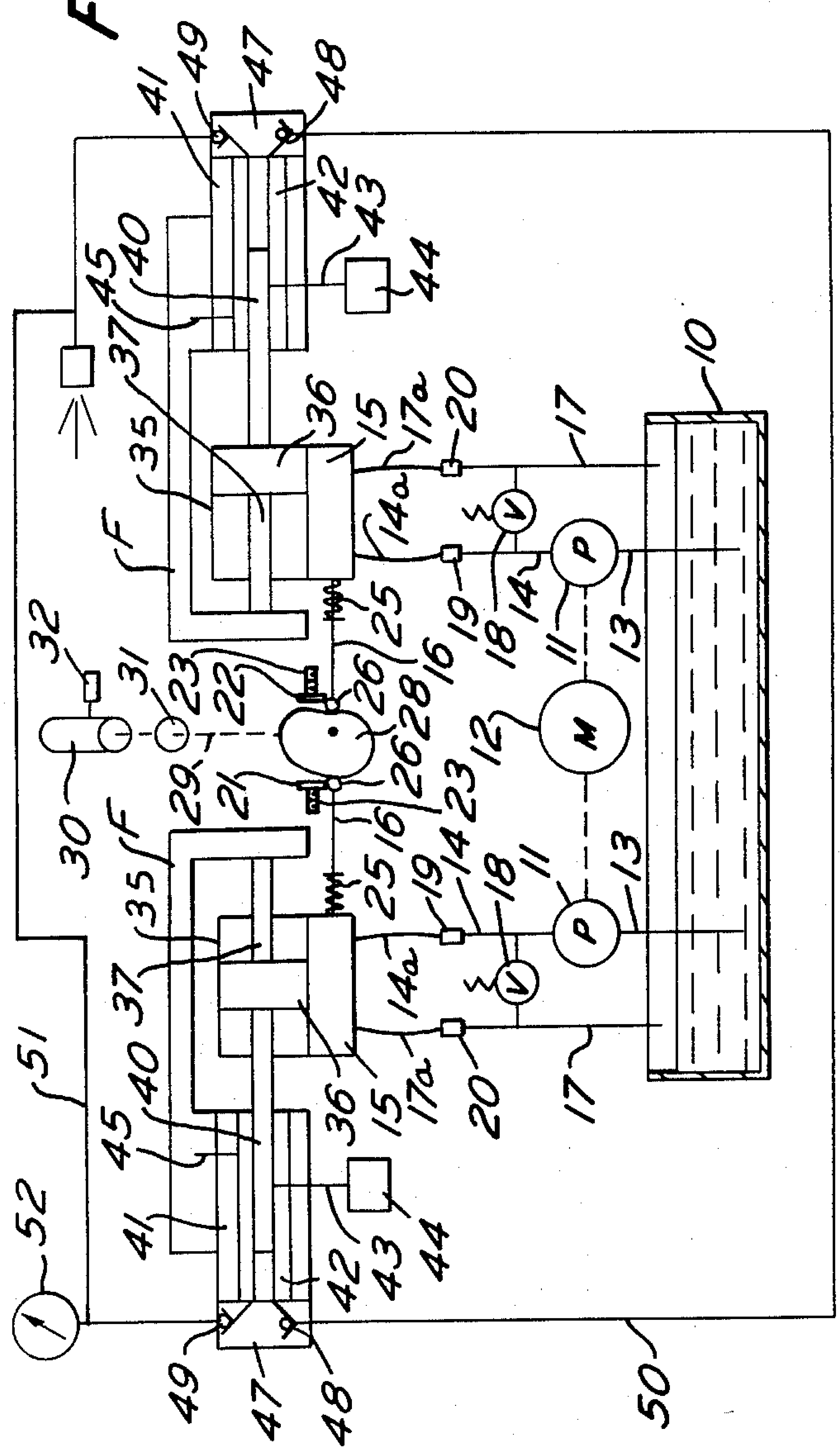
74
26
76
21
22
23

FIG. 1B

FIG. 1C


10
11
12
13
14
14a
15
16
17
17a
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21
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29
30
31
32
35
36
37
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41
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43
44
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47
48
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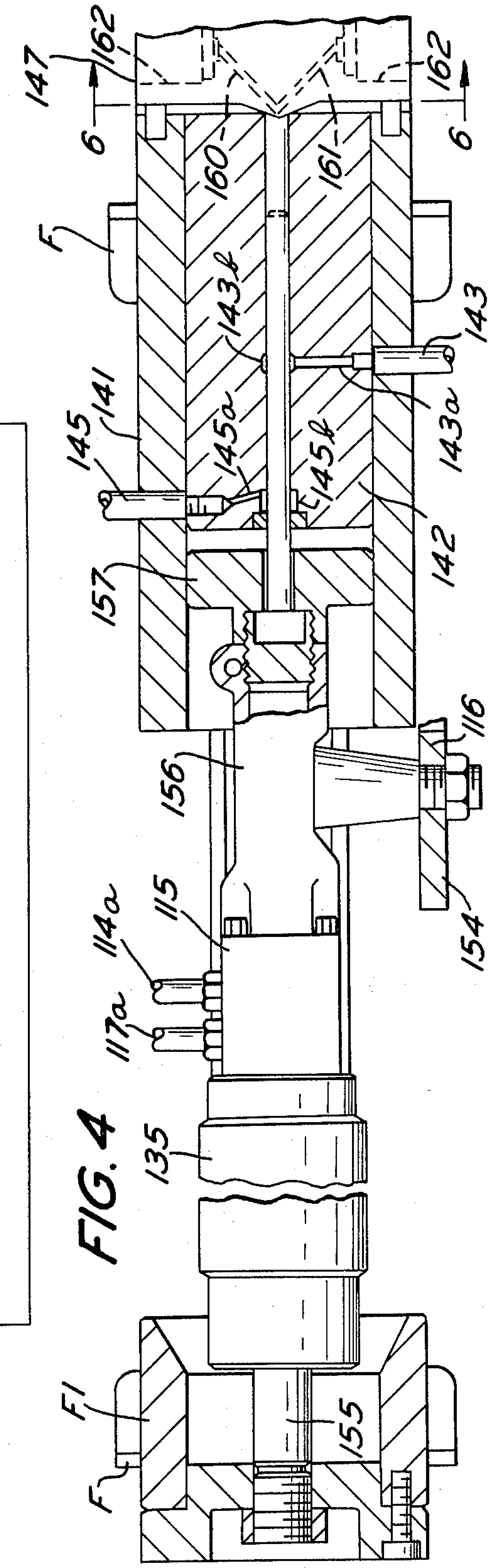
52
F
M
P
V

FIG. 4


6
F
F1
115
116
114a
117a
135
141
142
143
143a
143b
145
145a
145b
147
154
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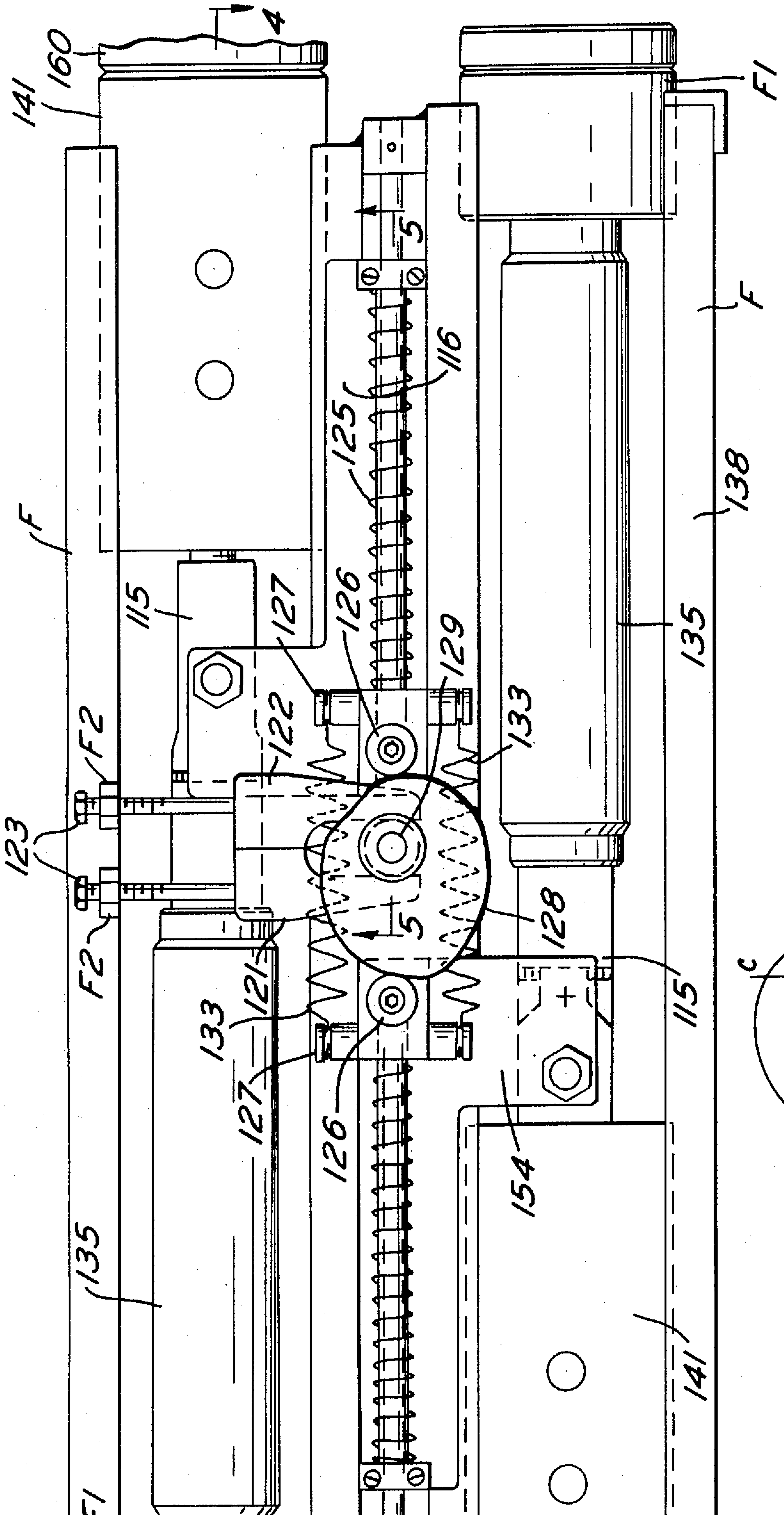
156
157
160
161
162


160
141
4
F1
F
5
116
125
138
F
127
126
115
129
135
122
133
F2
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121
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133
127
126
154
135
141
F1
3
4
160
3

FIG. 2

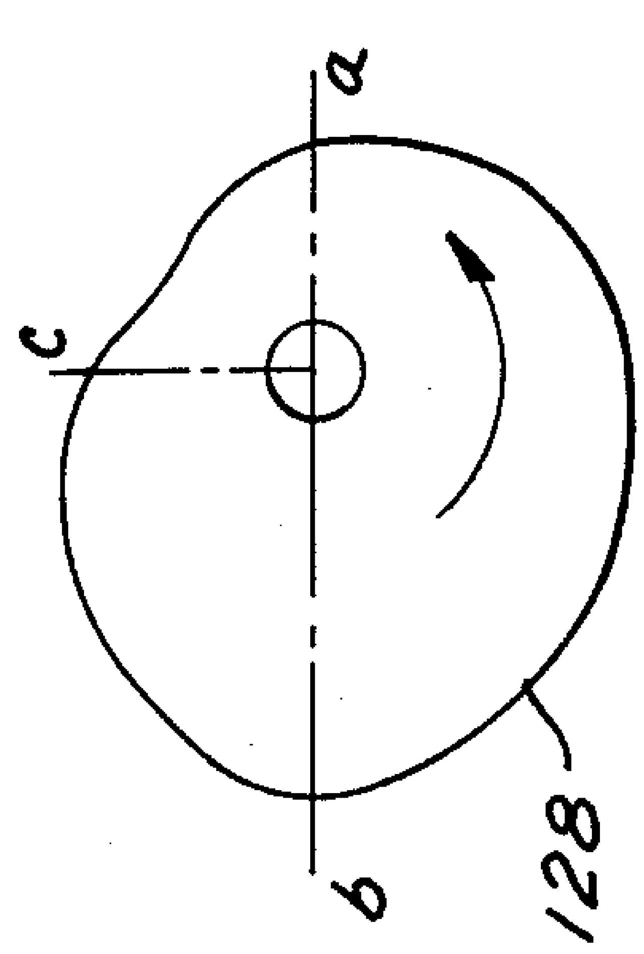

a
c
b
128

FIG. 10

FIG. 3

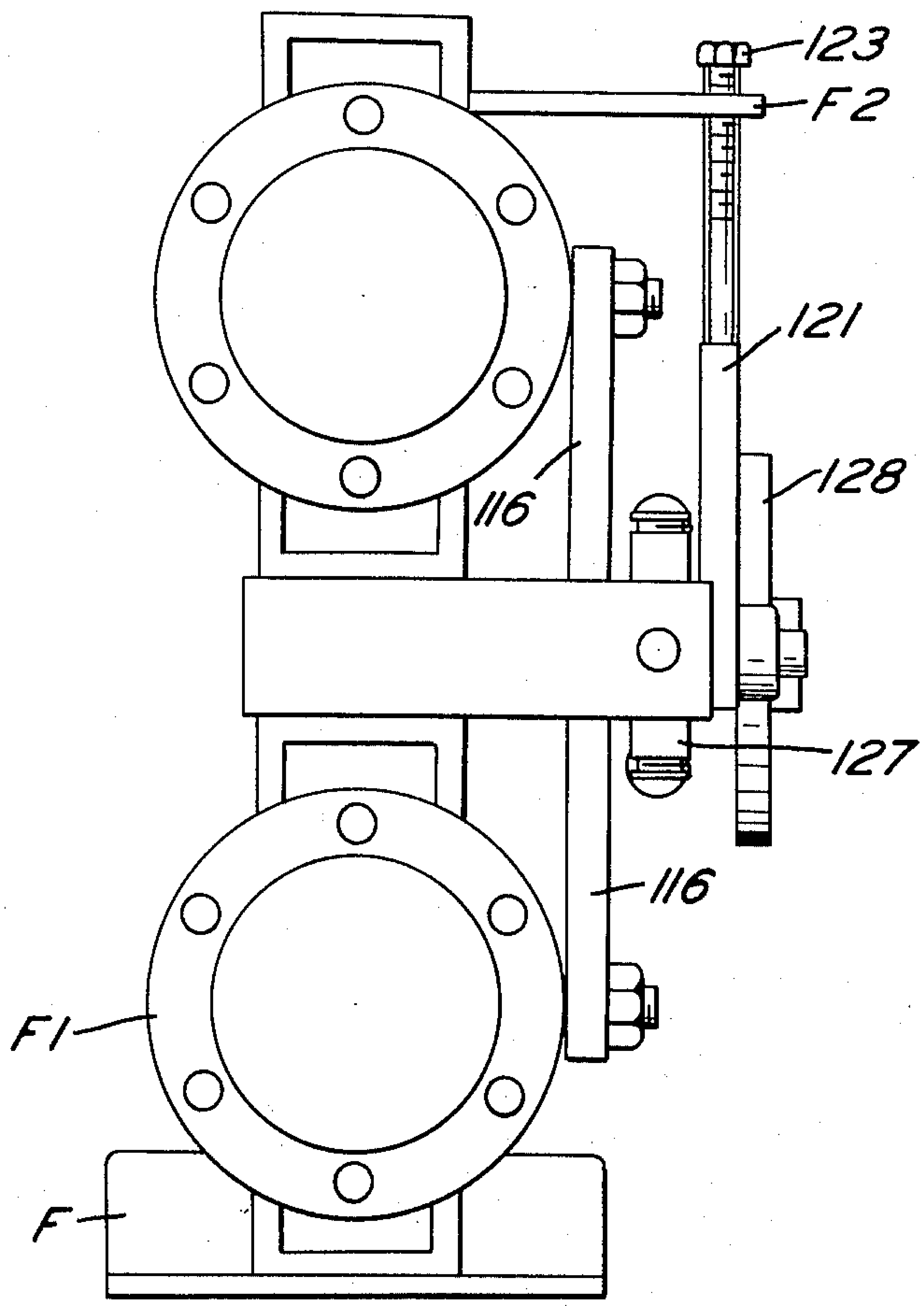
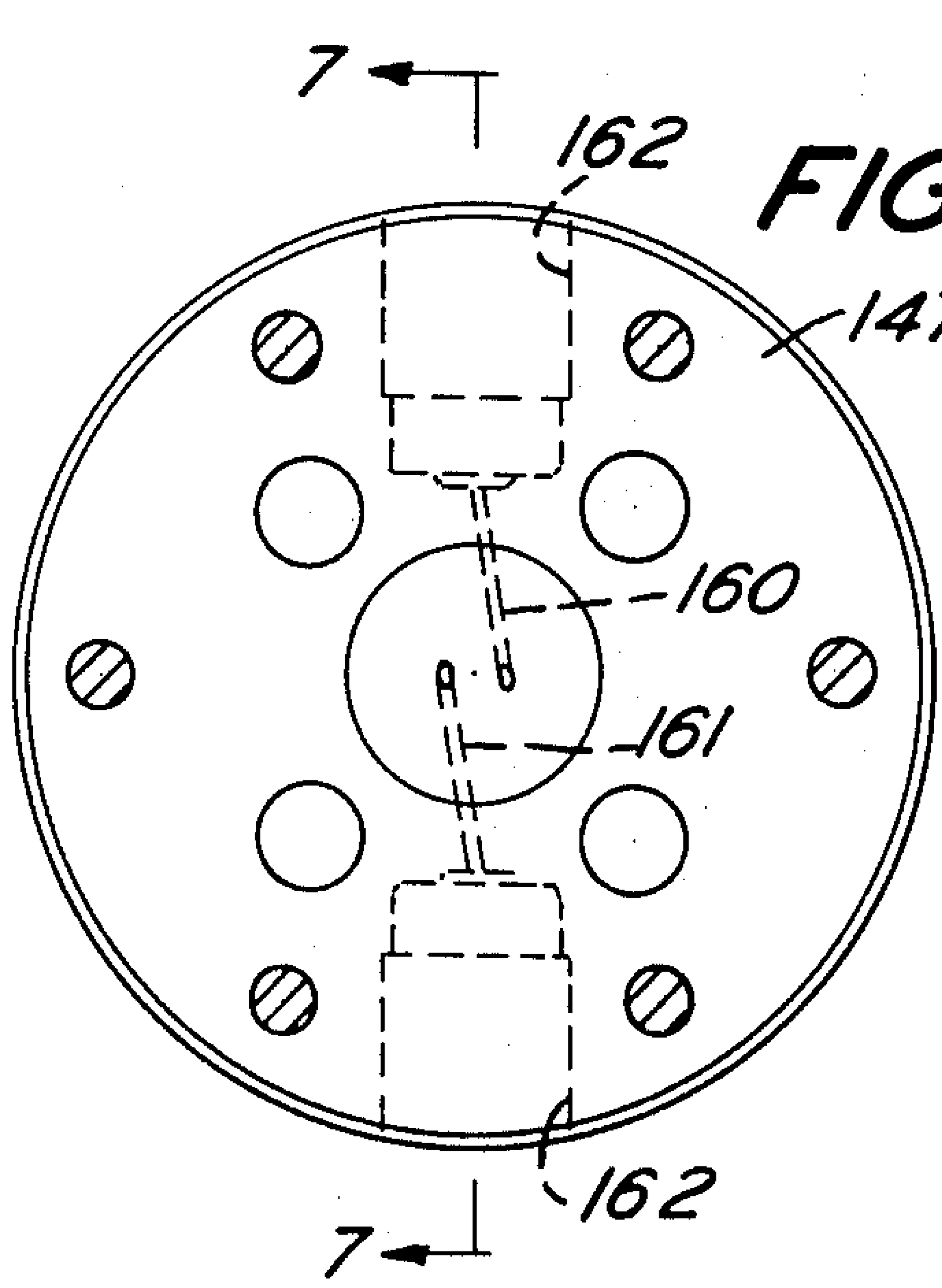


FIG. 6



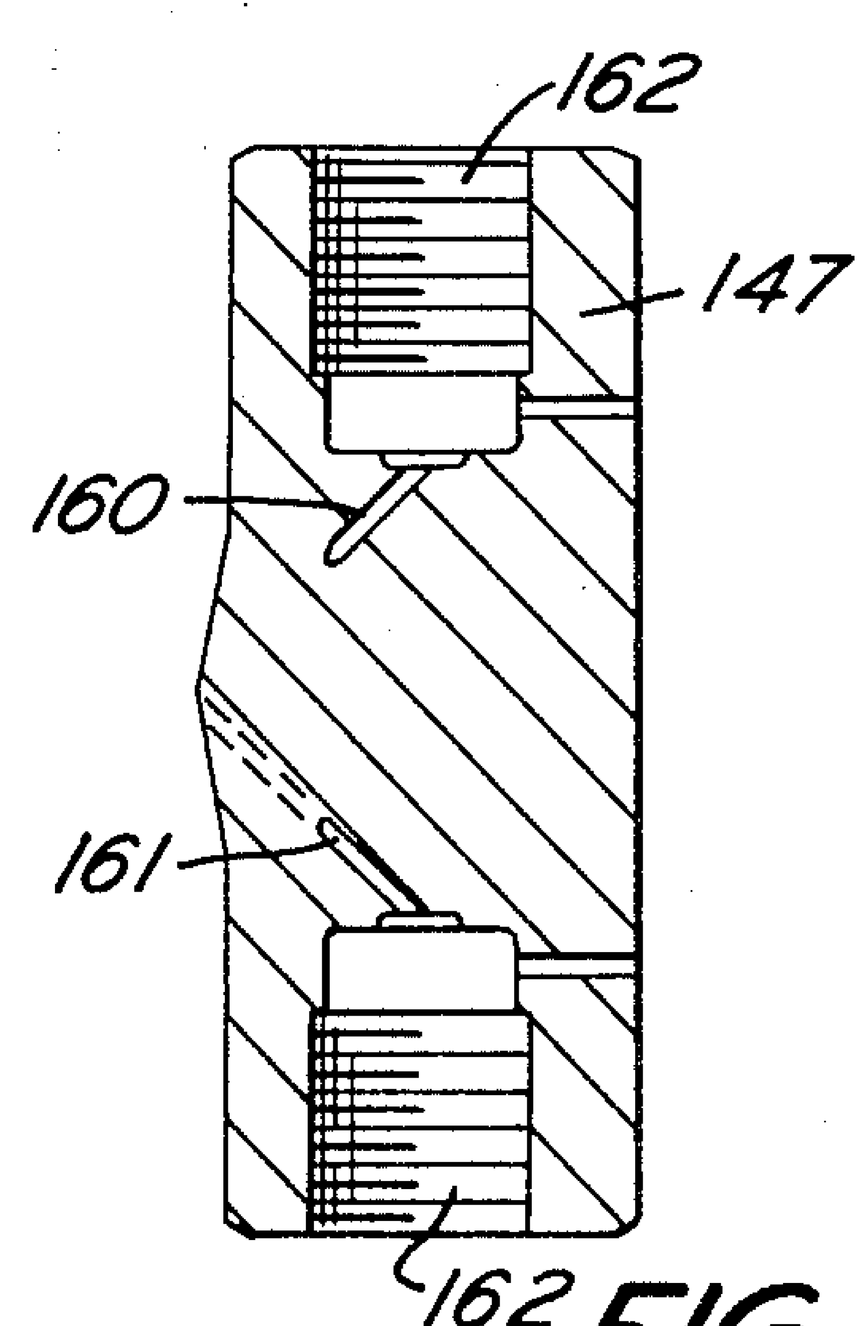


FIG. 7

FIG. 5

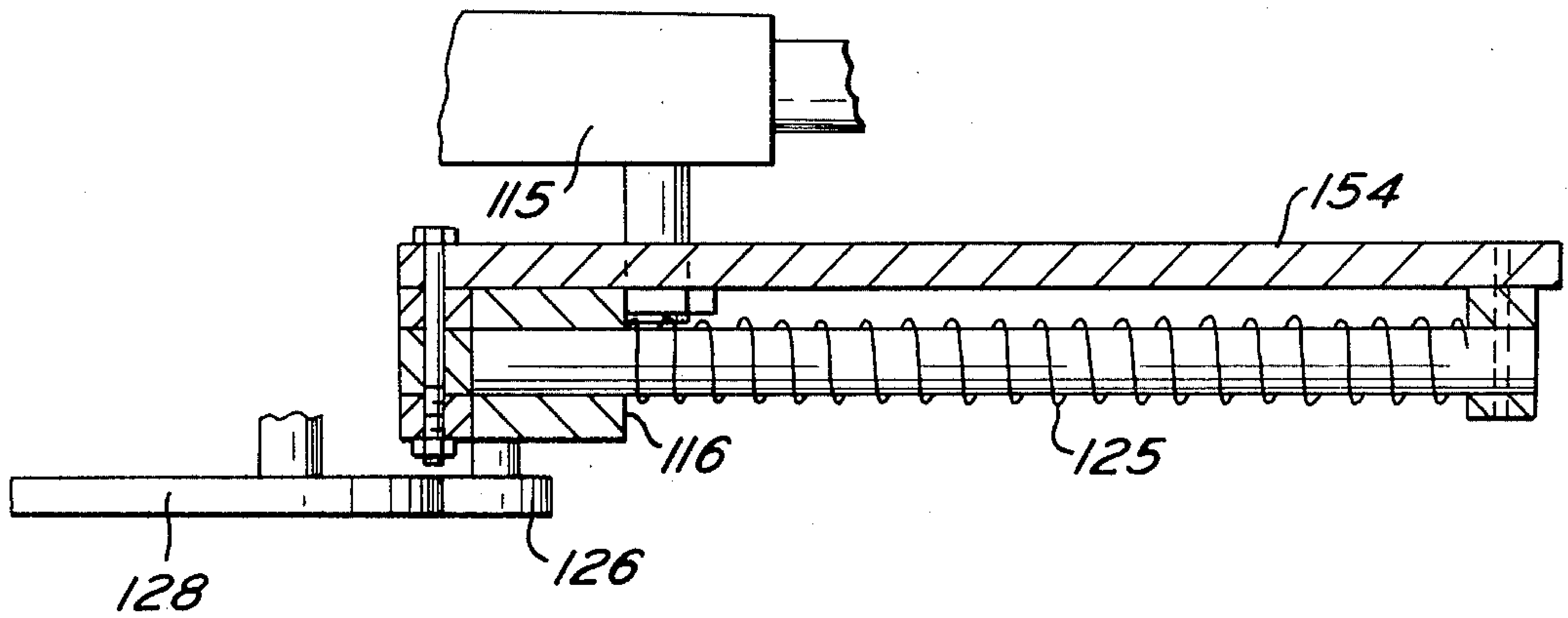
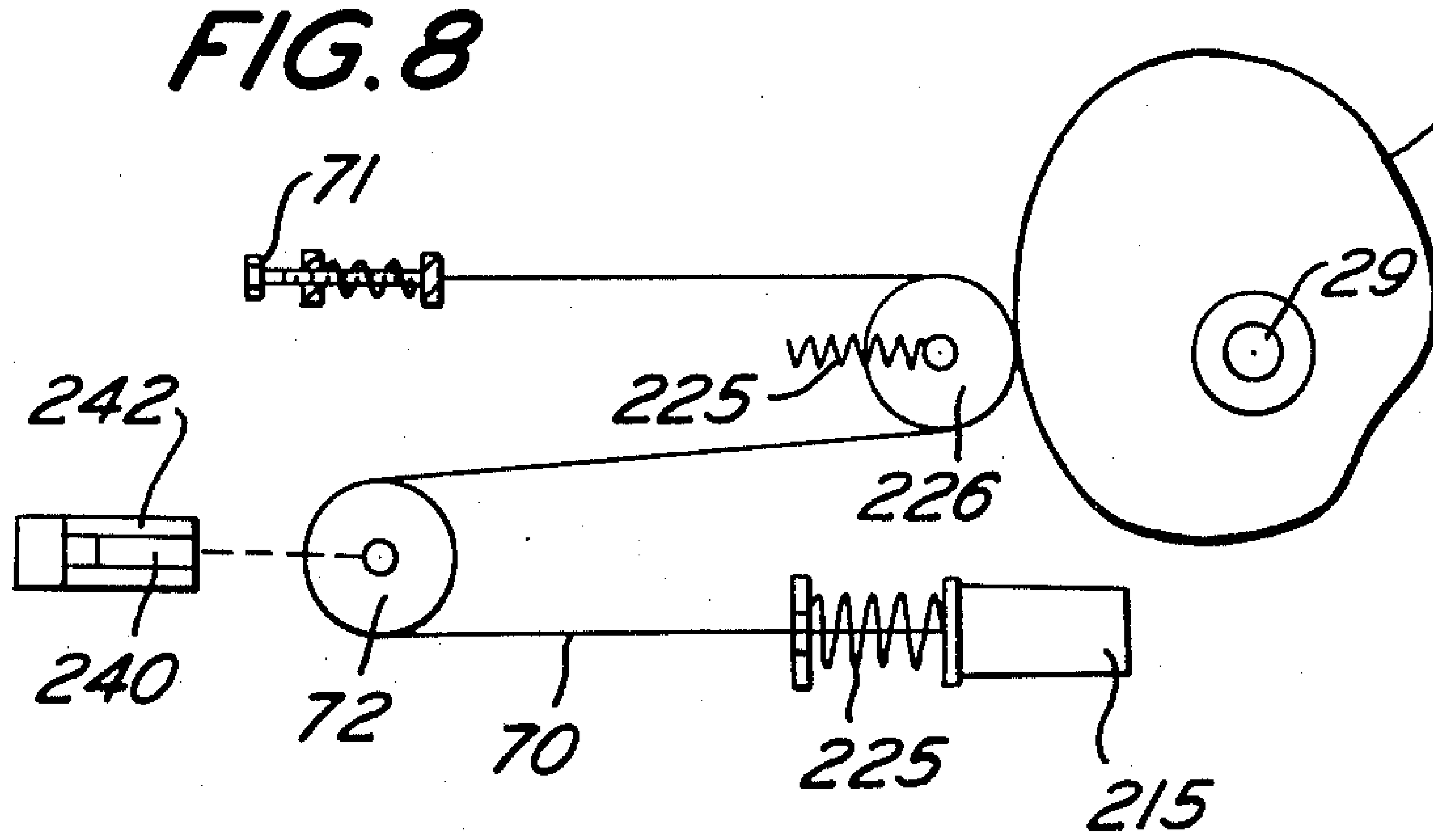


FIG. 8



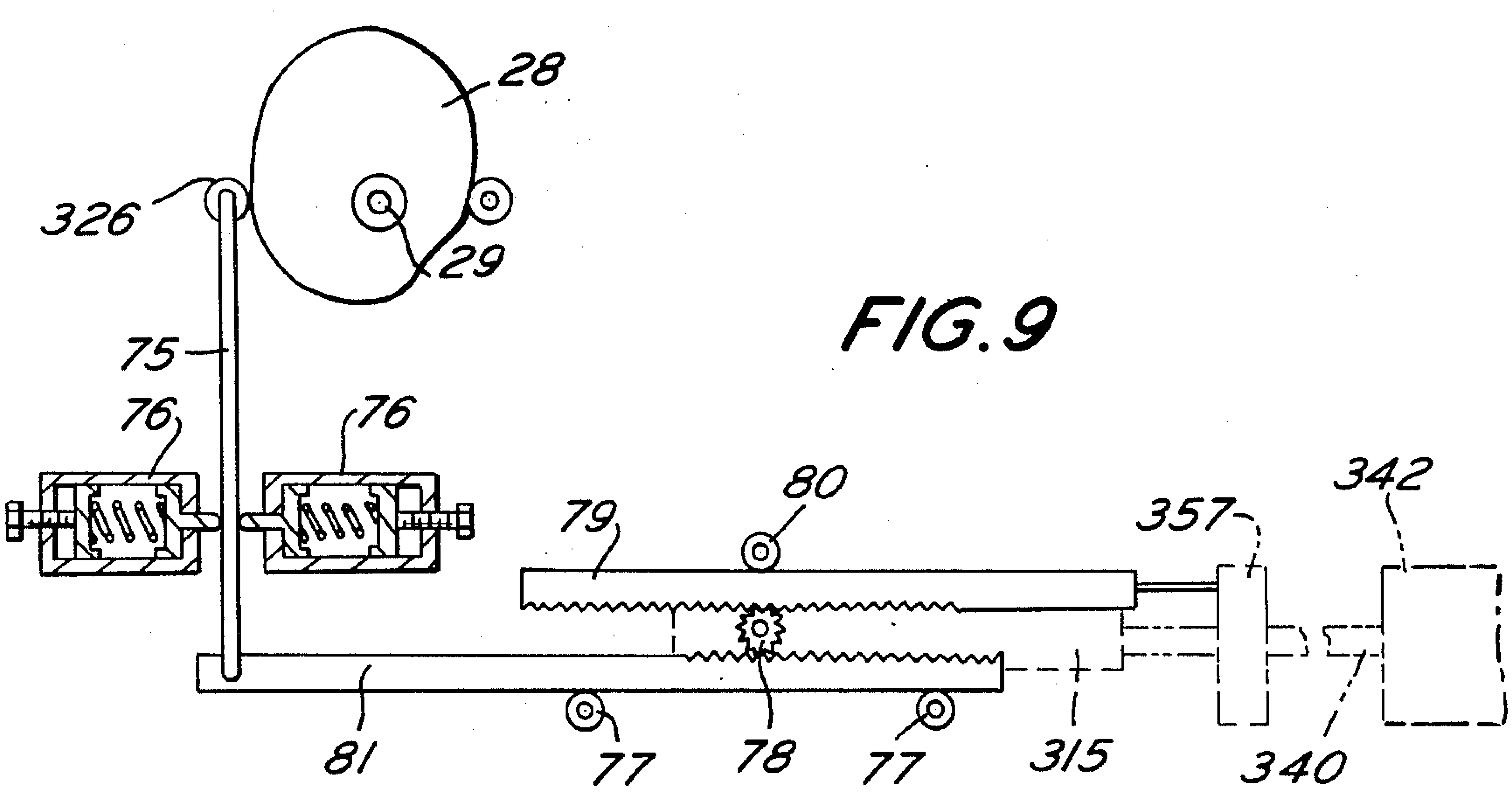


FIG. 9

PUMPING UNIT FOR CONSTANT PULSELESS FLOW

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to pumping units for pulseless delivery of fluids such as catalysts and the like at very high pressures.

2. Description of the Prior Art

It has heretofore been proposed in high pressure pumps to vary the stroke of the pump for volume or other control. Typical structures for this purpose are shown in U.S. Pats. to Denny, No. 2,612,839; Wolf, No. 212,777; Louis, No. 1,649,356; Eagen No. 2,771,845; Sato et al., No. 3,398,691; Dodson et al., No. 3,301,197; Sheen et al., No. 2,613,606; and Thurman, No. 2,863,471.

Saalfrank, in U.S. Pat. No. 2,620,734, undertakes to obtain constant volume fluid delivery but has very complex structure for this purpose.

It has also been proposed to use various packing materials in high pressure pumps but none of these has proven satisfactory for continuous operation say for 8,000 hours at nominal speeds of 20–30 cycles per minute and pressure levels above 10,000 psi.

In such pumps, if some leakage is permitted in order to reduce the friction between the packing and the plunger, erosion due to the fluid occurs with undesired increase in leakage. The action is accentuated if the leaking liquid is water because of its solvent action. Increase of pressure of water, also, does not bring about an increase in viscosity which is sufficient to decrease leakage.

If the packing is tight enough to prevent leakage then the friction between the packing and the plunger becomes so high that small particles of the packing material are torn off. Alternately, material is transferred to the plunger which then rips off larger portions of packing material. In addition to shortened packing life, particles of packing also cause check valve malfunction.

It has been recognized that hydrocarbon oils and certain other fluent materials become more viscous as the pressure is increased, (see Fuchs, U.S. Pat. No. 3,354,792), and this property is utilized in the apparatus of the present invention for centering the pump piston and prevention of process leakage with lubrication while maintaining steady or pulseless liquid delivery.

Other intensifiers have been proposed in U.S. Pats. to Douglas et al., No. 3,234,882 and Newhall No. 2,189,835, but these have various shortcomings as indicated above and are complex in construction.

SUMMARY OF THE INVENTION

In accordance with the invention an intensifier pumping unit is provided in which a pulseless flow is obtained, a cam of special configuration being employed and structure associated with the cam gives an adjustable return stroke of the cam follower, the cam directly or through fluid systems with valves controlling the position of the pump pistons, the pistons preferably having a fluid seal utilizing a fluid whose viscosity increases substantially with increase of pressure.

It is the principal object of the invention of provide a pumping unit which has improved operating characteristics including smooth essentially pulseless delivery of a fluid at very high pressure and with freedom from interruption over extended periods of time of the order of 8,000 hours continuous duty at nominal speeds of 20–30 cycles per minute.

It is a further object of the invention to provide a pumping unit which is relatively simple in construction and reliable in its action and eliminates the necessity for accumulators or for multi-stage and multiple cylinder pumps with complex valving with careful phasing.

It is a further object of the invention to provide an intensifier pumping unit which includes a variable volume pump having a continuous discharge and which can operate at slow speed as well as at high speeds.

It is a further object of the invention to provide a pumping unit of the character aforesaid with reduced tendency to heating and in which cooling is effected by the packing fluid.

Other objects and advantageous features of the invention will be apparent from the description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The nature and characteristic features of the invention will be more readily understood from the following description taken in connection with the accompanying drawings forming part hereof, in which:

FIG. **1A** is a diagrammatic view of a mechanical pumping unit in accordance with the invention;

FIG. **1B** is a diagrammatic view of an intensifier pumping unit in accordance with the invention;

FIG. **1C** is a diagrammatic view of another intensifier pumping unit in accordance with the invention;

FIG. **2** is a side elevational view of the high pressure cylinders, control valves therefor, cam and return stroke control mechanism in accordance with the invention shown in FIG. **1C**;

FIG. **3** is an end elevational view of the structure of FIG. **2** as seen from the line **3—3** of FIG. **2**;

FIG. is a horizontal sectional view taken approximately on the line **4—4** of FIG. **2**;

FIG. **5** is a horizontal sectional view taken approximately on the line **5—5** of FIG. **2**;

FIG. **6** is a vertical sectional view taken approximately on the line **6—6** of FIG. **5**;

FIG. **7** is a vertical sectional view taken approximately on the line **7—7** of FIG. **5**;

FIG. **8** is a diagrammatic view of another form of servo action which can be employed;

FIG. **9** is a diagrammatic view of still another form of servo action which can be employed; and

FIG. **10** is a detailed view of the cam.

It should, of course, be understood that the description and drawings herein are illustrative merely and that various modifications and changes can be made in the structure disclosed without departing from the spirit of the invention.

Like numerals refer to like parts throughout the several views.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now more particularly to FIGS. **1A** and **10** of the drawings, in which one form of pumping unit is shown diagrammatically, a cam **28** is provided.

The shape of the cam **28** and the stroke control structure is described in detail below. The cam **28** is secured to a shaft **29**, driven by a cam operating motor **30**, an overload clutch **31** being interposed in the shaft **29.** A speed controller **32** is provided for the motor **30** so that the motor **30** can be driven at the desired speed and thus determine the rate of feed of the high pressure fluid.

The cam **28** has followers **26** in engagement therewith carried by guides **33** in cylinders **42,** the followers **26** being urged by springs **34** into cam engagement. The cylinders **42** have pump pistons **40** connected to the guides **33.** Follower control plates **21** and **22** on threaded adjusting rods **23** are provided to control the return of the followers **26** to modify the cam action.

The pump cylinders **42** have valve heads **47** secured thereto with inlet and delivery check valves **48** and **49** connected thereto. The inlet check valves **48** have fluid connections **50** extending thereto from a source of liquid (not shown) to be pumped, such as a catalyst, to very high pressure with pulseless flow.

The delivery check valves **49** have a liquid delivery pipe **51** connected thereto for the delivery of the high pressure liquid. A pressure gage **52** may be connected to the pipe **51** for indicating the delivered pressure.

Referring now more particularly to FIG. **1B** of the drawings in which another form of the invention is shown diagrammatically, a cam **28** is provided as before, secured to a shaft **29** and driven by a cam operating motor **30,** an overload clutch **31** being interposed in the shaft **29.** A speed controller **32** is provided for the motor **30** so that the motor **30** can be driven at the desired speed and thus determine the rate of feed of the high pressure fluid.

The cam **28** has followers **26** in engagement therewith, carried by guides **74,** which engage wedges **75** positioned as hereinafter explained, for controlling four way valves **76** connected to a supply of fluid under pressure and by pipes **77** and **78** to opposite sides of fluid operated pistons **79** in fluid cylinders **80.** The pistons **79** are connected to pump pistons **40** in a pump cylinder **42.** The pump cylinders **42** have inlet and delivery check valves **48** and **49** connected thereto. The inlet check valves **48** have fluid connections **50** extending thereto from a source of liquid (not shown) to be pumped, such as a catalyst, under very high pressure with pulseless flow.

The delivery check valves **49** have a liquid delivery pipe **51** connected thereto for the delivery of the high pressure liquid. A pressure gage **52** can be connected to the pipe **51** for indicating the delivered pressure.

Follower control plates **21** and **22** on threaded adjusting rods **23** are provided to control the return of the followers **26** to modify the cam action.

The wedges **75** are connected by cords **82** extending over pulleys **83** and connected for movement with the pistons **79** and pistons **40** to provide a servo action with feedback.

Referring now more particularly to FIG. **1C** of the drawings in which another form of the intensifier pumping unit is shown diagrammatically, a reservoir tank **10** for liquid such as oil for the low pressure hydraulic circuit is shown with pumps **11** driven by a motor **12** having supply connections **13** extending into the liquid in the tank **10.** The delivery connections of the pumps **11** are connected by pipes **14** to four way valves **15** of well known type, operated by valve operating structure such as operating rods **16.** The valves **15** have return pipes **17** to the tank **10** and pressure relief valves **18** can be connected between the pipes **14** and **17** for excess pressure relief.

The pipes **14** and **17** can have non-return or check valves **19** and **20** therein to prevent reversal of flow therethrough.

The valve operating rods **16** are preferably spring urged by springs **25** to urge their followers **26** into engagement with a cam **28.** The shape of the cam **28** and the stroke control structure is described in detail below. The cam **28** is secured to a shaft **29,** driven by a cam operating motor **30,** an overload clutch **31** being interposed in the shaft **29.** A speed controller **32** is provided for the motor **30** so that the motor **30** can be driven at the desired speed and thus determine the rate of feed of the high pressure fluid.

A servo action is desired and one suitable structure for the purpose utilizes the valves **15** which determine the delivery to and discharge of liquid from opposite ends of motor cylinders **35.** The motor cylinders **35** preferably have flexible pipes **14***a* and **17***a* connected thereto and the cylinders **35** are preferably mounted for reciprocation and to provide a feed back. Each of the motor cylinders **35** has a motor piston **36** therein with a piston rod **37** extending therefrom through one end of the cylinder **35** to a fixed frame F. The pump **11** with control valves **15** as referred to above are only required to generate sufficient pressure to keep the cylinders **35** in position.

The pumps **11** have capacity greater than that required to move the pistons **36, 136** at maximum design speed and excess fluid is diverted through the open centers of the spools of the valves **15** and **115** or through valves **18** if high pressure discharge of the pump is blocked or if closed center spools are used in valves **15, 115.**

Each of the motor cylinders **35** is shown as having a pump piston **40** extending from the end opposite the piston rod **37.** The pump pistons **40** are each reciprocable in a pump cylinder **42** mounted in a housing **41** on the frame **38.** The cylinders **42** have connections **43** which extend from a pump **44** for the supply of the lubricating seal fluid for the pistons **40.** A fluid return connection **45** is provided for the return of the lubricating seal fluid.

The pump cylinders **42** have valve heads **47** secured thereto with inlet and delivery check valves **48** and **49** connected thereto. The inlet check valves **48** have fluid connections **50** extending thereto from a source of liquid (not shown) to be pumped such as a catalyst under very high pressure with pulseless flow.

The delivery check valves **49** have a liquid delivery pipe **51** connected thereto for the delivery of the high pressure liquid. A pressure gage **52** may be connected to the pipe **51** for indicating the delivered pressure.

Referring now more particularly to FIGS. **2** to **6** of the drawings, there is illustrated structural details of the principal parts of a preferred form of the unit shown diagrammatically in FIG. **1C.**

The fixed frame F has the cam shaft **129** mounted thereon carrying the cam **128.**

The cam **28** or **128** has three portions (see FIG. **10**). One cam portion between lines a and b has a constant rate of rise which is effective during the discharge or delivery stroke. The next portion, between lines *b* and *c* is an accelerated return stroke and permits including a stop or dwell at a fixed location. The remaining portion, between lines *c* and a includes the beginning of the constant rate of rise, part of which may be effective on the cam followers **126** to which valve actuators **116** are connected. The rise portion of the cam **28** or **128** is accordingly in excess of 180° so that as one cylinder overcomes compressibility and commences discharging fluid the other cylinder is finishing thereby assuring a constant pulseless flow.

The return strokes of the cam followers **126** and their connected valve actuators **116** is determined by follower control plates **121** and **122** which are separately adjustable by their threaded adjusting screws **123** carried in portions F2 of the frame F. The cam followers **126** are carried on follower blocks **127** with which the overload springs **126** are in engagement, the blocks **127** being urged towards each other by follower block springs **133** for engagement with the cam **128** or the cam follower control plates **121** or **122**, dependent on the orientation of the cam **128** and the adjusted position of the cam follower control plates **121** and **122**.

In FIGS. **2, 3** and **4** one unit comprising pump housing **141**, pump cylinder **142**, motor cylinder **135** and four way valve **115** is disposed above the other related unit with the upper pump cylinder **142** shown as to the right while the lower pump housing **141**, and pump cylinder **142** is shown as to the left.

Flexible pipes **114***a* and **117***a* for supply and discharge of lower pressure fluid are shown.

The valve actuators **116** include valve actuator plates **154** connected thereto to position the spools of the valves **115** which in turn control the actuation of the motor pistons (not shown) in the motor cylinders **135**.

The motor cylinders **135** are slidably supported at their outer ends on rods **155** on fixedly carried mounting portions of the frame F and at their opposite ends have driving yokes **156** extending to cross heads **157** mounted in the pump cylinders **142** for reciprocation. The cross heads **157** have the pistons **140** connected thereto for movement within the cylinder housings **141**.

The pump cylinders **142** have pipes **143** extending through housings **141** to radial passageways **143***a* and circumferential passageways **143***b* around the pump pistons **140** for the delivery of the lubricating and sealing liquid previously referred to. Passageways **145***b* and **145***a* communicate with return pipe **145**.

The pump cylinders **142** have cylinder heads **147** secured to housing **141** in which inlet and delivery valves are provided which can be of any suitable type. U.S. Pat. No. 3,245,429 to Bacino and Bowen, shows suitable valves.

For some designs, and in order to reduce stress concentration at very high pressures, the pump cylinder heads **147** are essentially flat plates with central portions concaved or convexed with straight bore holes **160** and **161** extending therefrom to sockets **162** in which the inlet and delivery valves are located and to which the supply and delivery connections are connected. The bore holes **160** and **161** are in non-intersecting relation to each other and are so disposed as not to be in the same plane.

Referring now to FIG. **8**, another form of servo action is there illustrated with which a feedback is obtained.

The cam **28**, in place of the follower **26**, is provided with an idler pulley **226**, urged by spring **225** into engagement with the cam **28** and which serves as a cam follower.

The idler pulley **226** has a cable **70** extending thereon to an adjustable end connection **71** to provide a zero adjustment. The cable **70** extends over an idler pulley **72** to a fixedly located four way motor piston control valve **215** urged in one direction by a spring **225***a*. The idler pulley **72** is carried by a movable pump piston **240** reciprocatory in a fixed pump cylinder **242**. The ratio of movement of the idler pulley-follower **226** to the valve **215** is one to one which provides a smooth and accurate operation.

Referring now to FIG. **9**, another form of servo action is illustrated with which a feed back is obtained.

The cam **28** has a cam follower **326** in engagement therewith. The follower **326** is carried on a lever **75** which is normally held against movement by spring stops **76** which may serve as a fulcrum, or the barrels of the spring stops **76** may be attached to the rack **81**. The lever **75** is pivotally connected to rack **81**, guided by guide rollers **77** with which a pinion **78** is in engagement. A rack **79** in engagement with the pinion **78** is held by guide roller **80** and is connected to the cross head **357** to which the pump piston **340**, movable in pump cylinder **342**, is attached. The pinion **78** is mounted on and positions a movable valve **315** for motor cylinder positioning.

The mode of operation will now be pointed out.

The pumps **11** are operated by the motor **12**, the motor **30** is operated to rotate the cam **28, 128**, lubricating seal fluid is supplied by the sources **44**, and fluid for pumping is available in the pipe **50**.

The movement of the cam **28, 128**, is effective to control the positioning of the valves **15, 115** to supply pressure fluid for the lower pressure hydraulic circuit to actuate the cylinders **35, 135**. It will be noted that in FIGS. **1B** and **1C** the load on the cam **28, 128** is small.

The cam **28, 128** has a constant rate of rise during the discharge or delivery stroke and upon the return stroke the cam follower control plates **121** and/or **122** become effective, dependent upon their setting, to arrest the return of the pistons. The pistons **36, 136** will remain at a constant position until the followers **26, 126** are again picked up by the advancing rate of rise portion of the cam **28, 128**. The adjustment of the cam follower control plates **121** and **122** will determine the length of the stroke of the pump pistons **40, 140** so that when the proper adjustment is made the delivery of pumped liquid by one cylinder **142** will commence just as the delivery from the other cylinder **142** is being completed so that substantially pulseless liquid delivery will be effected.

The adjustment of the cam follower control plates permits adjustment of variable compressibilities of the same fluid at different pressure levels or the variable compressibility of different fluids at the same pressure level.

The use of a hydrocarbon oil, mineral oil or other fluent material having lubricating qualities and the characteristic of becoming substantially more viscous with pressure applied thereon, supplied from the source **44** through the pipes **43, 143** has been found effective to center the pump pistons **40, 140** and to seal the process fluid against leakage.

Such fluent materials are effective to provide a barrier seal because they heat up as they are subjected to shear when the pistons move. The small amount of heat changes the fluid flowing characteristics of the material and provide a thin film of fluid material for lubrication surrounded by non-moving viscous material which acts as a seal.

Not only is the function of lubrication served, but the use of packings which erode or are eroded is avoided at high pressures of the order of 45,000 psi and higher. Additionally, a straight bore cylinder **142** is achieved thereby reducing stresses to a minimum.

We claim:

1. Pumping apparatus comprising
a fluid pump having a pair of cylinders each with a reciprocatory piston and inlet and delivery valves for supply of fluid to said cylinders for pumping by each of said pistons and delivery from said cylinders to a common discharge pipe, and
means for actuating said pistons,
said means comprising
a rotary cam having on its exterior a constant rate of rise portion in excess of 180° for actuation of said pistons in overlapped relation to effect continuous pulseless flow from said cylinders and to said discharge pipe, and
means for modifying the action of said cam to accommodate changes in compressibility of the fluid being pumped.

2. Pumping apparatus as defined in claim **1** in which
an adjustable speed driving means is provided for rotating said cam.

3. Pumping apparatus as defined in claim **2** in which
an overload clutch is interposed in said driving means.

4. Pumping apparatus as defined in claim **1** in which
said means for modifying the action of said cam comprises at least one control member for adjustable positioning contiguous to said cam to modify the action of the rise portion of said cam.

5. Pumping apparatus as defined in claim **1** in which
operating members are provided for said fluid delivery and discharge valves interposed between said valves and said cam, and
said means for modifying the action of said cam comprises
at least one slidably mounted control member for engagement with said operating members to modify the action of the return portion of said cam.

6. Pumping apparatus as defined in claim **1** in which
said means for actuating said pistons comprises
fluid pressure actuated means having reciprocatory members for actuating said reciprocatory pistons, and

control means for said fluid actuated means including
pressure fluid supply means, and
a fluid delivery and discharge valve to which said supply means is connected controlled by said rotary cam and said modifying means.

7. Pumping apparatus as defined in claim **6** in which
said cam has a follower in engagement therewith, and
a feedback connection is provided between said piston and said follower.

8. Pumping apparatus as defined in claim **1** in which
means is provided for preventing fluid leakage along said piston,
said means including a fluid supply connection to said piston intermediate its ends, and
means for supplying to said fluid supply connection a fluent material whose viscosity increases with pressure applied thereon.

9. Pumping apparatus as defined in claim **6** in which
said fluid pressure actuated means includes fixedly mounted members and movable members connected to each of said pump pistons, and
said movably mounted members and said fluid delivery and discharge valves are mounted for movement together.

10. Pumping apparatus as defined in claim **6** in which
said control means includes
follower members engaged with said cam and to which said fluid delivery and discharge valves are connected, and
resilient members for positioning said follower members.

11. Pumping apparatus as defined in claim **10** in which
said resilient members urge said follower members into engagement with said cam.

12. Pumping apparatus as defined in claim **10** in which
resilient overload release members are provided in engagement with said follower members.

13. Pumping apparatus comprising
a fluid pump having a pair of cylinders each with a reciprocatory piston and inlet and delivery valves for supply of fluid to said cylinders for pumping by each of said pistons and delivery from said cylinders to a common discharge pipe, and
means including a single rotary cam having on its exterior a constant rate of rise portion in excess of 180° for actuating said pistons in overlapped relation to effect constant pulseless flow from said cylinders at a predetermined compressibility of the fluid being pumped.

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