

Dec. 31, 1968

N. F. BROWN

3,419,074

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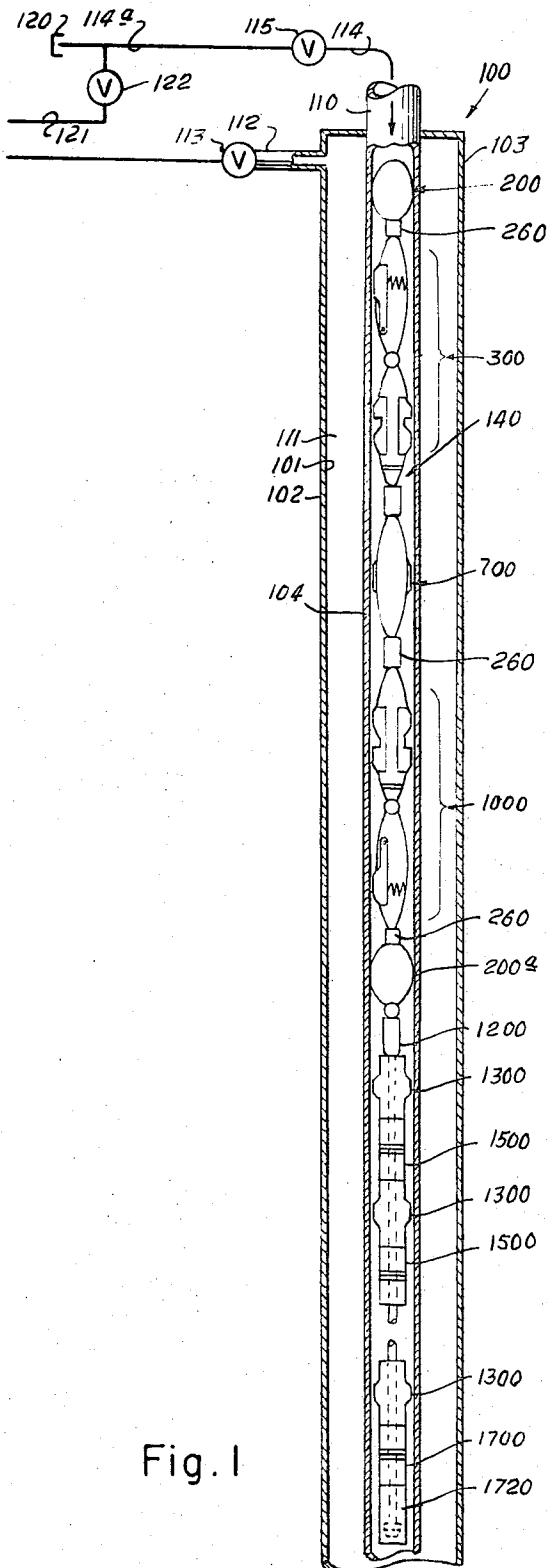


Fig. 1

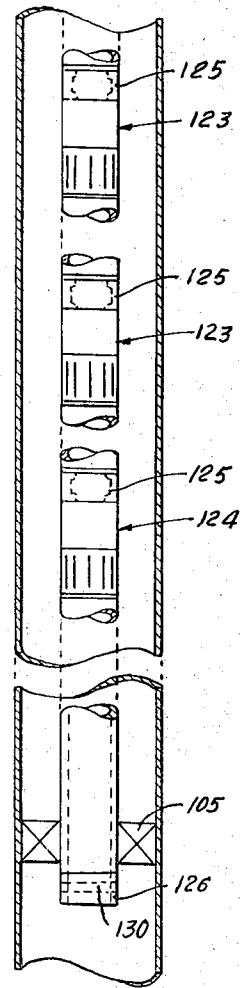


Fig. 2

INVENTOR

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*Walter J. Jagm*  
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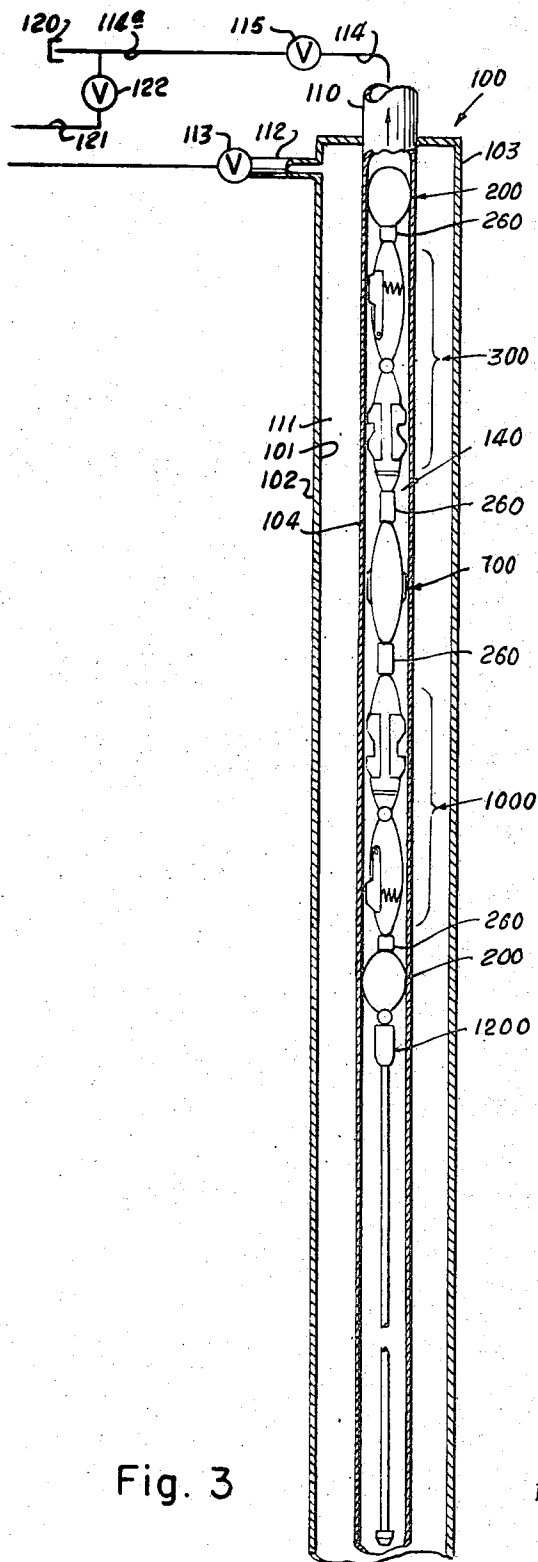


Fig. 3

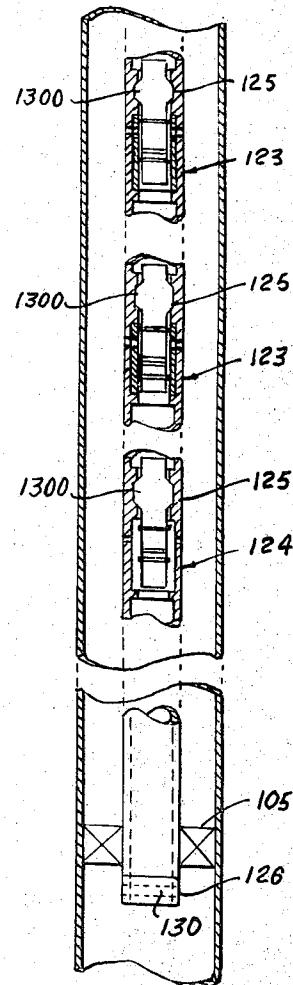


Fig. 4

INVENTOR

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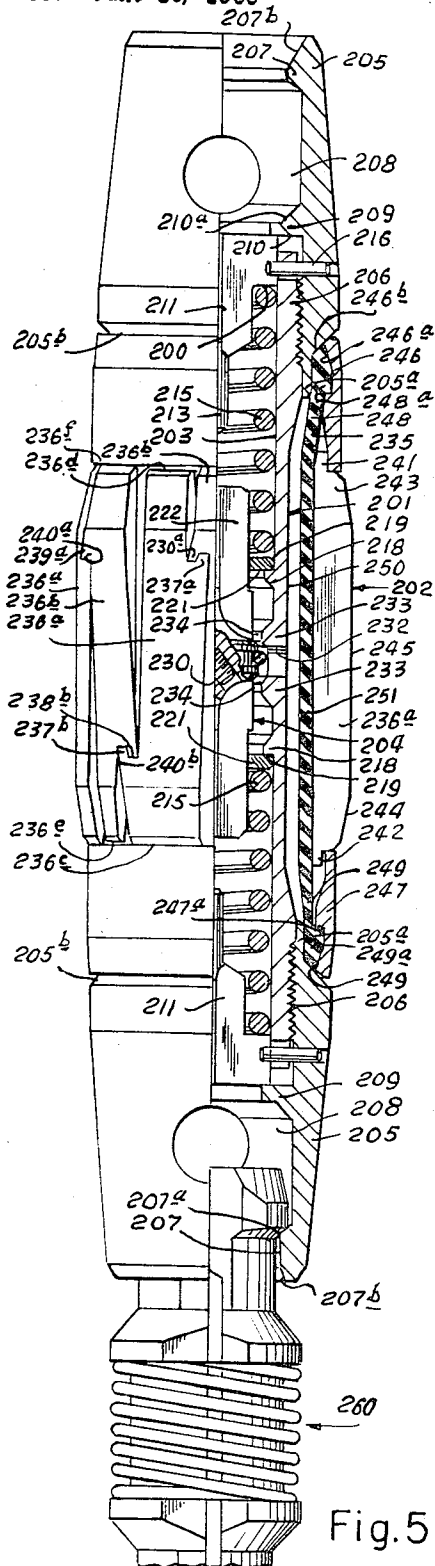


Fig. 5

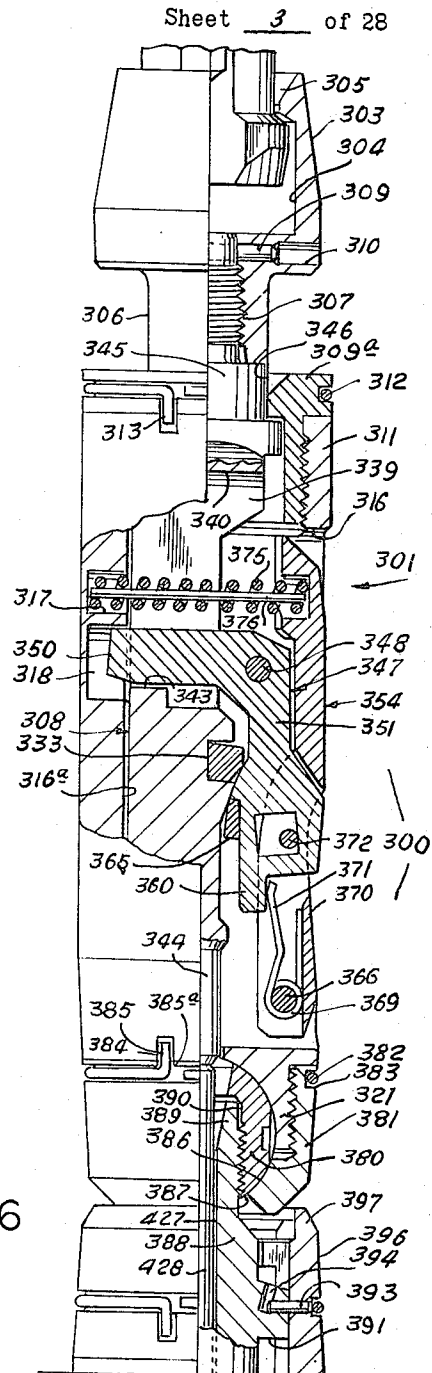


Fig. 6

INVENTOR

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and  
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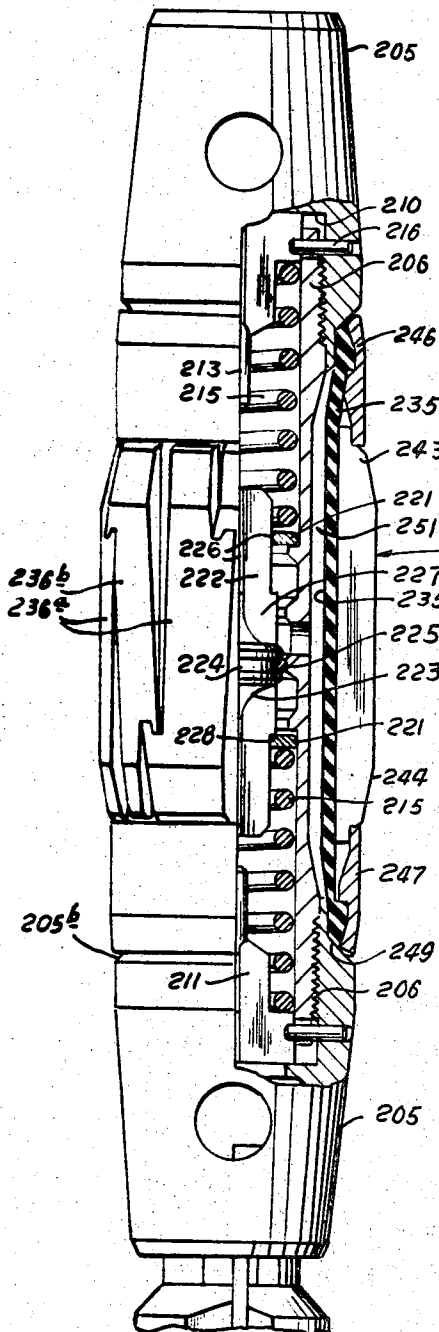


Fig. 5A

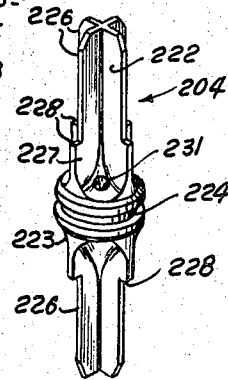


Fig. 5C

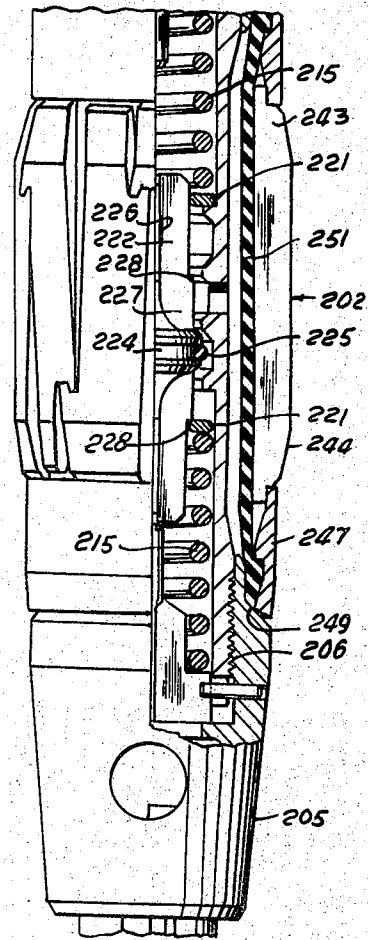


Fig. 5B

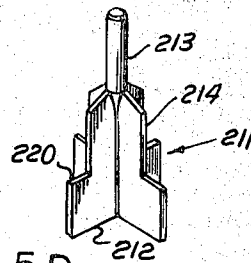


Fig. 5D

INVENTOR

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and  
*Walter J. Jager*  
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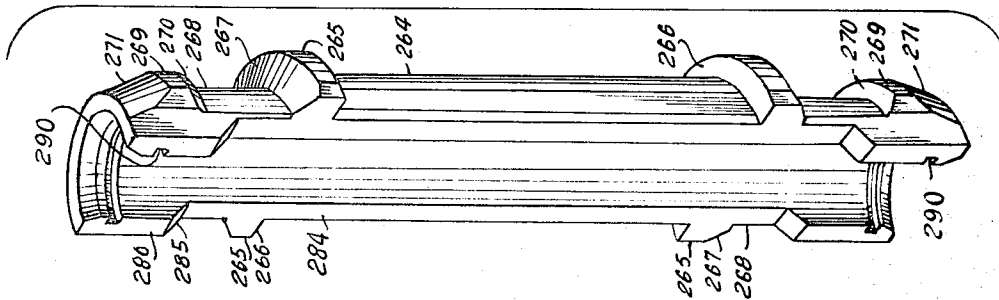


Fig. 5G

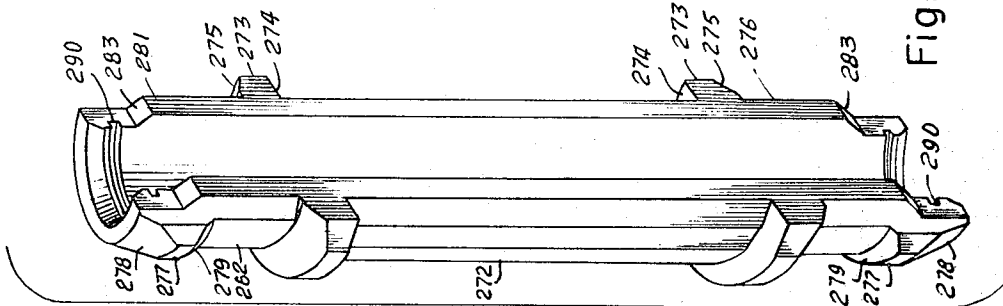


Fig. 5F

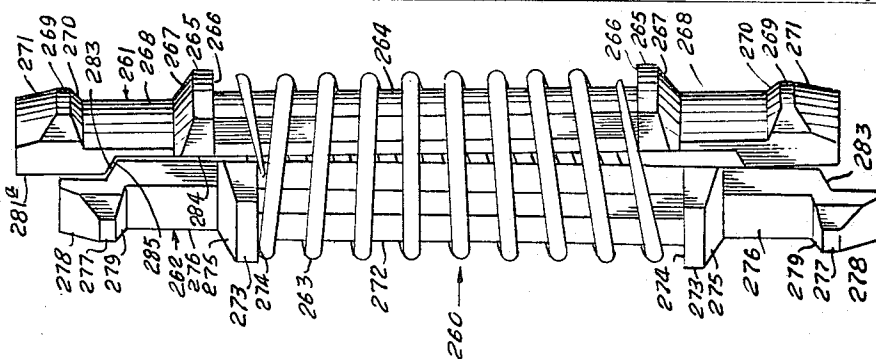
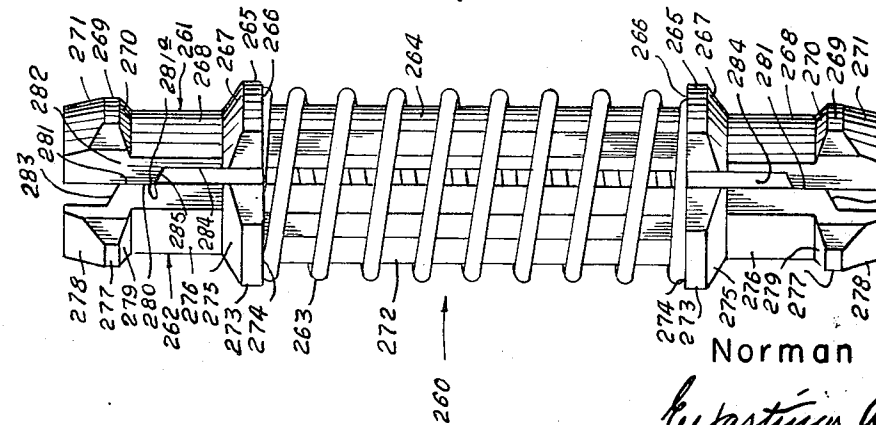


Fig. 5E



INVENTOR

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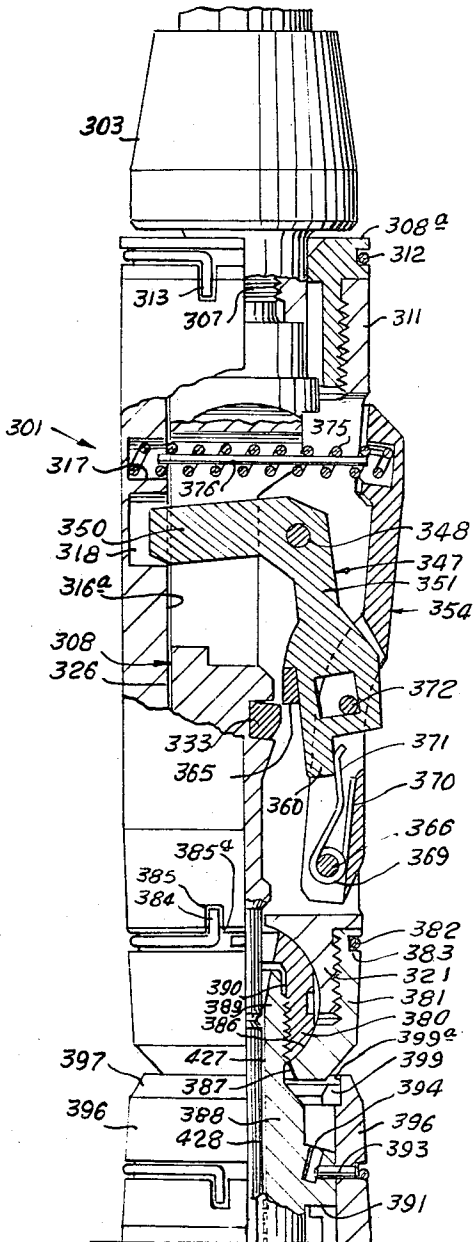


Fig. 6A

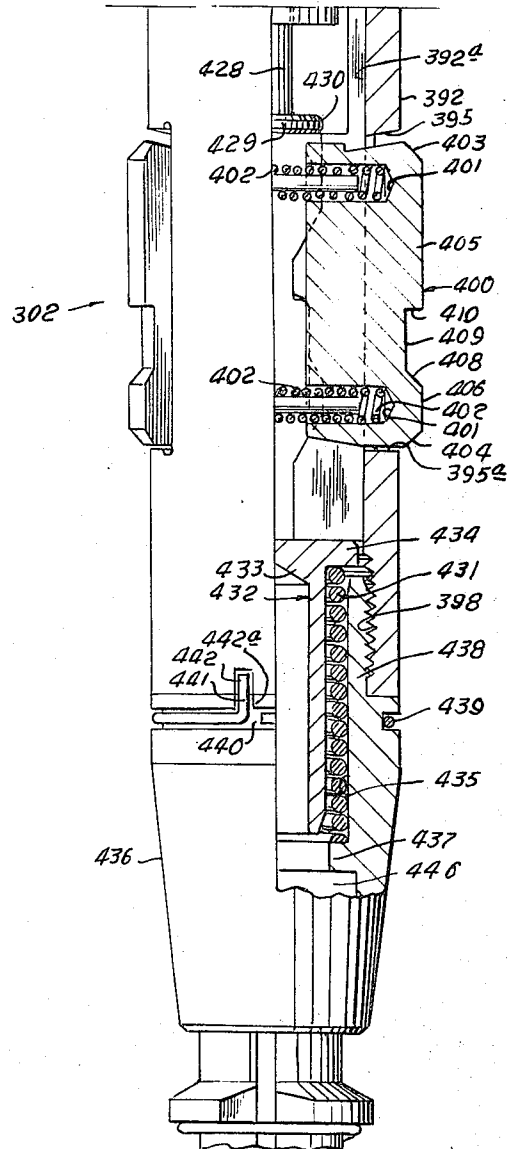


Fig. 7A

INVENTOR

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*Walter J. Jahn*  
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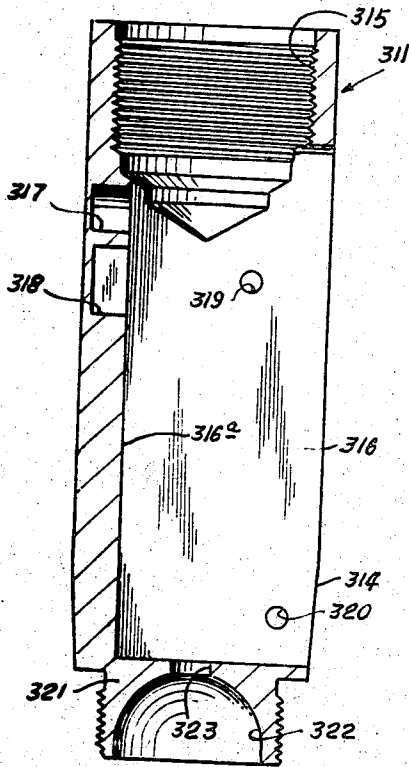


Fig. 6 B

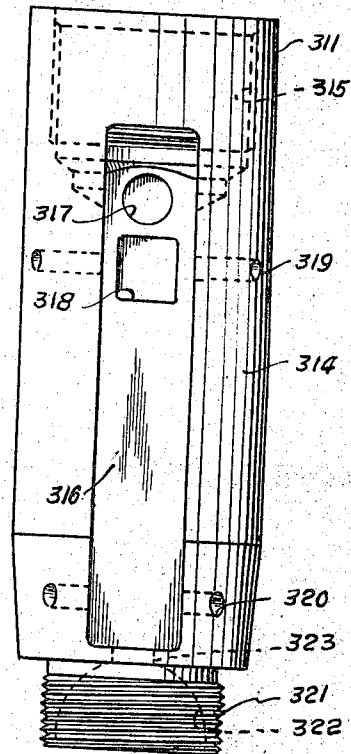


Fig. 6 C

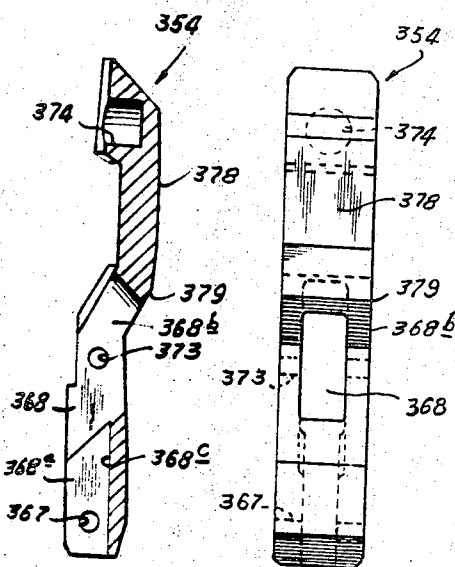


Fig. 6 F

Fig. 6 G

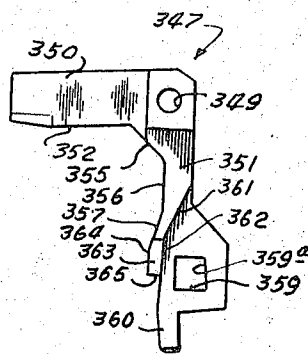


Fig. 6 D

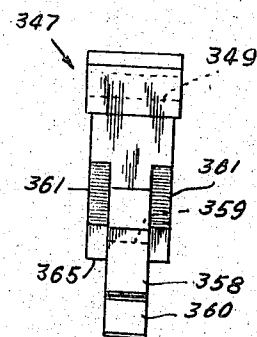


Fig. 6 E

INVENTOR  
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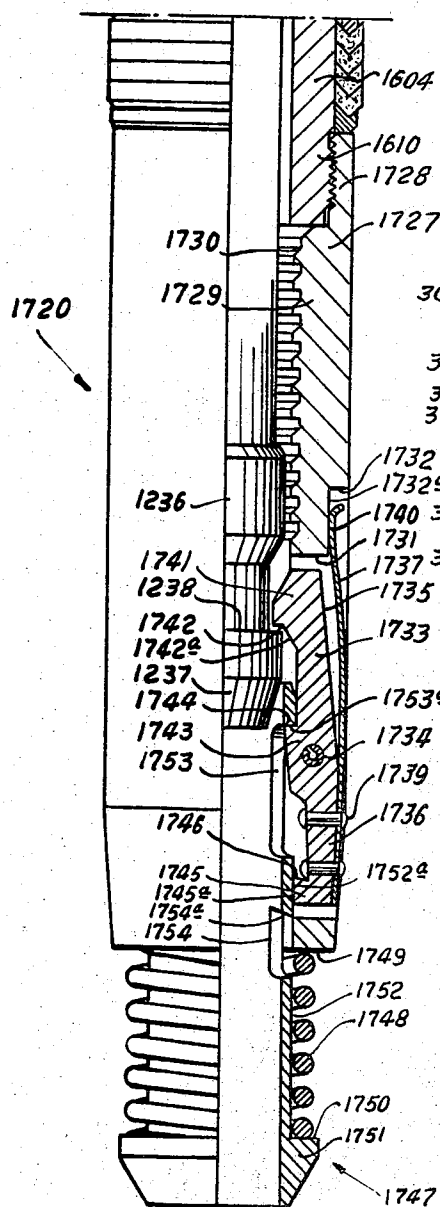


Fig. 17

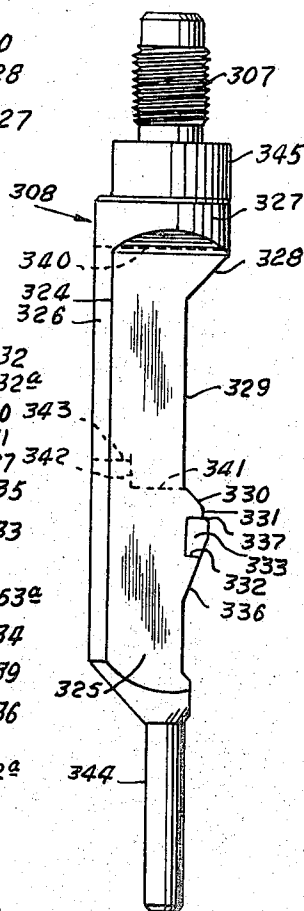


Fig. 6 H

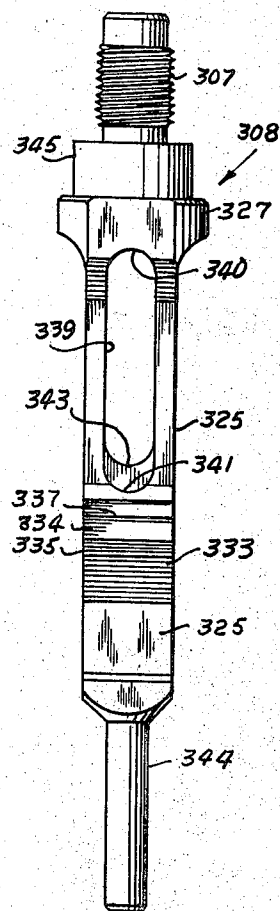


Fig. 6-I

INVENTOR  
Norman F. Brown

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*Walter J. Jagm*  
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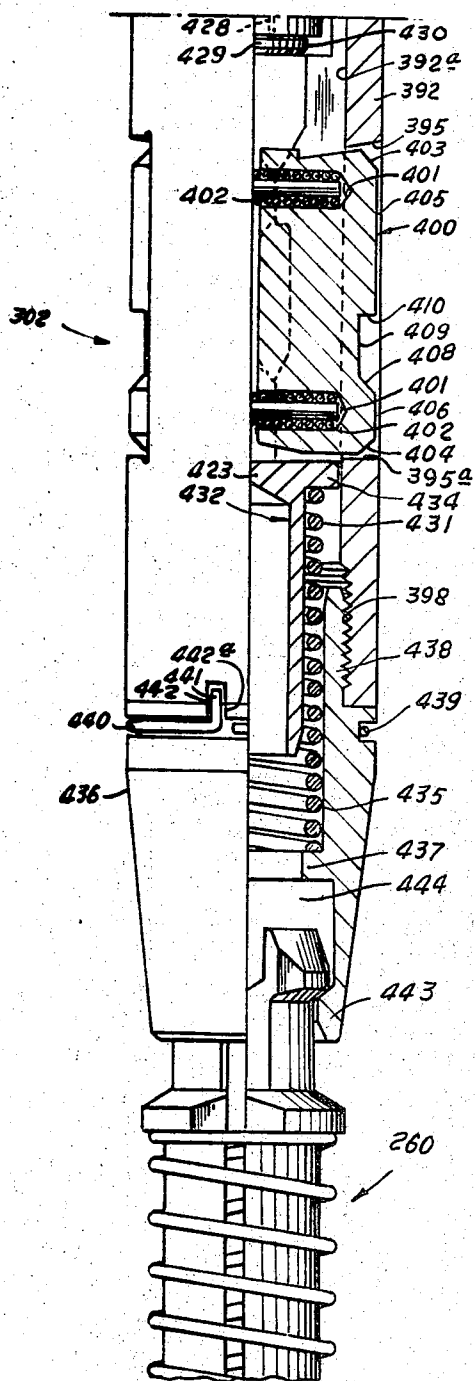


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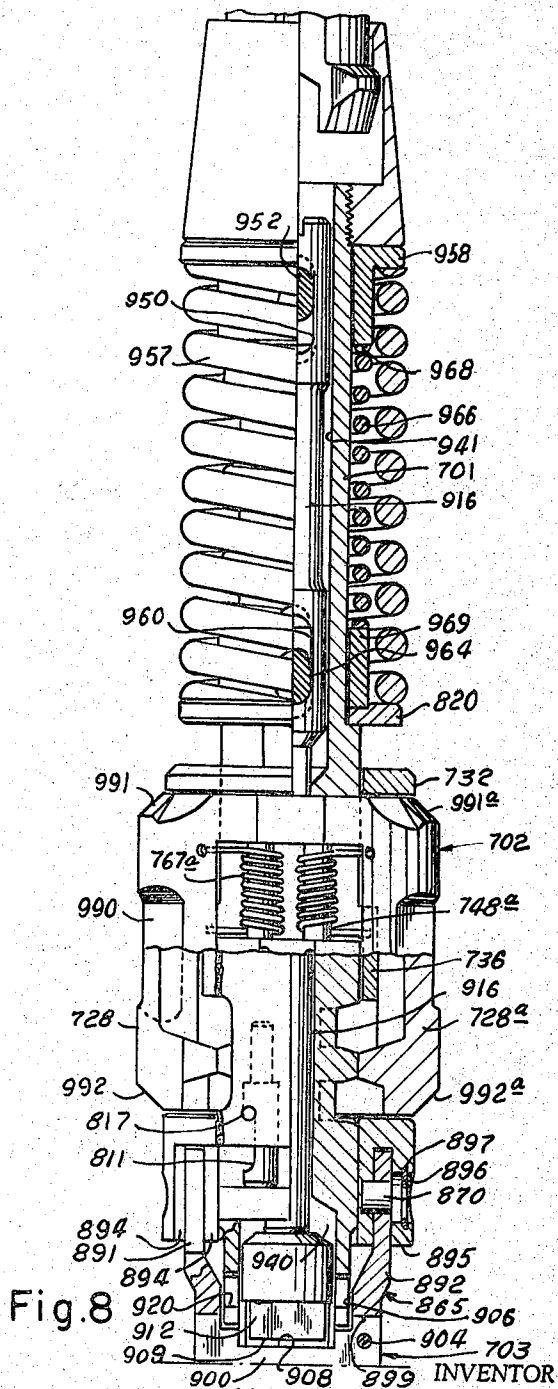


Fig. 8

INVENTOR  
Norman F. Brown

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and  
*Walter J. Jagan*  
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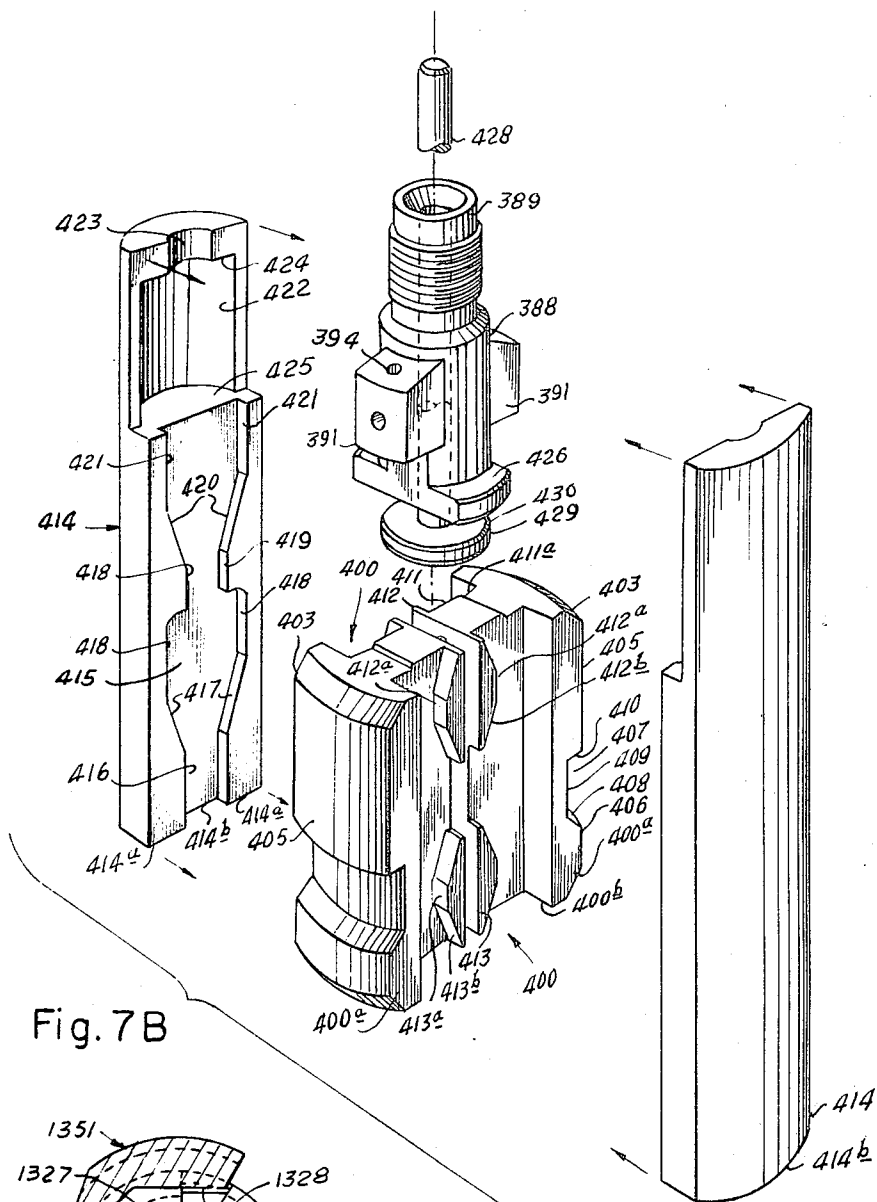


Fig. 7B

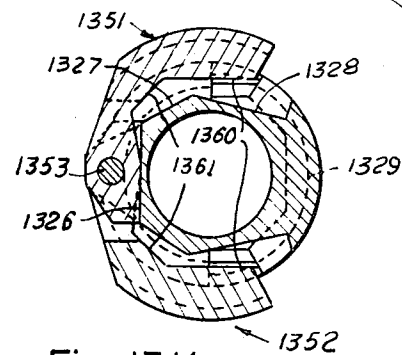


Fig. 13K

INVENTOR  
Norman F. Brown  
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and  
*Walter J. Jager*  
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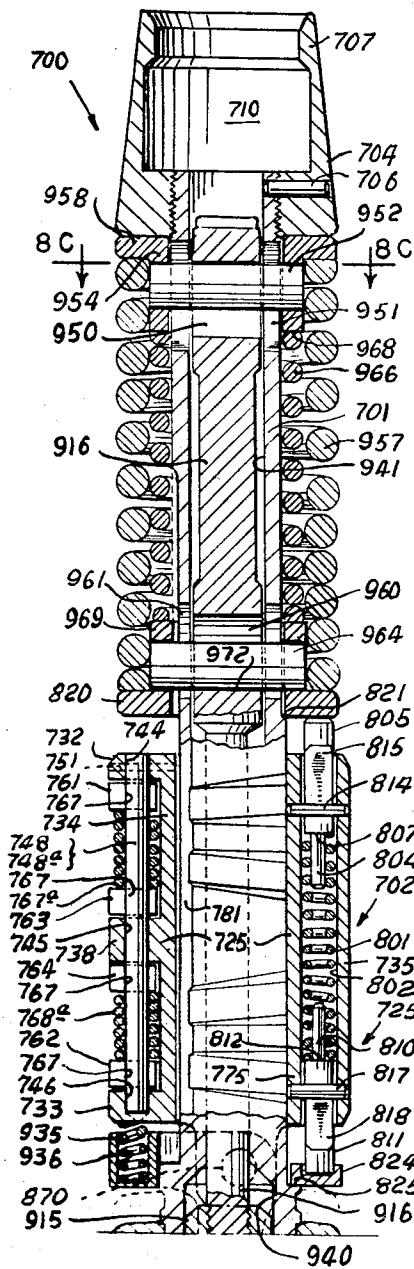


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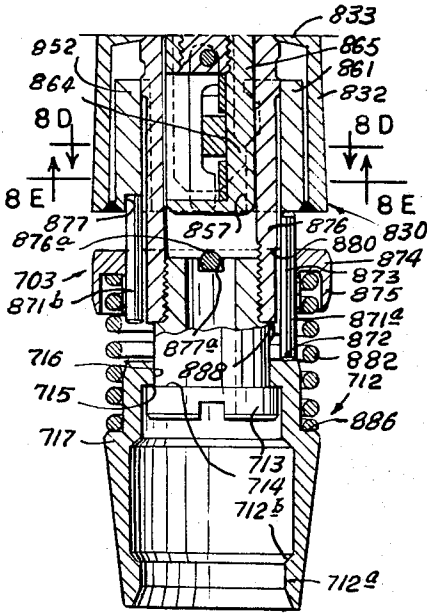


Fig. 8B

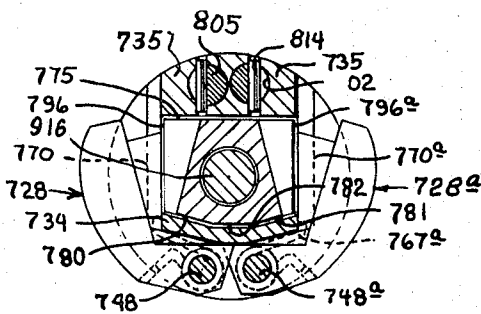


Fig. 8G

INVENTOR  
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*By* *Walter J. Jay*  
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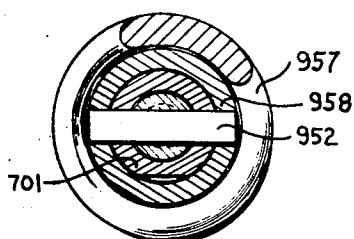


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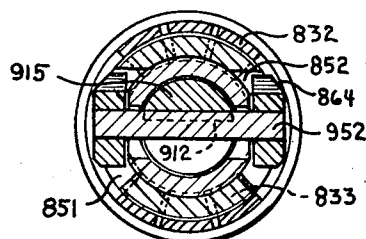


Fig. 8 D

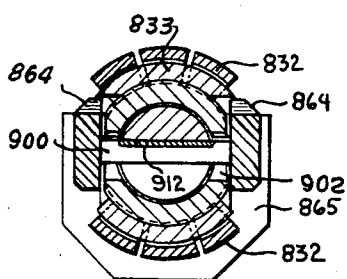


Fig. 8 E

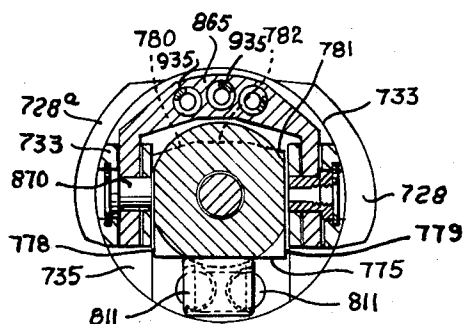


Fig. 8 F

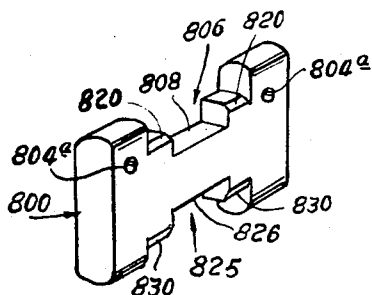


Fig. 8 L

INVENTOR  
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BY *Walter J. Jay*  
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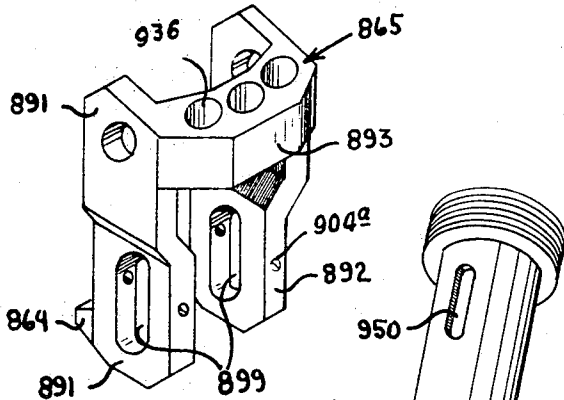


Fig. 8 I

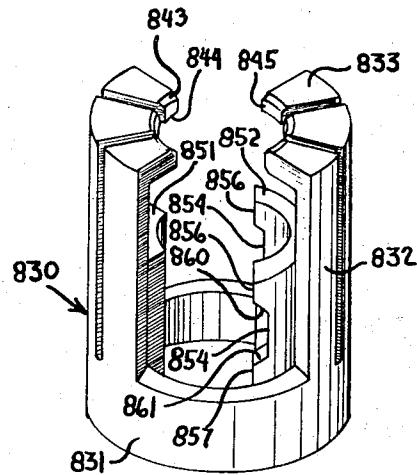


Fig. 8 J

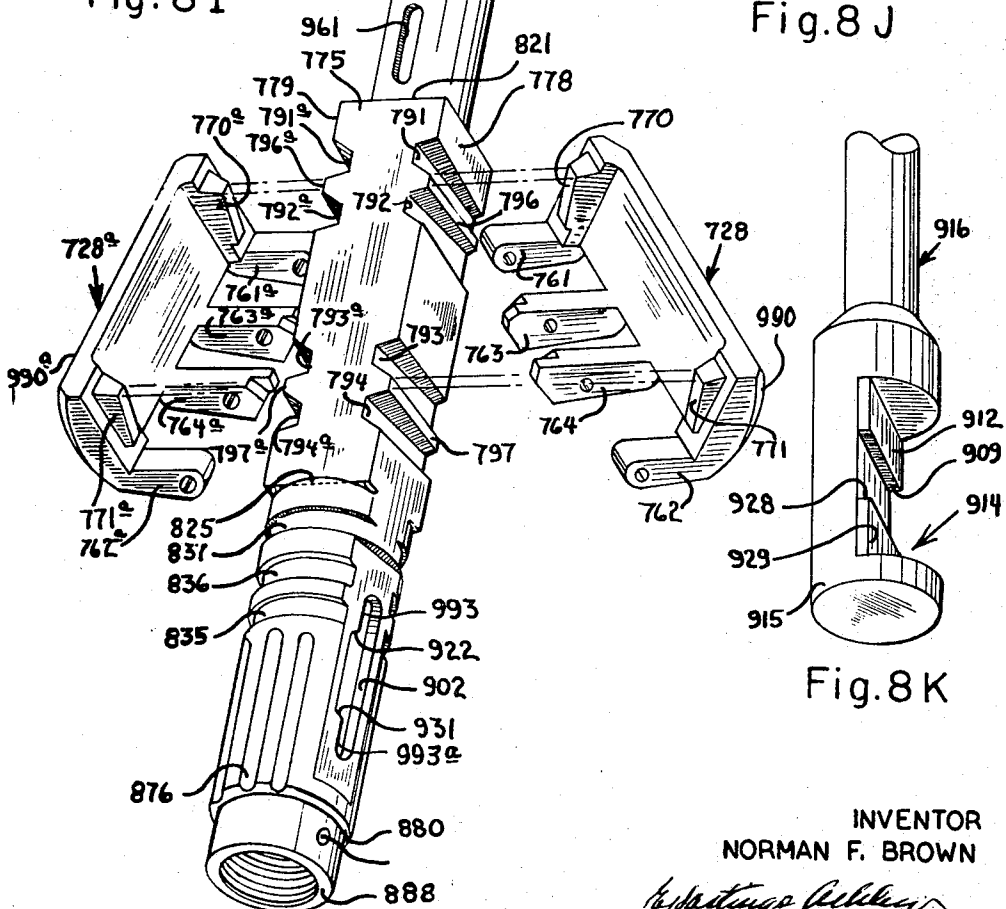


Fig. 8 H

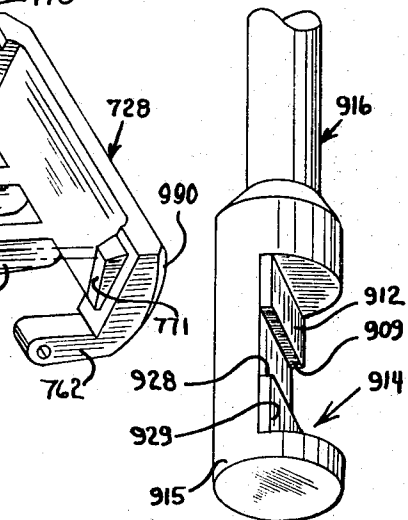


Fig. 8 K

INVENTOR  
NORMAN F. BROWN

BY

*Walter J. Jager*

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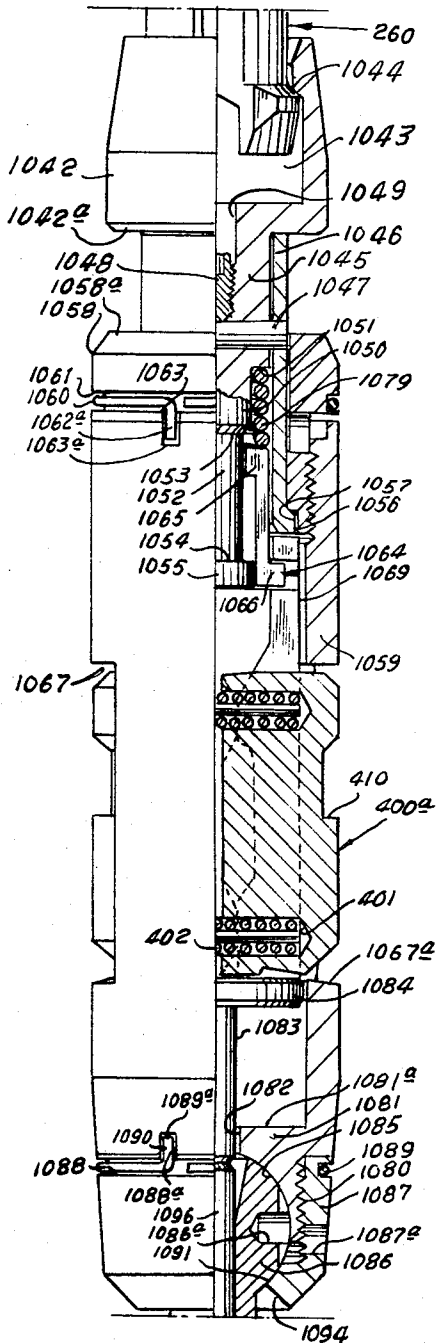


Fig. 10

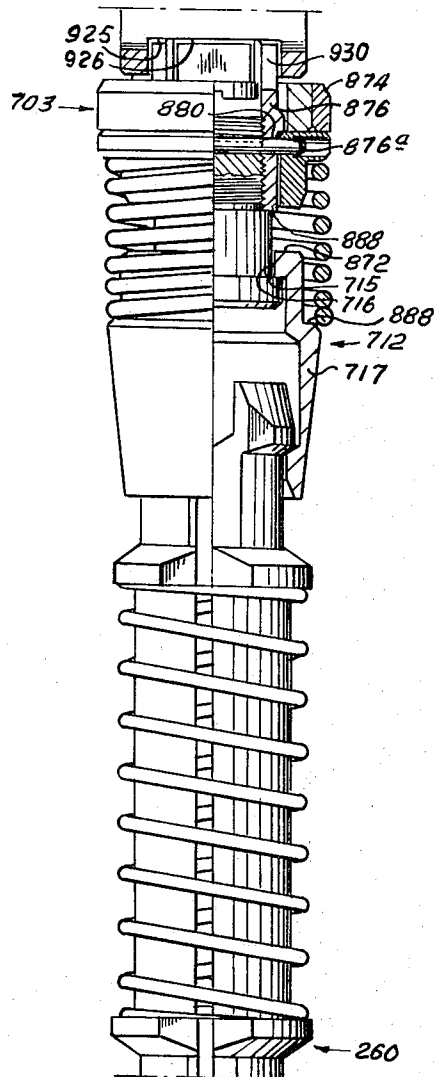


Fig. 9

INVENTOR

Norman F. Brown

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and  
Walter J. Jago*  
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1000

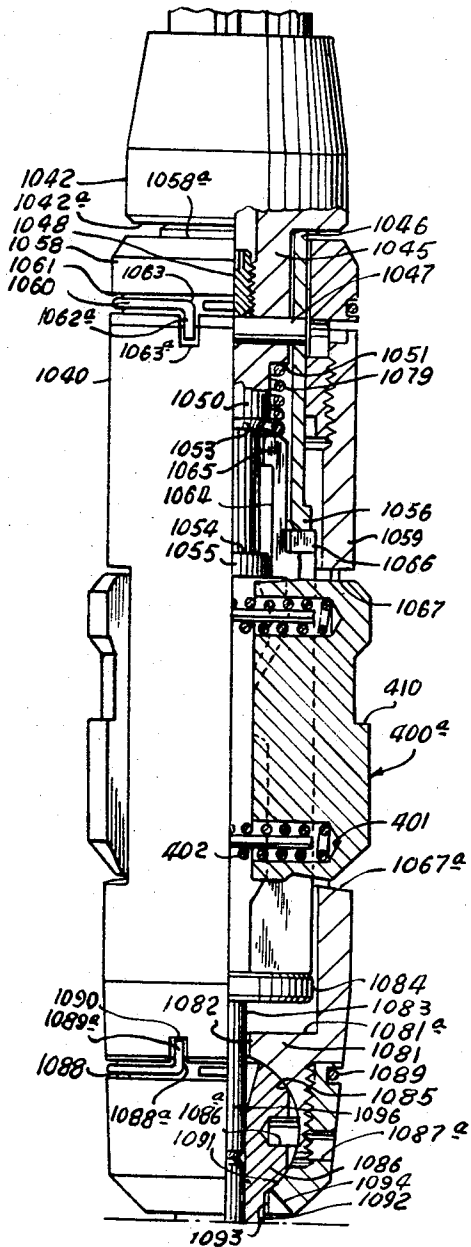


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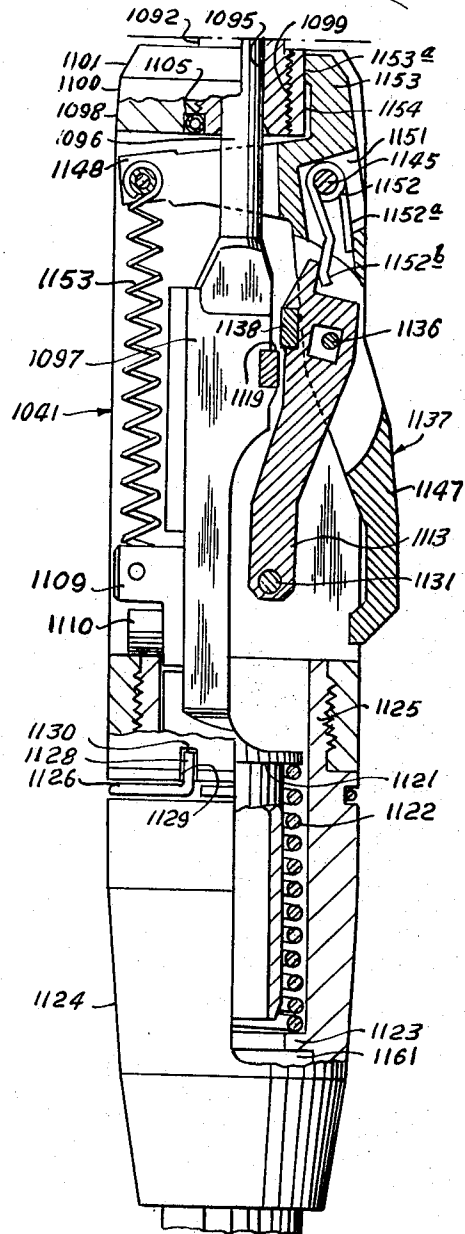


Fig. 11A

INVENTOR

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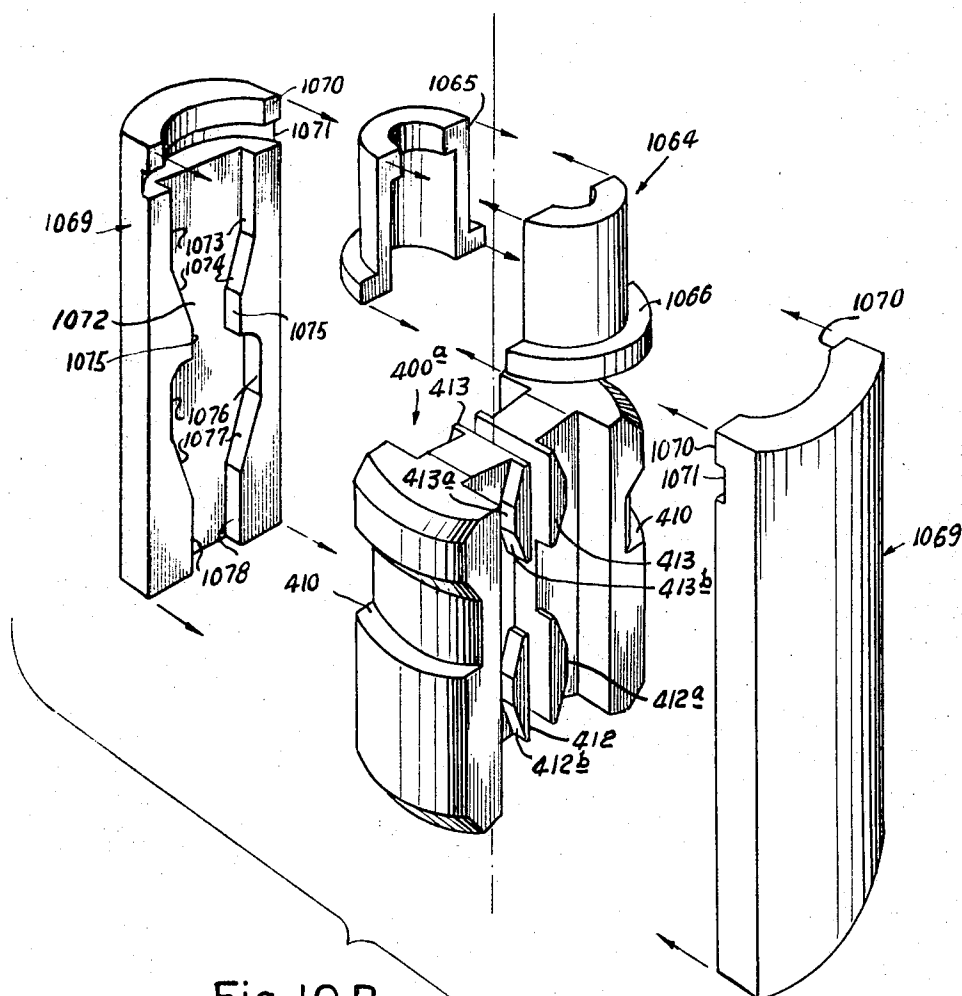


Fig. 10B

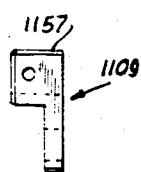


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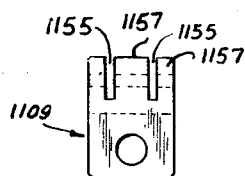


Fig. 11J

INVENTOR

Norman F. Brown

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*Walter J. Jago*

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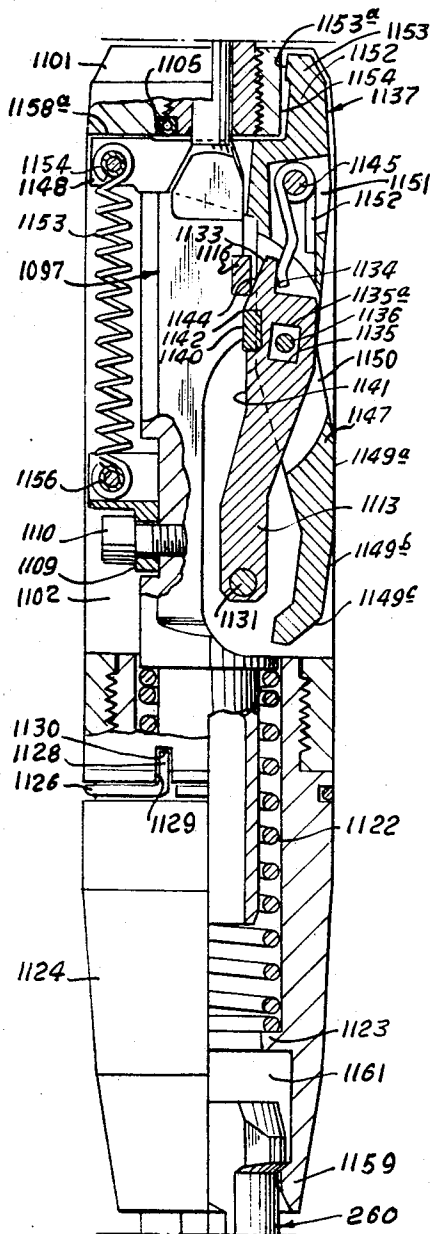


Fig. 11

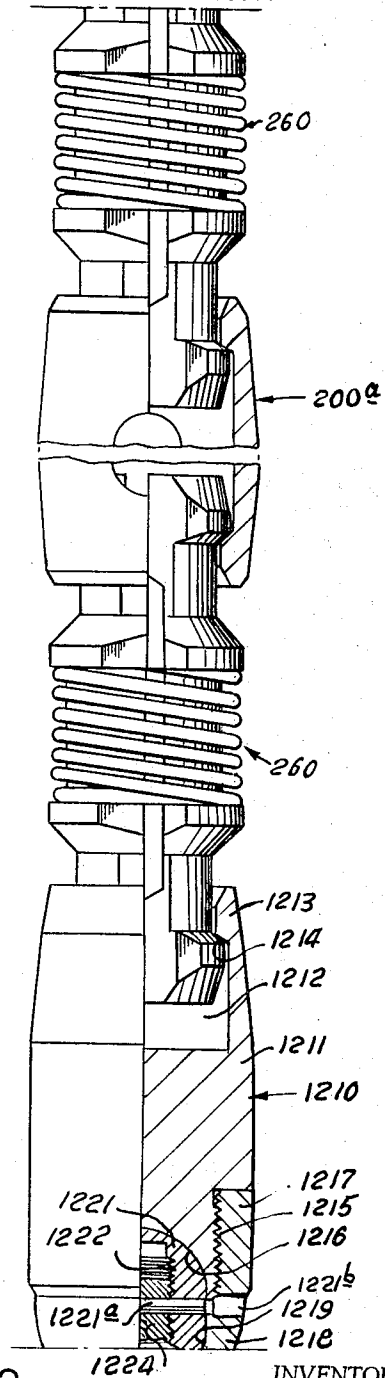


Fig. 12

INVENTOR

Norman F. Brown

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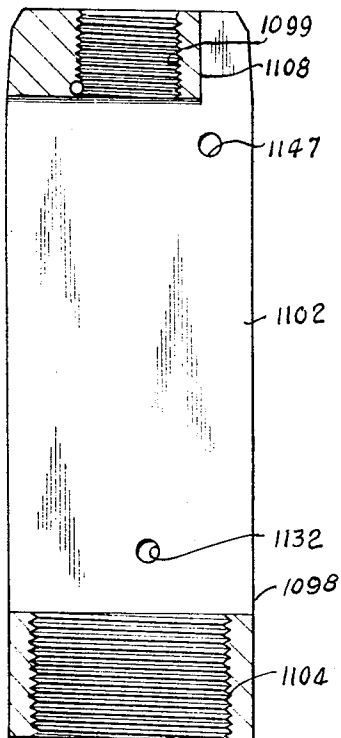


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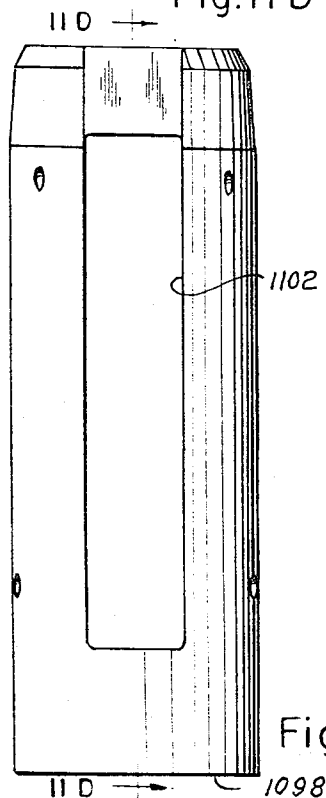


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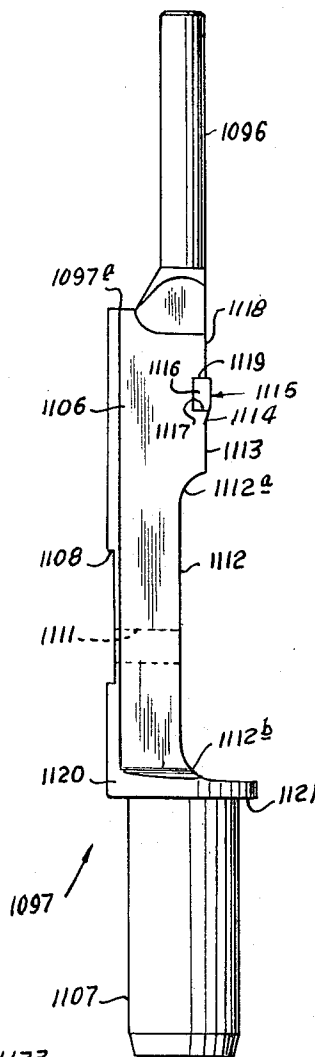


Fig. IIB

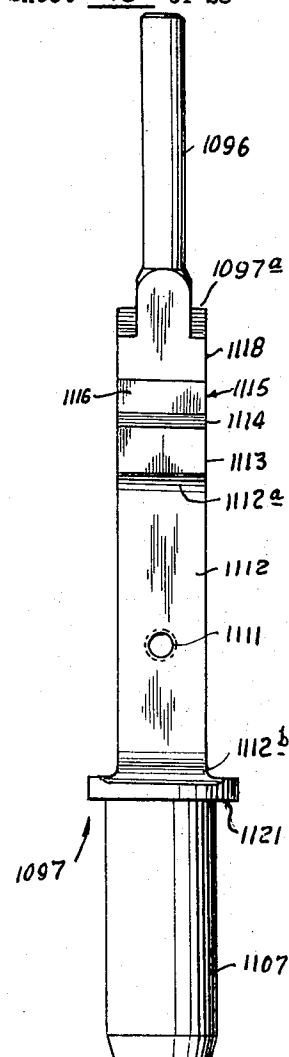


Fig. IIC

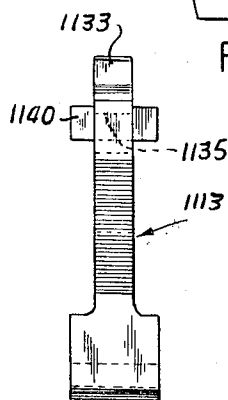


Fig. IIF

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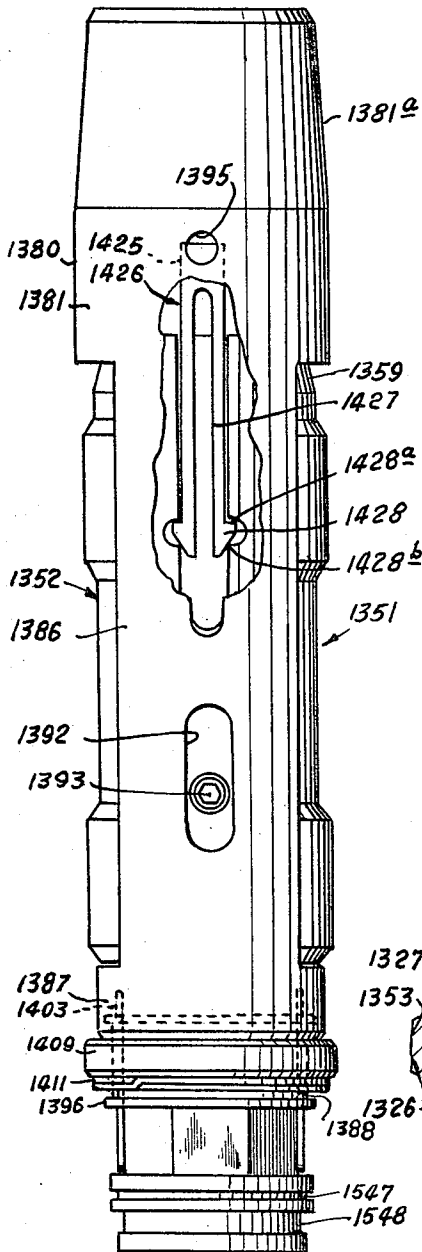


Fig. 13 A

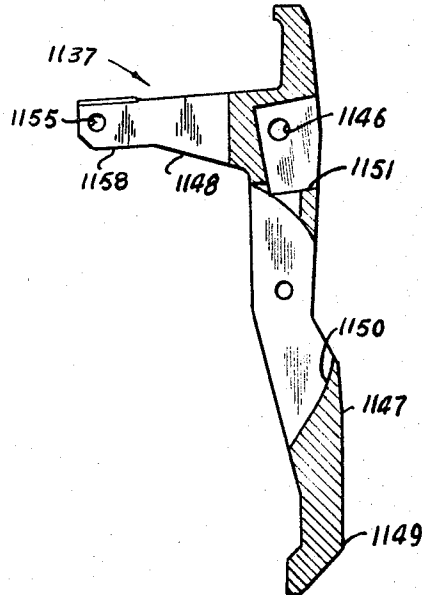


Fig. 11 G

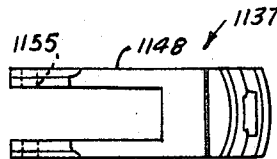


Fig. 11 H

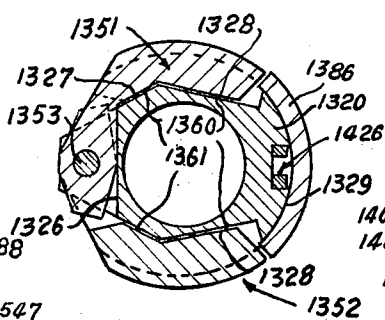


Fig. 13 B

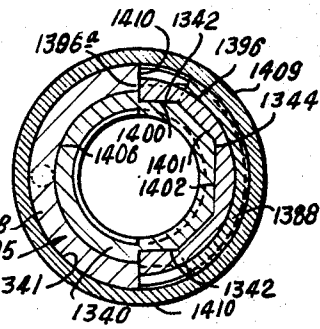


Fig. 13 BB

INVENTOR

Norman F. Brown

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*Walter J. Jagman*  
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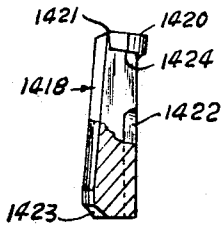


Fig. 13 C

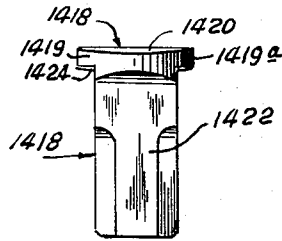


Fig. 13 D

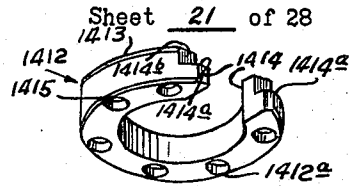


Fig. 13 E

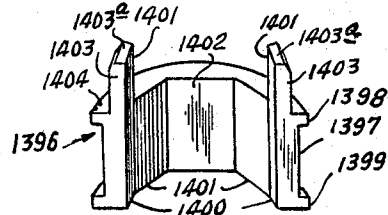


Fig. 13 I

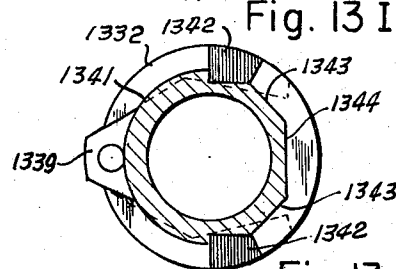


Fig. 13 H

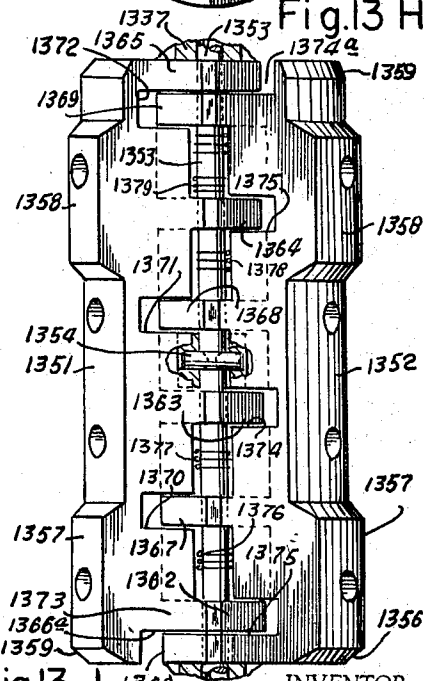


Fig. 13 J

INVENTOR

Norman F. Brown

*Les Hastings Ackley*  
and  
*Walter J. Gagnier*  
ATTORNEYS

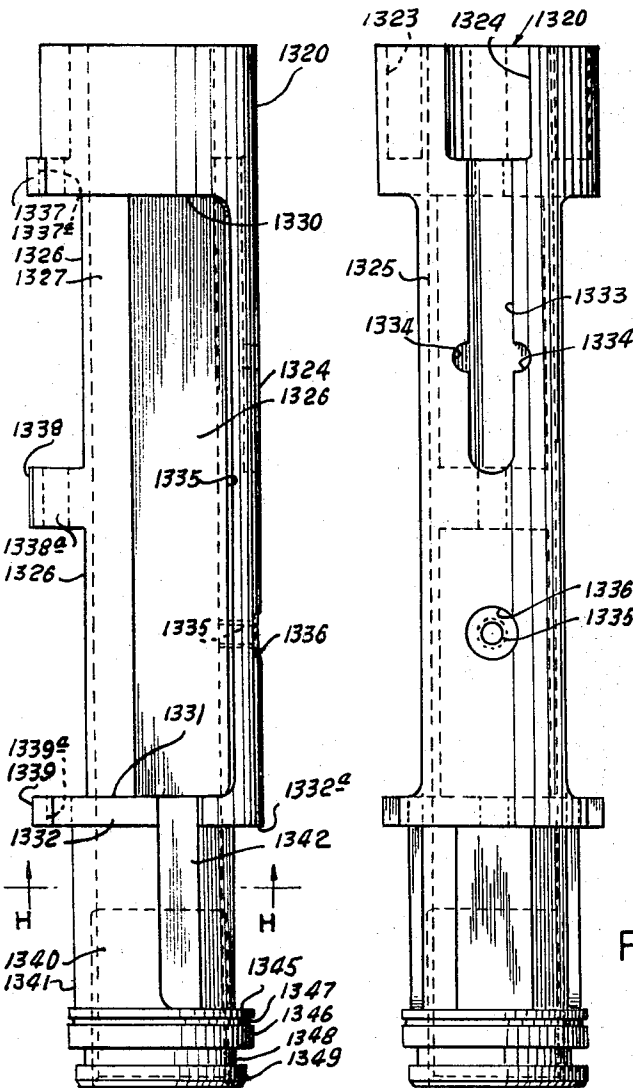


Fig. 13 F

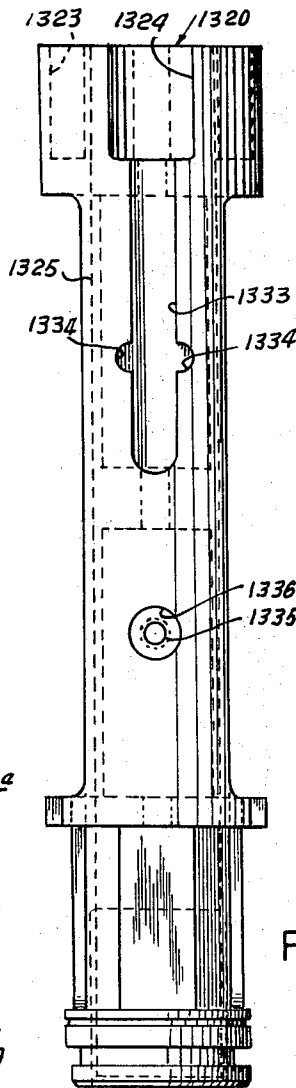


Fig. 13 G

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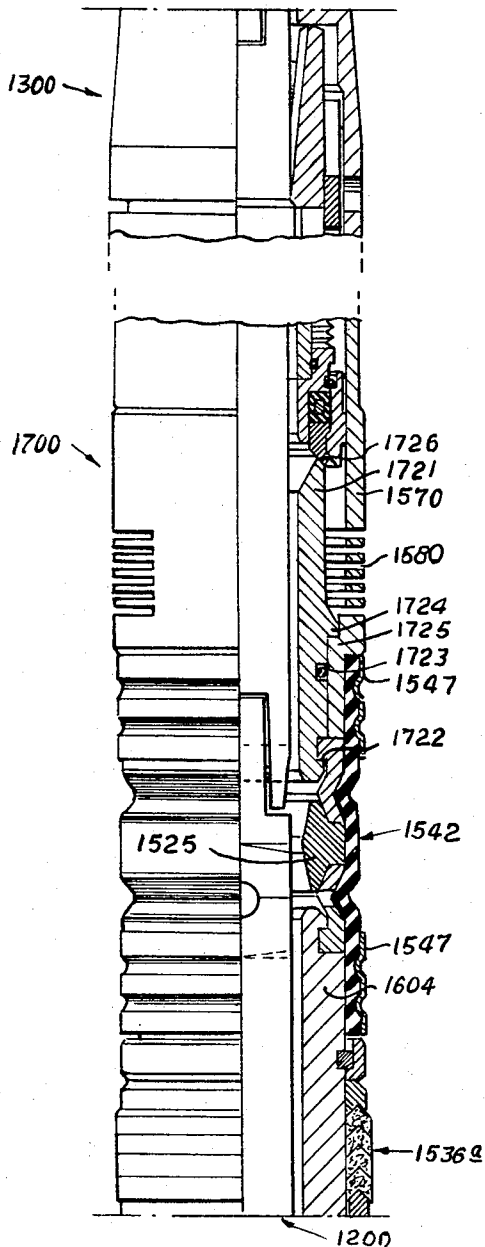


Fig. 16

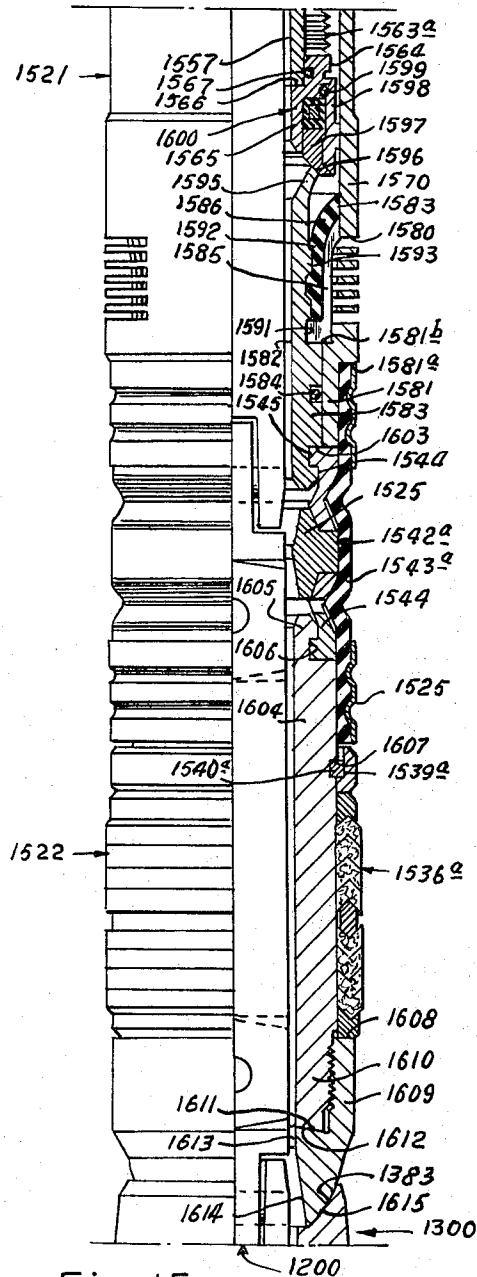


Fig. 15

INVENTOR

Norman F. Brown

BY

*W. Hastings Ackley*  
and  
*Walter J. Jago*  
ATTORNEYS

Dec. 31, 1968

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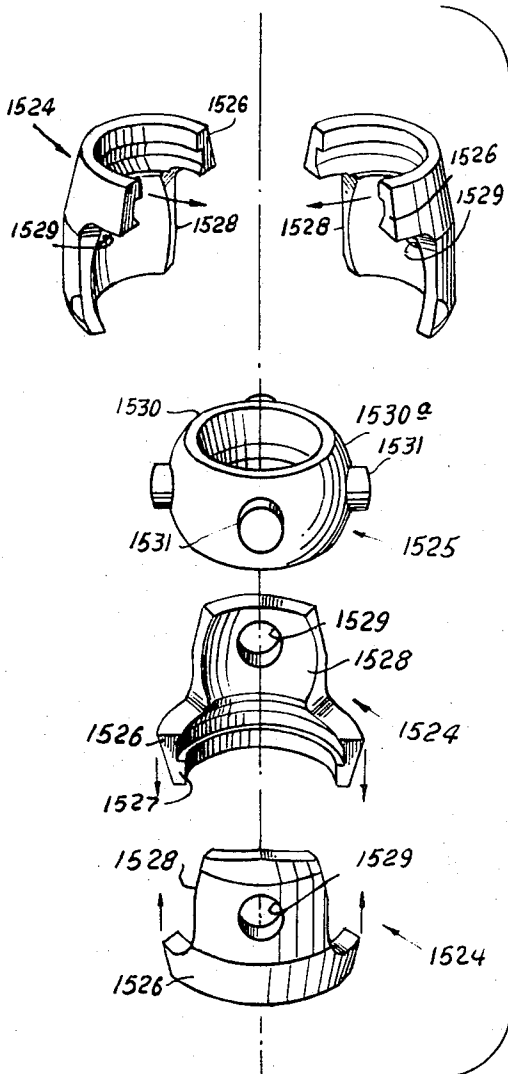


Fig. 14 A

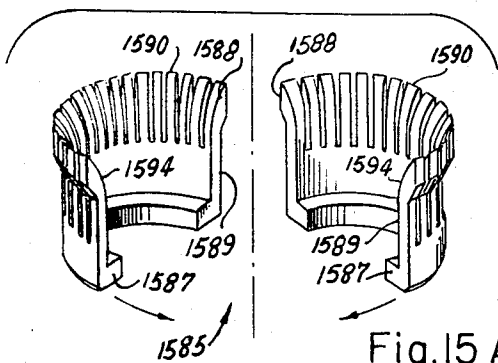


Fig. 15 A

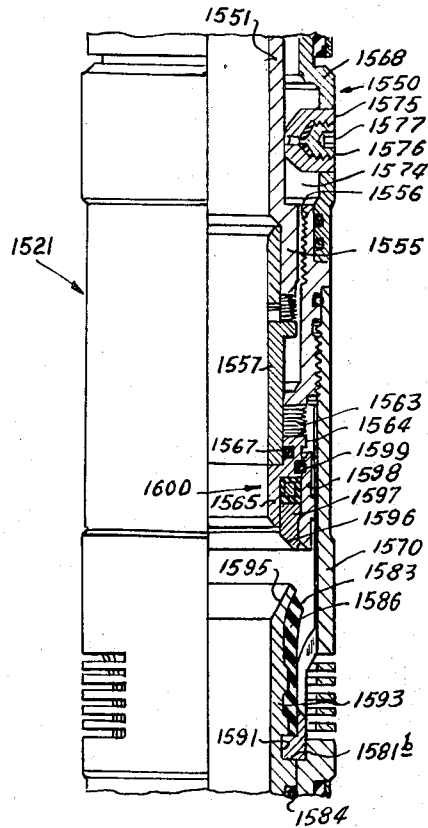


Fig. 15 B

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3,419,074

WELL TOOLS

Filed June 10, 1966

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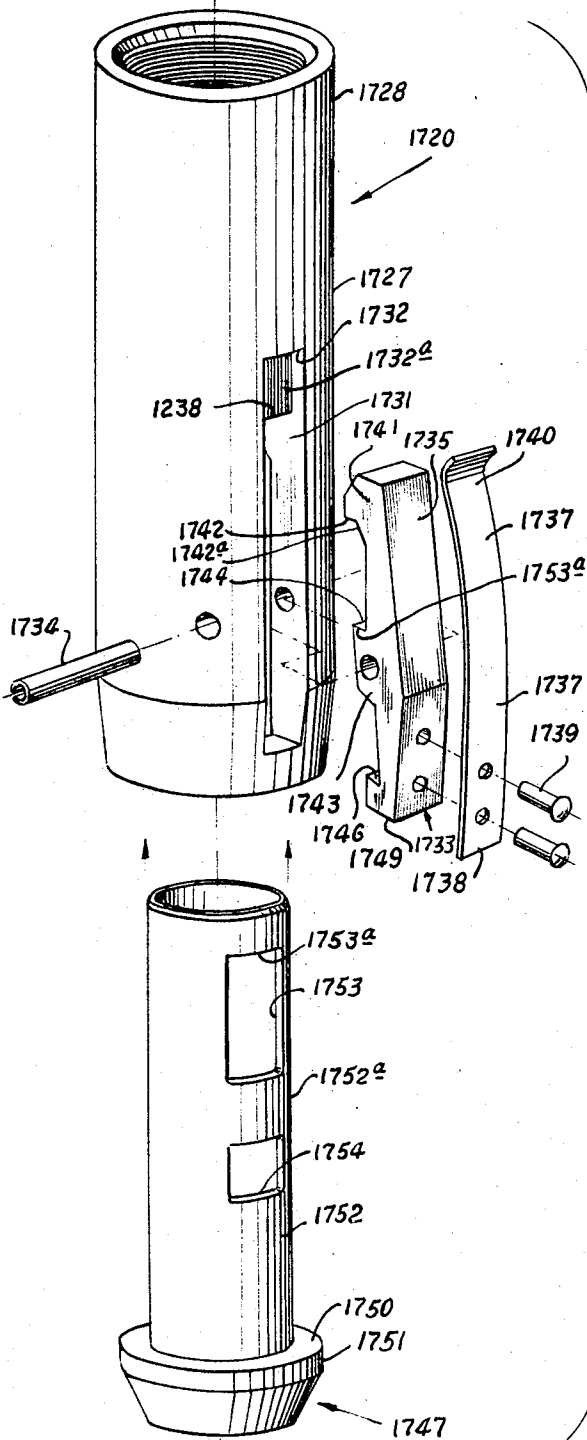


Fig. 17 A

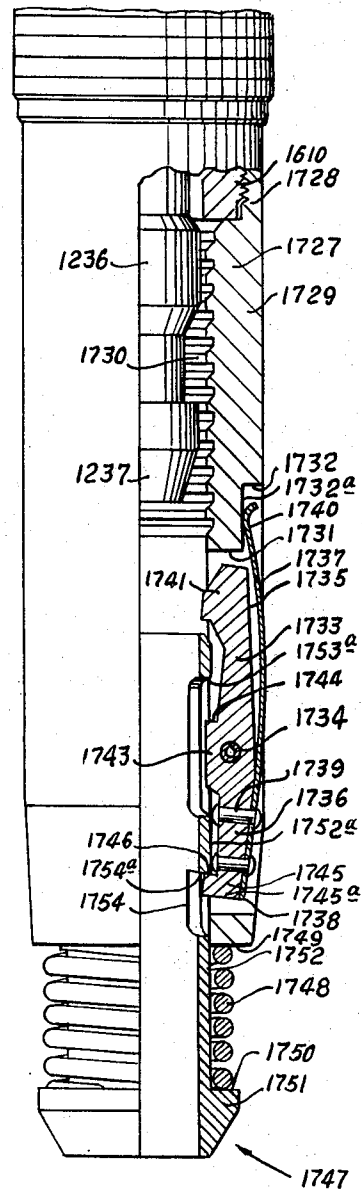


Fig. 17 B

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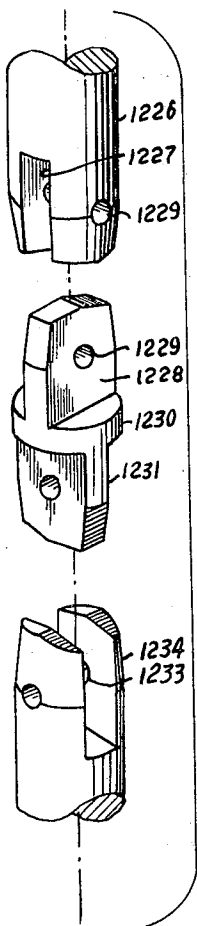
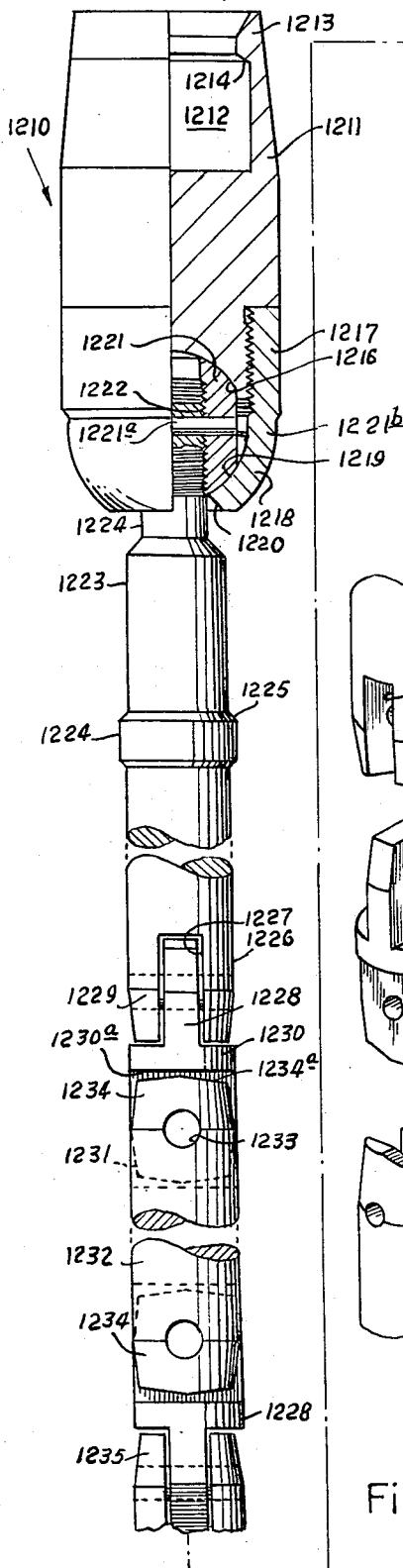


Fig. 18A

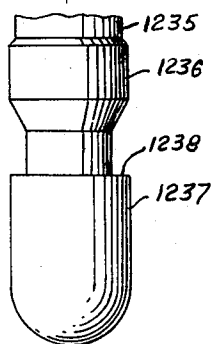


Fig. 18

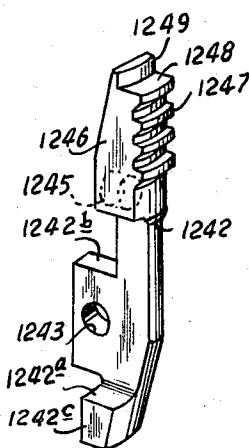


Fig. 18 C

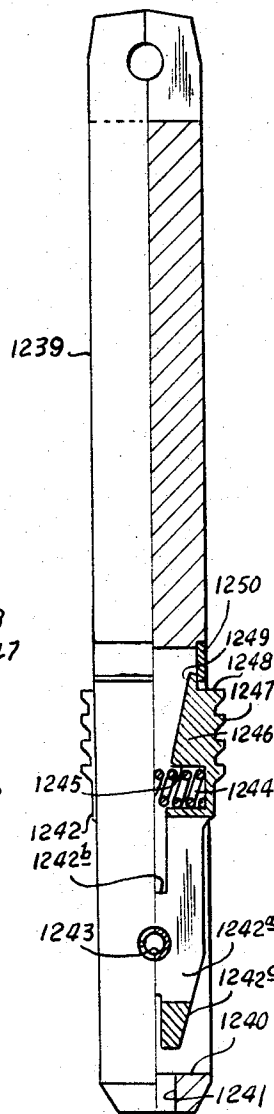


Fig. 18 B

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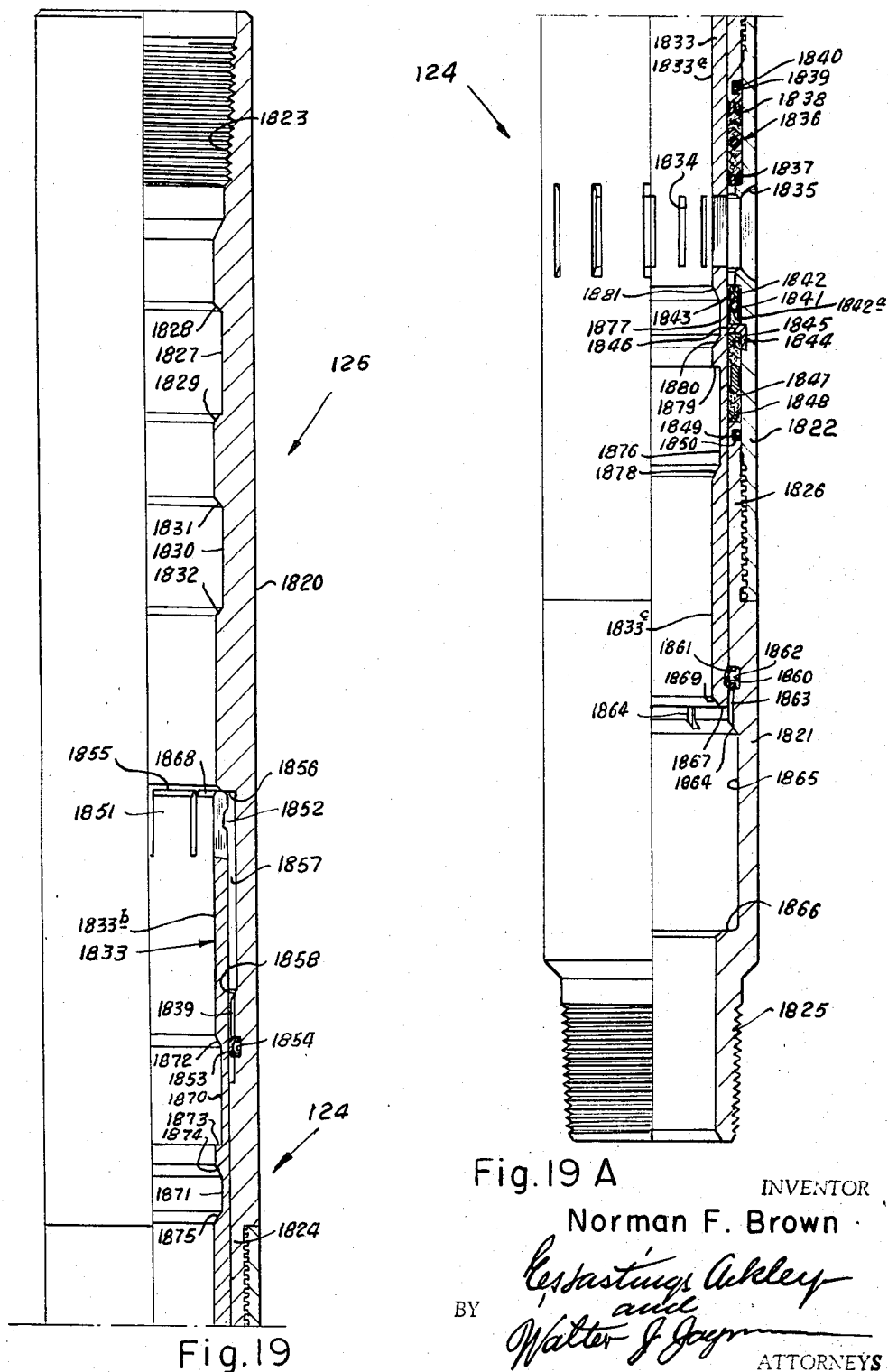
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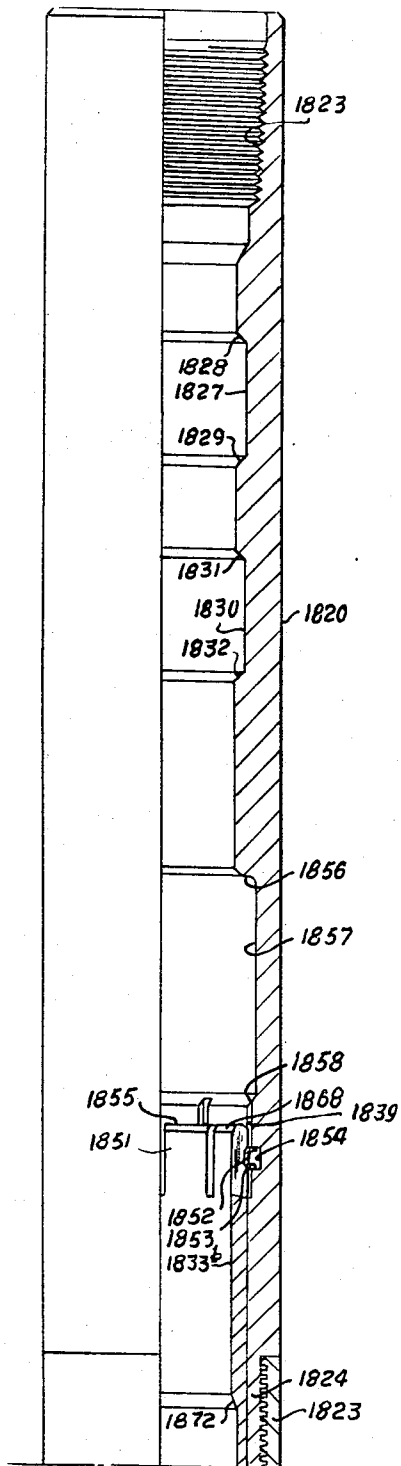


Fig. 20

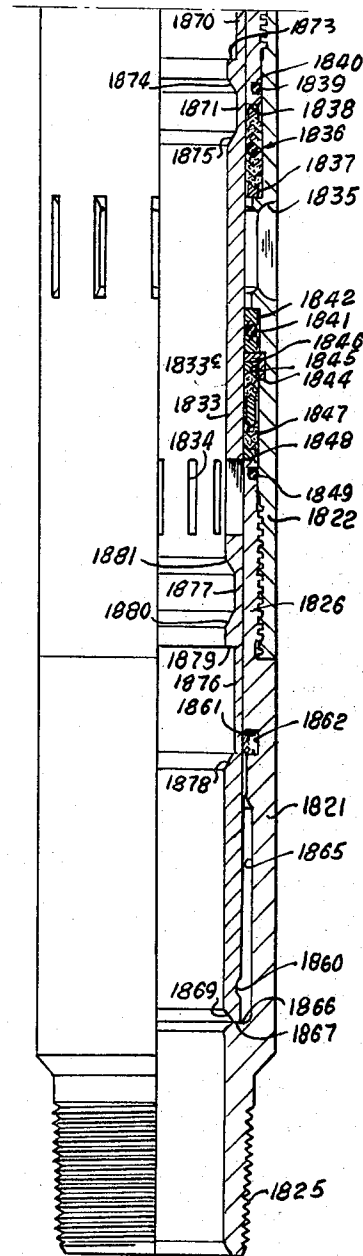


Fig. 20 A

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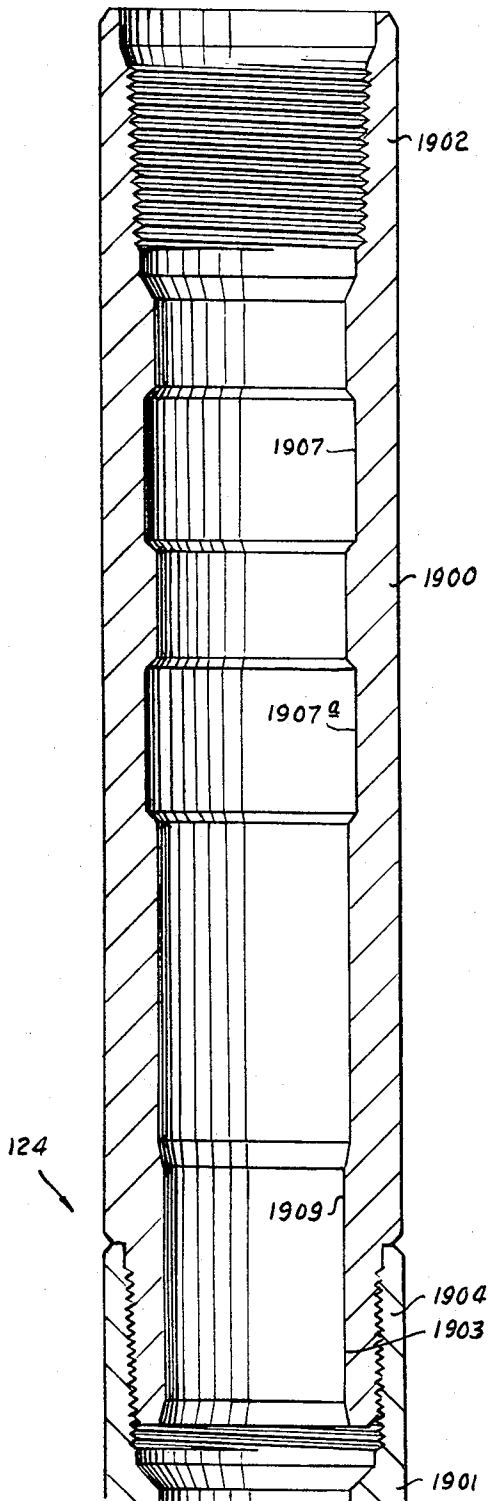


Fig. 21

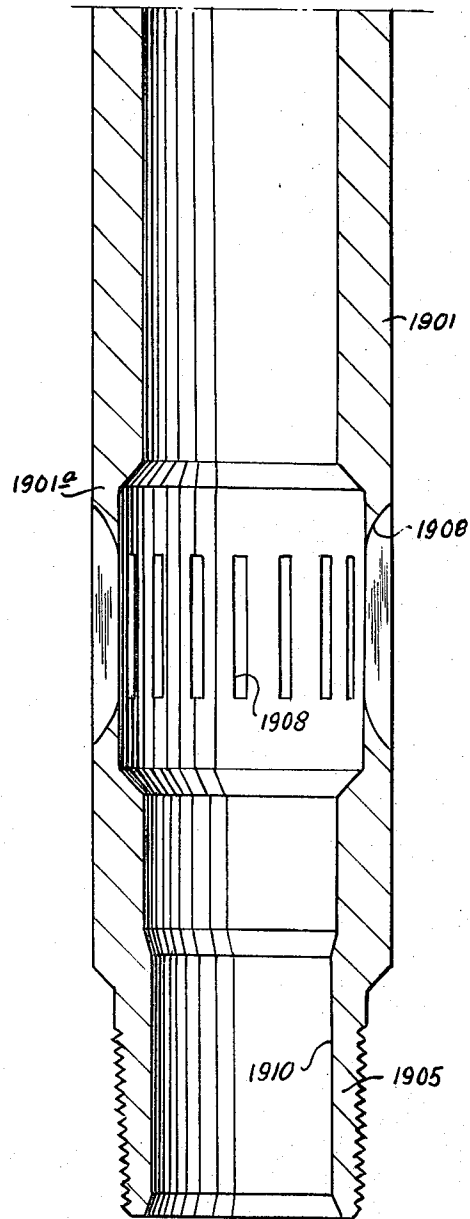


Fig. 21 A

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## WELL TOOLS

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Filed June 10, 1966, Ser. No. 556,594  
47 Claims. (Cl. 166—46)

This invention relates to well tools and more particularly relates to a gas lift system and apparatus and methods for the installation and removal of valves in a well flow conductor.

It is one object of the invention to provide a new and improved system for producing fluids from a well.

It is another object of the invention to provide a new and improved gas lift system for production of well fluids.

It is a still further object of the invention to provide a new and improved apparatus for installation and removal of a gas lift system.

It is still a further object of the invention to provide a method and apparatus for the installation and removal of a gas lift system wherein a train of well tools for installing and removing gas lift valves is moved through a flow line between a surface location and the operating positions of the gas lift valves within a well by pumping the tool train between such locations.

It is another object of the invention to provide a gas lift system for a well having a production tubing string including a sliding sleeve type valve at each depth at which a gas lift valve is to be installed.

It is still another object of the invention to provide a method and apparatus for closing and opening sliding sleeve valves in a string of well production tubing during the installation and removal of gas lift valves within the tubing.

It is a still further object of the invention to provide a method of installing a gas lift system wherein each sliding sleeve valve in the production tubing of the well in which the system is installed is moved downwardly to a closed position during the pumping of the installation tool string through the production tubing to its bottom end within a well bore.

It is another object of the invention to provide a tool train for the installation of gas lift valves in production tubing of a well including apparatus which includes means for closing open sliding sleeve valves in the production tubing as the tool train is pumped through the tubing to its lower end.

It is another object of the invention to provide a tool train for installation and removal of a gas lift system including apparatus for engaging sliding sleeve valves included in the production tubing of a well and moving the sleeve valves upwardly to an open position as the tool train is moved upwardly in the tubing.

It is another object of the invention to provide a tool train for installation and removal of a gas lift system in a well including apparatus for releasing a gas lift valve and its locking assembly and releasably locking them in a sliding sleeve valve included in the production tubing of the well.

It is another object of the invention to provide a tool train for installation and removal of a gas lift system in a well including an articulated flexible probe for supporting the gas lift valves of the system while installing, removing and transporting them through the production tubing.

It is a still further object of the invention to provide a tool train for installation and removal of a gas lift system in a well including pumpable piston or locomotive units adapted to be displaced through a flow line responsive to a fluid pressure differential across the units and to bypass fluid responsive to a pressure differential in excess of a predetermined value.

It is another object of the invention to provide a tool train for installation and removal of a gas lift system in a well bore which includes a drag or detent unit adapted to releasably lock the tool train at selected locking nipples within a flow line when the force applied to the unit in moving the tool train is below a predetermined value and to release the tool train when such force exceeds such value.

It is still a further object of the invention to provide a gas lift system including a plurality of gas lift valves at selected depth locations in the production tubing of a well and a circulating valve within the production tubing below the gas lift valves permitting circulation of fluids in either direction between the production tubing and an annular flow channel within the well bore around the production tubing.

It is another object of the invention to provide a tool train for installation and removal of gas lift valves in a well bore including both "down-shift" and "up-shift" units for opening and closing sliding sleeve valves, such units being activated to engage each sliding sleeve valve by a compressive force applied between the drag unit and the locomotive or piston units of the tool string.

It is still another object of the invention to provide a tool train for installation and removal of a gas lift system in a well bore including apparatus for moving a sliding sleeve downwardly in a flow channel of the well bore, the apparatus moving downwardly past each such sliding sleeve which has been previously closed.

It is another object of the invention to provide a method of installing gas lift valves in a gas lift system of a well wherein a plurality of gas lift valves supported in end-to-end array on a tool string which is pumped to the lower end of a production tubing string in a well bore and then pumped back to the surface while each gas lift valve is sequentially released and locked at a selected location, the lowermost of the valves being first released during the return of the tool train to the surface.

It is a still further object of the invention to provide a method of removing gas lift valves from sleeve valves in a production tubing of a well by sequentially releasing the gas lift valves beginning at the uppermost valve, displacing the gas lift valves downwardly to the lower end of the production tubing, and withdrawing the gas lift valves simultaneously in end-to-end array from the lower end of the production tubing.

It is a still further object of the invention to provide a method of removing gas lift valves from the production tubing of a well bore wherein a flexible probe is moved downwardly into the production tubing of a well bore, sequentially introduced into each gas lift valve beginning at the top valve with each valve being released from its locking nipple until the probe has been inserted through all of the valves, the valves have been displaced downwardly to the lower end of the production tubing in end-to-end array, the lower end of the probe is locked in the bottom valve, and the valves are lifted by the probe by pumping the tool string by fluid pressure from the lower end of the production tubing to the surface.

It is still a further object of the invention to provide a method and apparatus for installation and removal of a gas lift system wherein a plurality of gas lift valves are releasably supported during both installation and removal on an articulated tool train displaceable by fluid pressure through flow passages including sections of minimum curvature.

Additional objects and advantages of the invention will be readily apparent from the reading of the following description of a device constructed in accordance with the invention, and reference to the accompanying drawings thereof, wherein:

FIGURES 1 and 2 taken together constitute a schematic view partially in section and partially in elevation illustrating a tool train supporting gas lift valves and a bottom circulating valve during an early stage in the installation of such valves in a production tubing string of a gas lift system in accordance with the invention;

FIGURES 3 and 4 taken together constitute a schematic view similar to FIGURES 1 and 2 showing the tool train returning to the surface subsequent to installation of the gas lift and bottom circulating valves;

FIGURES 5-16 taken together constitute a detailed longitudinal view partially in section and partially in elevation of a tool train supporting gas lift and bottom circulating valves as they are assembled during installation;

FIGURE 5 is a longitudinal view partially in section and partially in elevation of a piston propulsion unit and a coupler used to connect it in the tool train of FIGURES 5-16;

FIGURE 5A is a view partially in section and partially in elevation of the valve assembly of the piston unit of FIGURE 5 at its closed position;

FIGURE 5B is a view similar to FIGURE 5A showing the valve assembly moved to its full open position against a lower spring guide;

FIGURE 5C is a view in perspective of the valve assembly shown in FIGURES 5A and 5B;

FIGURE 5D is a view in perspective of one of the valve spring guides of the piston unit of FIGURE 5;

FIGURE 5E is a side view in elevation of one of the couplers used for interconnecting the various functional units of the tool train, the coupled being shown in its locked position;

FIGURE 5F is a side view in elevation of the coupler of FIGURE 5E with the coupler members displaced longitudinally relative to each other and one set of adjacent end sections compressed laterally toward each other for insertion into a locking socket on one of the units of the tool train;

FIGURE 5G is an exploded view in perspective of the pair of mating coupler components illustrating the longitudinal boss along one of the components and the longitudinal recess along the other of the components;

FIGURE 6 is a view partially in section and partially in elevation of the monitor unit of the down-shift assembly of the tool train in its deactivated condition;

FIGURE 6A is a view similar to FIGURE 6 of the monitor unit in activated condition with its feeler laterally expanded;

FIGURE 6B is a side view in cross section of the trigger housing of the monitor unit;

FIGURE 6C is a front view in elevation of the trigger housing of FIGURE 6B;

FIGURE 6D is a side view in elevation of the trigger housing of the monitor unit;

FIGURE 6E is a front view in elevation of the trigger of the monitor unit of FIGURE 6;

FIGURE 6F is a side view in elevation of the feeler member of the monitor unit of FIGURE 6;

FIGURE 6G is a front view in elevation of the feeler member of FIGURE 6F;

FIGURE 6H is a side view in elevation of the slider of the monitor unit of FIGURE 6;

FIGURE 6I is a front view in elevation of the slider of FIGURE 6H;

FIGURE 7 is a view partially in elevation and partially in section of the sleeve shifting unit of the down-shift assembly of the tool train showing the sleeve shifting keys of the unit in their retracted positions;

FIGURE 7A is a view similar to FIGURE 7 showing the sleeve shifting unit of the down-shift assembly with its sleeve shifting keys expanded;

FIGURE 7B is an exploded view in perspective of the ball link, key retractors, and shifting keys of the sleeve shifting unit of the down-shift assembly shown in FIGURES 7 and 7A;

FIGURE 8 is a view partially in elevation and partially in section of the upper end and central sections of the pressure signal generator or detent unit of the tool train with its locking dogs in activated or expanded position;

FIGURE 8A is a view partially in section and partially in elevation of the upper end and central sections of the detent unit along a plane at a 90 degree angle with the view of FIGURE 8;

FIGURE 8B is a view similar to FIGURE 8A of the lower end section of the detent unit;

FIGURE 8C is a view in cross-section along the lines 8C-8C of FIGURE 8A;

FIGURE 8D is a cross sectional view along the line 8D-8D of FIGURE 8B;

FIGURE 8E is a view in cross-section along the line 8E-8E of FIGURE 8B;

FIGURE 8F is a view in section along the line 8F-8F of FIGURE 8;

FIGURE 8G is a view in section along the line 8G-8G of FIGURE 8;

FIGURE 8H is an exploded perspective view of the mandrel and locking dogs of the detent unit;

FIGURE 8I is a perspective view of the trigger link of the detent unit;

FIGURE 8J is a perspective view of the control sleeve assembly of the detent unit;

FIGURE 8K is a fragmentary view in perspective of the control rod of the detent unit;

FIGURE 8L is a perspective view of the trigger plate of the detent unit.

FIGURE 9 is a fragmentary view partially in elevation and partially in section of the lower end section of the detent unit and opposite end sections of a coupler connecting the lower end of the detent unit with the upper end of the up-shift assembly;

FIGURE 10 is a view partially in section and partially in elevation of the sleeve shifting unit of the up-shift assembly of the tool train;

FIGURE 10A is a view partially in section and partially in elevation of the sleeve shifting unit of the up-shift activated condition with its sleeve shifting keys expanded;

FIGURE 10B is an exploded view in perspective of the key retractors, the sleeve shifting keys, and a split sleeve engageable with the key retractors of the sleeve shifting unit;

FIGURE 11 is a view partially in section and partially in elevation of the monitor unit of the up-shift assembly;

FIGURE 11A is a view partially in elevation and partially in section of the monitor unit in activated condition with its feeler expanded;

FIGURE 11B is a side view in elevation of the slider member of the up-shaft assembly;

FIGURE 11C is a front view in elevation of the slider member of FIGURE 11B;

FIGURE 11D is a side view in section of the trigger housing of the monitor unit;

FIGURE 11E is a front view in elevation of the trigger housing;

FIGURE 11F is a front view in elevation of the trigger of the monitor unit;

FIGURE 11G is a side view in elevation of the feeler member of the monitor unit;

FIGURE 11H is a top end view in elevation of the feeler member;

FIGURE 11I is a side view in elevation of a spring anchor of the monitor unit for holding one end of the feeler member biasing springs;

FIGURE 11J is a front view in elevation of the spring anchor of FIGURE 11I;

FIGURE 12 is a fragmentary longitudinal view partially in section and partially in elevation showing a portion of a lower piston unit and the head assembly of the flexible probe for supporting the gas lift valves;

FIGURE 13 is a view partially in section and partially

in elevation showing a lower end section of the head assembly of the flexible probe and the latch unit for the uppermost gas lift valve supported on the probe;

FIGURE 13A is a front view in elevation with a broken out section of the latch unit shown in FIGURE 13;

FIGURE 13B is a sectional view along the line 13B—13B of FIGURE 13 showing the locking dogs in retracted position;

FIGURE 13BB is a view in section along the line 13BB—13BB of FIGURE 13;

FIGURE 13C is a side view in elevation of a latch cleat in the latch unit of FIGURE 13;

FIGURE 13D is a front view in elevation of the latch cleat;

FIGURE 13E is a perspective view of the latch cleat ring used with the latch cleat;

FIGURE 13F is a side view in elevation of the mandrel of the latch unit;

FIGURE 13G is a front view in elevation of the latch unit mandrel;

FIGURE 13H is a view in section along the line 13H—13H of FIGURE 13F;

FIGURE 13I is a perspective view of a lock member used for locking the dogs of the latch unit at an outward position;

FIGURE 13J is a view in elevation of the pair of latch dogs of the latch unit at expanded position and showing a longitudinal fragmentary section of the portion of the latch unit body to which the dogs are pivotally secured;

FIGURE 13K is a view in section along the line 13K—13K of FIGURE 13;

FIGURE 14 is a view partially in section and partially in elevation showing an upper section of the uppermost gas lift valve supported on the flexible probe;

FIGURE 14A is an exploded view in perspective of the components of a universal joint connecting the latch unit with the gas lift valve;

FIGURE 15 is a view partially in section and partially in elevation of a lower section of the gas lift valve of FIGURE 14;

FIGURE 15A is a perspective view of a check valve retainer employed in the gas lift valve of FIGURES 14 and 15;

FIGURE 15B is a fragmentary view in section illustrating the valve assembly of the gas lift valve at an open position;

FIGURE 16 is a fragmentary view partially in section and partially in elevation showing the upper end section of a latch unit supporting the bottom circulating valve on the probe and a central section of the bottom circulating valve including its valve assembly;

FIGURE 17 is a view partially in section and partially in elevation showing a lower end section of the bottom circulating valve and a bottom release assembly connected thereto for releasable connection of the bottom circulating valve to the lower end section of the flexible probe;

FIGURE 17A is an exploded view in perspective showing the body of the bottom release assembly, its locking key, and its key lock member;

FIGURE 17B is a fragmentary view in section showing the components of the bottom release assembly moved to their release positions;

FIGURE 18 is a fragmentary view partially in section and partially in elevation of a flexible articulated probe used in the tool train to support and install the gas lift valves and bottom circulating valve;

FIGURE 18A is a fragmentary exploded view in perspective showing one of the universal joints of the articulated probe;

FIGURE 18B is a longitudinal view partially in section and partially in elevation of a bottom pulling link of the flexible probe used for removal of the bottom circulating and gas lift valves;

FIGURE 18C is a perspective view of one of the dogs of the pulling link of FIGURE 18B;

FIGURES 19–19A taken together constitute a view partially in section and partially in elevation of an open sliding sleeve valve used with each gas lift valve in the gas lift system of the invention;

FIGURES 20–20A are views similar to FIGURES 19–19A showing the sliding sleeve valve closed; and

FIGURES 21 and 21A taken together constitute a view in section and elevation of a bottom circulation nipple used with the bottom circulating valve of FIGURES 16 and 17.

FIGURES 1 and 2 together illustrate a gas lift system 100 during the initial phases of installation of its gas lift valves. Referring specifically to FIGURES 1 and 2, the gas lift system is installed in a well 101 which is equipped with a casing string 102 having a wellhead 103. A production tubing string 104 is supported in the well from the wellhead and extends downwardly through a suitable well packer 105 secured between the production tubing and the well casing. The production tubing and the casing define a central production flow channel 110 through the tubing and an annular flow channel 111 around the tubing within the casing. A flow conduit 112 having a valve 113 is connected through the wellhead into the annular flow channel. The production tubing is connected with a flow conduit 114 which is equipped with a valve 115 and in spaced apart relation thereto a removable end cap 120 defining a lubricator end section 114a of the flow conduit which permits well tools to be introduced into and removed from the flow conduit. A flow conduit 121 having a valve 122 is connected into the section 114a near the end cap 120 to permit fluid circulation with the conduit 114 through the section 114a for introducing and removing pumpable well tools into and from the production tubing string through the flow conduit 114.

The lubricator section 114a may be located immediately adjacent the wellhead 103 on a suitable platform supported either on the earth's surface, or, in the case of an off-shore located well, above the surface of water. In the alternative, the lubricator may be at a shore location with the conduit 114 extending to an off-shore located well whereby various service functions and equipment installation and removal may be carried out in the off-shore well from a land location without the necessity of using ships, floating barges, or an above-water platform.

The production tubing 104 includes a plurality of sliding sleeve valves 123 and a bottom circulating nipple 124 each of which has a landing nipple or well tool locking section 125. A suitable sliding sleeve valve is illustrated in FIGURES 18–19B. A sleeve valve is provided in the production tubing for each gas lift valve in the system and for a bottom circulating valve below the gas lift valves. The sleeve valves are movable by the up-shift and down-shift assemblies of the tool train between open and closed positions to control fluid flow between the central flow channel 110 and the annular flow channel 111 at the level of each of the sleeve valves. Each of the sleeve valves is connected in the production tubing string as it is run into the well so that each of the valves is located at a desired depth within the well to support a gas lift valve in the gas lift system at such depth. Below the lowest sliding sleeve the bottom circulation nipple is included in the production tubing string. Also included in the production tubing string is a pin collar 126 which is a suitable section of conduit threaded or welded into the production tubing string and having a laterally extending pin 130 for preventing the displacement of well tools either out the bottom end of the production tubing string or below a desired depth in the tubing string. As explained hereinafter, the pin collar is located in the tubing string at a predetermined distance below the bottom circulation nipple.

A pumpable tool train 140 for installing and removing

the gas lift and bottom circulating valves comprises one or more upper piston propulsion units 200, a down-shift assembly 300 for moving sliding sleeve valves downwardly to a closed position, a detent unit 700 for yieldably resisting the movement of the tool string through the production tubing at the sleeve valves; an up-shift assembly 1000 for engaging and shifting sliding sleeve valves upwardly, one or more lower piston units 200a, and an articulated or flexible probe 1260 for supporting a plurality of gas lift valves 1500 and a bottom circulating valve 1700, each of which is releasably secured on the probe in end-to-end array by its latch unit 1300. The various functional units of the tool train are connected by couplers 260.

The tool train 140 is assembled as shown in FIGURE 1 and the gas lift and bottom circulating valves are locked on its probe. While the valve 115 is closed the end cap 120 is removed and the tool train and valves are inserted into the lubricator section 114a. The valves 115, 122 and 113 are opened and the tool train and valves are pumped through the conduit 114 into and downwardly through the production tubing 104. Fluid in the production string in advance of the tool string and valves moves downwardly through the production string, outwardly through the sliding sleeve valves, and upwardly through the annular space 111 passing outwardly from the well casing and the conduit 112. As the valves and tool string are pumped downwardly in the production tubing the valves, the flexible probe, the lower piston unit 200a, and the up-shift assembly 1000 pass freely through the uppermost sliding sleeve valve. When the detent unit 700 reaches the uppermost sliding sleeve valve it releasably engages a locking recess in the sleeve valve while the top piston 200 compresses the down-shift assembly 300 to activate the assembly by expanding its sleeve shifting keys for shifting the uppermost sliding sleeve valve downwardly to its closed position. A pressure increase pulse is transmitted to the surface through the liquid above the detent unit and is recorded by a suitable pressure recording meter, not shown, to provide intelligence concerning the position of the tools. The pressure on the tool train is then increased to apply a force on the detent unit above a predetermined value to release the unit from the sliding sleeve valve permitting the tool string to move farther downwardly until the down-shift assembly engages the sliding sleeve valve. The down-shift assembly shifts the sleeve valve downwardly to its closed position and releases from the sleeve valve to permit the tool train to continue downwardly to the next sliding sleeve valve where the procedure is repeated to shift it downwardly to its closed position.

The tool train along with the bottom circulating and gas lift valves supported on its probe continue downwardly shifting each of the sliding sleeve valves to its closed position until the lower end of the bottom circulating valve 1700 engages the pin collar 126 which prevents further movement of the tool train downwardly, releases the bottom circulating valve from the probe, and shifts the latch 1300 on the bottom circulating valve from a locked condition to an intermediate activated condition set to release upon arrival at the locking section 125 of the bottom circulating nipple. When the tool string is stopped by the pin collar the increase in pressure in the production tubing above the tool string effected by stoppage of the string is transmitted through the liquid column in the production string to the surface indicating the stoppage of the tool string at which time the direction of fluid circulation is reversed with return fluid passing upwardly through the production tubing string and supply fluid being introduced into the annular space 111 through the conduit 112. The circulation pattern being reversed the tool string is pumped upwardly in the production tubing with the tool string and valves moving freely upwardly until the latch 1300 on the bottom circulating valve engages the bottom circulation nipple effecting release of the latch unit from the flexible probe so that the latch unit

is locked in the landing nipple with the bottom circulating valve positioned below it to control flow between the annular space 111 and the production tubing string flow channel 110 through the circulation nipple. The release of the bottom circulating valve latch unit from the flexible probe frees the tool train along with the gas lift valves on its probe to move upwardly to the lowermost sliding sleeve valve and activates the latch unit on the lowermost gas lift valve on the probe. As the tool string moves upwardly, the upper piston unit 200 and the down-shift assembly 300 pass freely through the lowermost sliding sleeve valve until the detent unit 700 engages a recess in the sleeve valve to releasably hold the tool train against upward movement while pressure within the production tubing string below the lower piston unit 200a is increased first to compress the up-shift assembly 1000 activating it and then with continued pressure increase, to release the detent unit allowing the tool train to resume its upward movement and causing the up-shift assembly to engage the sleeve valve shifting it upwardly to an open position. After shifting the sleeve valve to its open position, the up-shift assembly releases from the sleeve valve permitting the tool train to continue upward movement with the activated latch unit on the lowermost gas lift valve engaging the locking recess 125 of the lowermost sliding sleeve valve to lock the lowermost gas lift valve in the sliding sleeve valve and disengage the latch unit and valve from the flexible probe. The tool train with its remaining gas lift valves continues upward movement, the sliding sleeves being sequentially shifted upwardly to an open position and a gas lift valve and its latch unit being released from the probe and engaged with and secured in each sliding sleeve valve. When the last and uppermost gas lift valve has been released from the flexible probe, the tool train with its empty flexible probe is pumped back into the manifold section 114a from which it is removed after the valve 115 is closed and the end cap 120 removed.

The gas lift valves and bottom circulating valve are removed or retrieved from the production tubing by introducing the tool train and flexible probe into the production tubing through the manifold section 114a as previously discussed. The tool train with its probe are pumped downwardly with the probe passing downwardly through the uppermost gas lift valve disengaging the valve so that it falls or is displaced downwardly by the tool train subsequent to which the down-shift assembly in the tool train engages and moves the uppermost sliding sleeve downwardly to a closed position. Each gas lift valve is similarly released and its sliding sleeve valve is moved downwardly to a closed position as the tool train and probe are pumped toward the lower end of the production tubing. When the probe has similarly released the bottom circulating valve, it and all of the gas lift valves with their respective latch units are in stacked or end-to-end array within the lower end section of the production tubing. The continued downward movement of the tool train and the flexible probe causes the probe to telescope in the gas lift valves and the bottom circulating valve with means on the lower end section of the probe engaging the bottom circulating valve to lock it along with all of the gas lift valves above it on the probe. Fluid circulation is then reversed in the system pumping the tool string and the valves supported on the probe back to the surface. During the return trip of the tool string to the surface the detent unit engages the recess provided in each of the sliding sleeve valves activating the up-shift assembly so that as the detent unit releases the tool string from each sliding sleeve valve the up-shift assembly shifts the valve upwardly to its open position and releases from the valve to permit the tool string to continue upwardly. Each sliding sleeve valve is similarly moved upwardly to its open position as the tool train passes through it during its movement back to the surface. The tool train is pumped back into the manifold

section 114a from which it is removed as previously discussed by closure of the valve 115 and removal of the end cap 120.

The above description of a gas lift system embodying the invention, and the installation and removal of its gas lift and bottom circulating valves is intended to be only general in nature and provide a basis for understanding the detailed description of the system, its components, and its operation.

The piston units 200 and 200a serve as "locomotives" for the tool train 140 to propel it along a flow passage, such as the passage 110 within the production tubing string, responsive to a fluid pressure differential applied across the units. Referring specifically to FIGURES 5-5D, each of the piston units includes a body or mandrel 201 supporting an external annular expandable packing assembly 202 for releasably sealing between the mandrel and the inner wall of a flow conduit. The mandrel has a central flow passage 203 in which is disposed a longitudinally movable spring biased valve assembly 204 adapted to move to the fully closed position shown in FIGURE 5A responsive to a pressure differential imposed across the valve assembly and to move farther to a fully open position, FIGURE 5B, allowing maximum flow through the flow passage 203 when the pressure differential across the piston unit within a conduit exceeds a predetermined value. So long as a pressure differential which does not exceed a predetermined value, is applied across the piston unit, it functions as a locomotive or propulsion capable of applying a force to a tool train of a magnitude determined by the cross sectional area of the piston unit and the pressure applied across it. The valve is adapted to open to permit full fluid flow through the passage 203 when the pressure differential exceeds the predetermined value so that tool damage may be avoided when the unit or any of the tool train propelled by it encounters an obstruction in a flow passage which prevents movement therethrough. The opposite end sections of the piston unit each comprises an internally threaded tubular connector socket 205 threaded on the opposite end sections 206 of the mandrel. Each of the connector sockets has an internal annular end flange 207 defining the outward end of a socket chamber 208 for receiving a locking head of a coupler used in securing the piston unit to adjacent tools in the tool train. The connector socket at the inward end of each socket has a central internal annular flange 209 providing an inwardly facing annular shoulder 210 for engaging an end of the mandrel to limit the movement of the socket connector on the mandrel and an outwardly facing internal annular shoulder 210a defining the inward end of the socket chambers 208. A spring spider member 211 is clamped at each end of the mandrel between the mandrel end and the internal shoulder 210 of the socket connector secured thereto. Each spring spider 211, FIGURE 5D, comprises four radial vanes 212 spaced 90 degrees apart and having formed integrally therewith a nose or a stop probe 213 which limits the longitudinal movement of the valve assembly 204 within the flow passage 203. The extent of longitudinal movement of the valve assembly within the mandrel is determined by the length of the valve assembly and the distance between the ends of the stop probes 213 of the spring spiders. Each of the vanes of the spiders has a reduced portion 214 about which extends an end section of a spring 215 positioned within the bore 203 whose other end section is telescoped over an adjacent end section of the valve assembly. The springs 215 engage each of the spiders 211 and telescope over each of the adjacent end sections of the valve assembly so that the valve assembly is yieldably biased to the central position illustrated in FIGURE 5.

Each of the connector sockets is held against rotation on the mandrel by a lock pin 216 extending through the connector socket into the mandrel. The finned construction of each spring spider provides for maximum fluid

flow into each end of the piston unit through the socket recess 208, around the radial fins of the spring spiders, and into the central flow passage 203 of the mandrel.

The mandrel is provided with internal longitudinally spaced flanges 218 each providing an outwardly facing annular shoulder 219. The springs 215 are confined between shoulders 220 of the vanes of the spring spiders at their outward ends and retainer rings 221 held against inward movement by the shoulder 219. The inward ends of the two springs 215 each acting through its retainer ring 221 bias the valve assembly 204 toward its central neutral position.

The valve assembly 204 of the piston unit, FIGURE 5C, includes an elongated body or core 222 which has a central portion 223 circular in cross section along a plane transverse to its longitudinal axis and is provided with an external annular recess 224 for an O-ring seal 225. The core includes longitudinal radial vanes 226 extending from opposite ends of the central portion 223 spaced around the valve member at 90 degree intervals defining four endwardly and radially opening recesses 227 spaced around each end section of the core separated by the four vanes 226. The recesses 227 defined by the vanes minimize the cross sectional area of each end section of the valve core to provide maximum fluid flow bypassing the core when it is positioned at one of its open positions. Each of the valve core vanes 226 is increased in radial width along an inward section adjacent to the central portion 223 providing a shoulder surface 228 on each of the vanes for engaging the spring retainer ring 221 positioned around them when the valve assembly in displaced longitudinally in either direction by fluid pressure applied across the piston unit. The valve core has a bore 229 extending therethrough at an angle to the longitudinal axis of the core providing a bypass flow channel through its central section communicating between two of the valve member recesses 227 along opposite end sections of the core so that a limited amount of fluid flow may occur through the valve assembly whether the assembly is at open or closed position within the piston unit mandrel. The bore 229 is internally threaded along a portion of its length to permit the threaded engagement therein of a flow bean 230 having a bore 231. A plurality of flow beans may be provided with different size bores to permit adjustability of the bypass flow rate through the central section 223 of the valve core.

The piston mandrel 201 has a plurality of radial circumferentially spaced ports 232 to allow the application of fluid pressure from the central flow passage 203 of the mandrel outwardly into the packing assembly 202 for expanding the packing assembly into sealing relationship with the inside wall of a conduit through which the piston is moving. On opposite sides of the ports 232 the mandrel has internal annular spaced flanges 233 providing internal annular facing valve seat surfaces 234 engageable by the O-ring 225 when the valve assembly is moved longitudinally to either of its closed positions.

The packing assembly 202 includes a resilient tubular body or sleeve 235 in which are embedded and bonded thereto a plurality of longitudinal, circumferentially spaced, arcuate segments 236a and 236b of a wear resistant rigid substance such as metal or the like. The identical segments 236a have configurations which are mirror images of the identical segment 236b. The segments 236a and 236b extend longitudinally and are spaced around the sleeve 235 in annular array or alignment with each segment 236a disposed between and pivotally connected to a pair of the segments 236b and with each segment 236b disposed between and pivotally connected between a pair of the segments 236a. Each segment 236a has a pair of longitudinally spaced hooks or pins 237a and 237b which extend divergently in the same longitudinal direction at opposite sides of the segment and which define with the segment the sockets 238a and 238b open-

ing in the same direction toward which the hooks or pins extend. Each segment 236b is similarly provided with a pair of hooks or pins 239a and 239b which extend divergently in one longitudinal direction at opposite sides of the segment and which define inwardly opening recesses or sockets 240a and 240b which open in the same direction that the pins 239a and 239b extend. By means of the pins and sockets the segments 236a and 236b are interlocked with each other. For example, the pin 239b of the segment 236b is received within the recess or socket 238b of the segment 236a while the pin 237b on the segment 236a is received within the socket 240b of the segment 236b. The surface of a segment in which a pin from an adjacent segment is received engages the surface of the pin of the adjacent segment thereby preventing longitudinal movement of each segment relative to those adjacent segments on opposite sides thereof with which it is interlocked by the respective pins of such segments. While the segments are held against longitudinal movement relative to each other the configuration of the pins and sockets and their relative dimensions are such that each pair of adjacent connecting segments may pivot about an axis which extends parallel to but spaced from a radial line passing through the central longitudinal axis of the packer element. The pins 237a and 237b of the segment 236a both face axially in one direction while the pins 239a and 238b of the segment 236b face axially in the other. The end faces 236c and 236f of the segments 236a and 236b, from which the pins are pointing, bear against the retaining rings 247 and transmit axial loads to the connectors 205 while the other ends, towards which the pins are pointing, do not bear against retaining rings and do not transmit axial loads. In this way the axial drag on the segments, resulting from their friction against the inner wall of the tubing while moving through it, acts always to assist the sealing engagement of all the linked pins and recesses of adjacent segments respectively, regardless of the direction in which the unit is moving through the pipe. Since the segments are embedded in the resilient sleeve 235 they are held against disengagement and the pivotal connections provided by their respective pins and recesses permits radial expansion and contraction of the packer element. Each segment has opposite end stop portions 241 and 242 extending outwardly of beveled end section shoulders 243 and 244 which extend in opposite longitudinal direction from the outer arcuate central seal surface 245 of each segment. The end stop portions 241 and 242 telescope respectively into annular retainer rings 246 and 247. The retainer rings telescope over opposite end sections 248 and 249 of the tubular sleeve 235.

The upper end section 248 of the resilient tubular body 235 has an external annular flange portion 248a which is received within an internal annular recess 246a of the retainer ring 246, while, similarly, the lower end section 249 of the body has an external annular flange section 249a which is received in an internal annular recess 247a of the retainer ring 247. The top socket connector 205 has a lower end downwardly facing annular stop shoulder 205b while the lower socket connector 205 similarly has an upwardly facing identical external annular stop shoulder 205b which holds the seal assembly 202 against downward movement on the piston. An upper end annular surface 246b of the tubular sleeve 235 is sealingly engageable with the downwardly facing stop shoulder 205b while, similarly, a lower end annular surface 249b on the tubular sleeve is sealingly engageable with the upwardly facing annular stop shoulder 205b on the lower socket connector 205.

The outer surfaces of the rigid seal segments 236a and 236b extend radially outwardly to engage the internal surface of a flow conductor through which the piston is movable.

The annular seal assembly 202, due to the resilient forces of the tubular body 235, prior to the insertion of the tool into a flow conductor, assumes a fully expanded

condition wherein any further expansion thereof is limited by engagement of the opposite end stop portions 241 and 242 of its metal seal segments with the internal surfaces of its top and bottom retainer rings 246 and 247, respectively, so that the segments extend outwardly of the retainer rings to a diameter greater than the internal diameter of the flow conductor. When the piston is inserted into a flow conductor its seal assembly is cammed radially inwardly around the piston mandrel to a partially contracted position. As the seal assembly is thus moved to its partly contracted or retracted position by engagement of its segment outer bosses with the inside wall of a flow conductor, the outer portions of the tubular body 235 may deform outwardly into the spaces between the seal segments 236a and 236b.

When the seal assembly is in its normal operative position in a well flow conductor the arcuate outer surfaces of the bosses of the segments 236a and 236b constitute sections of and lie in a cylindrical plane whose diameter is substantially equal to the normal internal diameter of the flow conductor and such surfaces sealingly engage the internal surfaces of the flow conductor along a substantially continuous seal line extending circumferentially around the outer surfaces of the segments. The only gaps in this line may occur between the edge surfaces of the segments at their sockets and the adjacent and contacting outer surfaces of the hooks disposed therein. Any such gaps will be of extremely small orifice so that the seal effectively closes the annulus between the flow conductor and the mandrel of the piston and any small leakage of fluid which passes such seal through such gaps does not decrease to any appreciable degree the efficiency of the well tool.

As the pressure in the flow passage of the flow conductor above the piston is increased due to the pumping of fluids into the flow conductor to a value which exceeds the pressure in the flow conductor below the piston, the seal assembly 202 is biased downwardly until the lower end surface 249b of the tubular body 235 engages the stop shoulder 205b on the lower connector socket effecting sealing engagement between the stop shoulder and the lower end of the tubular body. Simultaneously the valve 204 is also biased downwardly to the position shown in FIGURE 5A thereby ensuring that it is the higher of the two pressures which acts radially outwardly through the ports 232 in the piston mandrel is applied within the tubular body acting on its internal surfaces expanding it radially outwardly and biasing the segments outwardly into tighter sealing engagement with the internal surfaces of the flow conductor. The seal assembly thus closes the annulus between the flow conductor and the mandrel of the piston and the downwardly acting force of the pressure differential across the piston as fluid is pumped into the flow conductor biases the piston in the flow conductor toward the lower pressure. The greater the pressure differential across the seal assembly the greater the force with which the lower end surface of the resilient body is held in sealing engagement with the stop shoulder 205b on the lower connector socket and the greater the force with which the segments are biased outwardly and held in sealing engagement with the internal surfaces of the well flow conductor thus assuring proper closure of the annulus between the piston mandrel and the flow conductor up to the value of the pressure differential at which the valve assembly of the piston is moved to its open position to permit fluid by-pass through the piston.

A pressure differential from below the piston similarly acts to effect a sealing relationship between the seal assembly 202 and the internal surfaces of the flow conductor while biasing the piston in upward direction. The seal assembly is biased upwardly with sealing engagement being effected between the upper end surface 246b of the tubular resilient body and the stop shoulder 205b on the top connector socket 205.

Annular packer seal elements similar to the seal ele-

ment **202** are disclosed in my copending United States patent applications Ser. No. 312,175, filed Sept. 27, 1963, now abandoned, and Ser. No. 402,707, filed Oct. 9, 1964, now Patent No. 3,318,605. A substantially identical packer assembly is illustrated on the piston unit shown in FIGURE 1 at page 3781 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 edition, published by World Oil, Houston, Tex.

Each of the socket connectors **205** at opposite ends of the piston unit is reduced in diameter along its inward end section providing an annular longitudinally extending flange **205a** around which the end sections **248** and **249** of the sleeve **235** are fitted. The inside wall or surface **235a** of the sleeve **235** is spaced apart from the outside tubular central section surface **250** of the piston mandrel providing an annular chamber **251** around the mandrel within the sleeve element between the end socket connectors which receives fluid displaced radially outwardly from the central flow passage through the piston mandrel through the radial ports **232** to expand the packer element within a flow conductor so that the segments **236a** and **236b** are displaced outwardly into engagement with the wall defining the flow conductor.

The valve assembly **204** which is shown at its central neutral position in FIGURE 5 functions to permit the piston unit **200** to be pumped in either direction through a flow conduit while being adapted to allow fluid flow in the conduit through the piston unit when the unit becomes lodged or for some other reason held against movement within the conduit. Ability to pump through the piston unit is desirable in well operations both for the purpose of preventing or minimizing damage to the piston unit or other apparatus in a well in which a piston unit becomes lodged and to permit continued fluid flow through a well in which a piston unit has become so lodged. The finned construction of the opposite end sections of the valve core **222** and the spring spiders **211** permits fluid flow through each end section of the piston unit in its central flow passage **203** up to the O-ring **225**. A fluid pressure differential across the valve assembly from either end displaces the valve assembly in the direction of the lower pressure. Since the valve assembly moves freely within the mandrel between the springs **215** only a slight pressure differential across the assembly is required to displace it to a closed position. The oppositely facing shoulders **228** on the valve core are so spaced from the spring retainer rings **221** that the valve assembly is displaced in either longitudinal direction by a pressure differential across it to a closed position at which the shoulder **228** facing in the direction of movement of the valve assembly engages the spring retainer ring **221** on the low pressure or downstream side of the valve assembly. Thus, a pressure differential imposed across the piston unit from above the unit as viewed in FIGURE 5 displaces the valve assembly downwardly until its lower shoulder **228** engages the lower spring retainer ring **221**, FIGURE 5A, at which position the O-ring **225** engages the lower valve seat surface **234** reducing the fluid flow through the central flow passage of the piston unit to zero if the member **230** in the bypass flow passage **229** of the valve member is a solid plug or to a substantially reduced minimum flow rate if a flow passage is provided in the member **230** in the bypass flow passage.

With the valve core **222** moved downwardly to its lower closed position fluid pressure applied above the valve member into the central flow passage of the piston mandrel is communicated radially outwardly through the ports **232** into the annular chamber **251** within the packing assembly **202** around the piston mandrel effecting expansion of the packing assembly into engagement with the inside wall defining the flow passage of the flow conduit in which the piston unit is positioned. With the packing assembly so expanded the annular space around the piston unit within the wall of the flow channel is thus sealed by the packer element and the piston unit is therefore biased longitudinally along the flow channel by the pressure being applied across it from end to end. The

pressure differential which can be resisted by the valve assembly and thus below which it remains in the closed position is determined principally by the strength of the springs **215** and the degree to which the spring is normally compressed between its spider and its retainer ring **221**. When the pressure differential imposed across the piston unit valve assembly is raised above the value below which it remains closed the valve core is moved toward the lower pressure while its lower shoulder **228** through its spring retainer ring **221** on the low pressure side compresses the spring **215** moves the valve assembly farther to an open position as illustrated in FIGURE 5B.

With the piston valve assembly at an open position as illustrated in FIGURE 5B fluid being pumped into the upper end of the piston unit flows around the fins **226**, through the recesses **227** of the valve core **222**, and annularly around the O-ring **225** within the flow passage **203** between its internal flanges **218** and **234**. So long as the pressure differential applied across the piston unit is of sufficient magnitude to maintain the spring **215** in a compressed condition, the valve assembly **204** is held at an open position and fluid may flow through the piston unit. The valve assembly is prevented from moving further downwardly from the position of FIGURE 5B by the engagement of the lower end of the valve core **222** with the upper end of the nose **213** on the lower spring spider **211**. When the pressure differential across the piston unit reduces to a lower value the valve assembly will return upwardly to either an intermediate position or back to the closed position of FIGURE 5A depending upon the extent of the reduction. It will be obvious that even with the valve assembly in the open position the pressure differential applied across the piston unit to maintain the valve assembly in such position is communicated into the annular space **251** holding the packer element **202** expanded outwardly and biasing the piston unit downwardly and if the obstruction in the flow conduit is not sufficient to hold the piston unit against movement the unit may move along the flow passage. Normally, of course, when the piston unit has not encountered an obstruction in the flow passage and when it is not overloaded by an excessively long or heavy string of well tools, the valve assembly will remain at a closed position so long as the pressure differential across it is maintained below the level determined by the springs **215** and the piston unit will be displaced along with its well tool string through the conduit or flow channel in the direction of the lower pressure.

The piston unit **200** is secured to the down-shift assembly **300** by a coupler **260** which provides an articulated connection between the lower end of the piston unit and the upper end of the down-shift assembly. The coupler, illustrated in further detail in FIGURES 5E-5G, consists of longitudinally extending male and female members **261** and **262** yieldably held against relative radial and longitudinal movement by an encircling spring **263**. The male coupler member **261** has a central semitubular section **264**, spring retainer flanges **265** providing inwardly facing stop shoulders **266** and outwardly convergent oppositely facing shoulders **267**. Extending endwardly from the flanges **265** are reduced semitubular end sections **268** each of which is provided with an end flange **269**. The end locking flanges **269** provide inwardly facing convergent shoulder surfaces **270** and opposing or oppositely facing outwardly convergent end shoulder surfaces **271**. The flanges **265** and **269** are each substantially semicircular in cross section.

The female coupler member **262** is provided with a central semitubular body section **272** having integral flanges **273** which provide facing spring retainer shoulders **274**. The flanges **273** are provided with the oppositely facing outwardly convergent shoulders **275**. Extending endwardly from the flanges **273** are reduced, semitubular, end sections **276** on each of which is formed an end locking flange **277**. The locking flanges **277** have oppositely

facing outwardly convergent end surfaces 278 and inside inwardly convergent facing shoulders 279. The spring retainer and end flanges together with the connecting reduced end sections of both the male and female connector members are identical in configuration.

The male member 261 has a pair of longitudinally extending parallel inside edge surfaces 280 which, along portions of their lengths as shown in FIGURE 5E, mate with a pair of similar inside longitudinal parallel edge surfaces 281 along the female coupler member when the couplers are aligned. The contour of the edges 281 on the male member provide a longitudinally extending male lug 282 along each edge defined between inwardly convergent end shoulders 283. The edges 281 of the female connector member are each shaped to provide a longitudinally extending female recess 284 defined between facing inwardly divergent shoulders 284 which slope at substantially the same angles as the shoulders 283 on the male lugs. The male lugs are longer than the female recesses so that the entire length of the male lugs is not receivable in the recesses.

The normal relative positions to which the male and female coupler members are biased by the spring 263 are shown in FIGURES 5 and 5E. The spring 263 encircles the semitubular central body section 264 and 272 of the coupler members and is confined at opposite ends between the spring retainer shoulders 266 on the male member and 274 on the female member, respectively. The spring biases the coupler members toward the longitudinal alignment illustrated particularly in FIGURE 5E such that opposite end sections of the male lugs 282 are held in engagement with end female mating edge surfaces 281a which form the end sections of the mating edges of the female member extending endwardly from the female recess 284. Since the male lugs on the male coupler member are longer than the female recesses, when the lug edges are held in engagement with the end edge surfaces 281a along the mating edges of the female member. The male and female members are held in substantially parallel relationship with each other. So long as the male and female members of the coupler are held by the spring in the longitudinal alignment shown, they will remain in the parallel relationship with the male lugs unable to enter the female recesses.

The coupler is connected with adjacent apparatus, such as the piston 200, by longitudinally misaligning the male and female members until the end sections of the members at the one end of the coupler may be compressed toward each other sufficiently for the locking flanges at that end of the coupler to pass within an internal annular locking flange in the tool to which the connector is being secured. Specifically, for example, to connect the coupler with the piston unit 200, the male and female members of the coupler are grasped either manually or with suitable tools and displaced longitudinally relative to each other so that at the end of the coupler to be connected with the piston unit the end section of the male member is moved toward the female recess of the female member until the end shoulder 283 of the male lug 282 is moved between the end shoulder 284s defining the female recess. The male lug should be moved only a minor distance beyond the female recess shoulder. The desired relative movement of the coupler members is effected by applying a force to the shoulder 267 of the male member at the end of the coupler to be connected with the piston unit and either holding or applying an oppositely directed force to the shoulder 275 of the female member at the opposite end of the member from the end of the coupler to be connected with the piston unit. The spring stop shoulder 266 on the male member at its end against which a force is applied to the member compresses the spring 263 moving it away from the shoulder 274 at that end of the female member. At the other end of the female member the spring is compressed against its retainer shoulder 274 while being displaced

from the male member spring retainer shoulder 266. An inward radial component of the forces applied to the sloping shoulders 267 and 275 to longitudinally misalign the coupler members biases the members toward each other. When the shoulders 283 on the male lugs at the ends of the lugs moving toward the female recess advance past the shoulders 284 of the female recess, the end of the male member at that end of the coupler is compressed toward the female member with an end section of the male lug at such end of the coupler being received in the female recess so that the locking flanges 269 and 277 of the male and female members are moved closer together. The contracted locking flanges of the coupler at its compressed end are inserted past the internal locking flange 207 on this end connector of the piston into the recess 208 of the piston unit end member. When both of the locking flange shoulders 270 and 279 on the coupler members have been inserted into the locking recess past the internal annular shoulder 207a of the flange 207 the opposing forces being applied to the opposite end section of the coupler members are relaxed allowing the spring 263 to expand so that the force applied by the opposite ends of the spring against the stop shoulders 266 and 274 of the male and female coupler members, respectively, realigns the members longitudinally. As the end of the male lug within the female recess 208a moves relative to the female member toward the adjacent end of the female member the shoulder 283 on the male lug engages the shoulder 284 defining the adjacent end of the female recess. The male lug is cammed outwardly from the female recess until the mating surfaces 280 on the male member again slide along the adjacent mating surfaces 281 of the female member as the coupler members return to longitudinal alignment. With the male and female members returned to their normal positions, the end section of the connector adjacent to the piston unit is locked within the locking socket chamber 208 of the piston unit.

The outside diameter of a circle coincident with the peripheral surfaces of the locking flanges 269 and 277 of the coupler within the locking socket recess of the piston unit is greater than the internal diameter of the locking flange on the piston end member so that a force tending to pull the coupler away from the piston unit engages the locking flange shoulders 270 and 279 on the coupler members with the shoulder 207a on the internal annular flange 207 of the end member of the piston unit. While such engagement between the shoulders 207a and the shoulders 270 and 279 of the coupler biases the end sections of the coupler towards each other, the longitudinal alignment of the male and female coupler members positions the end sections of the male lugs 283 within the piston member along the portions 281 of the adjacent mating surfaces of the female member so that the male and female member end sections cannot be cammed together sufficiently for the withdrawal of the coupler from the end socket member of the piston unit.

The coupler is similarly connected with the upper end of the monitor unit of the down-shift assembly by forcing the coupler members longitudinally in the other opposite directions relative to each other so that the other end section of the male lug adjacent to the monitor unit is receivable in the female recess of the female coupler member adjacent to the monitor unit. The coupler members at such ends are compressed together for insertion into the locking socket of the monitor unit as previously described.

It will be clear that the locking recess 208 in the end members of the piston unit must be of sufficient length, that is, the distance between the internal annular flanges 207 and 209 must be sufficiently great to permit the longitudinal displacement of the male and female coupler members required for the end sections of the coupler members to be compressed together for insertion into the

locking socket. Thus, the distance between the flanges 207 and 209 must be greater than the distance between corresponding locking flange shoulders or the coupler member end sections when they are longitudinally displaced and compressed together. The locking recess 208 must also be of greater internal diameter than the external diameter of the circle in which lie the external surfaces of the locking flanges of the coupler members when the coupler members are in the position illustrated in FIGURE 5E. This permits slight outward movement of the adjacent ends of the coupler members, for example the lower ends thereof, FIGURE 5E, when the members are misaligned to permit connection of the coupler to one tool at one end while connected to another tool at its other end. The outer surfaces of the coupler members when the coupler members are in alignment must be spaced from the annular vertical surface defining the recess 208 and the outer surfaces of the coupler members must be spaced from the flange 207 to permit pivotal movement of the coupling relative to the tool 200. The coupler is removable by longitudinally displacing its male and female members as described above to compress the end sections of the members together at the end of the connector which is to be removed from a locking socket. When the coupler member end sections are so compressed the coupler is withdrawn from the locking socket.

When adjacent tools connected by a coupler 260 are compressed toward each other longitudinally, each opposite end section of the coupler is inserted farther into the locking socket of the tool to which it is connected until the outwardly facing shoulders, such as the shoulders 207b on the end member of the piston unit, engage the shoulders 267 and 275 of the male and female members of the connector member. When such shoulders of adjacent tools interconnected by a connector member 260, such as the piston and down-shift units, are engaged with the opposite end shoulders 267 and 275 on the coupler members an essentially solid connection is provided between the connected tools through the coupler members. The tolerances provided within the connector sockets, such as the end members 205 of the piston unit, and the locking flanges and other characteristics of the coupler 260 are such that an articulated connection is provided between adjacent tools connected by a coupler, thereby facilitating the movement of a tool train including a plurality of tools connected by couplers 260 through curved portions of a flow conductor. The male and female members of the coupler may be displaced longitudinally to a minor degree when the longitudinal axis of the coupler is not aligned with the longitudinal axis of the tools between which the coupler is secured. Sufficient displacement, however, is not effected to permit one end of the male lug to move into an end of the female recess and thus the coupler remains engaged within the locking socket of connected tools even while curved sections of the flow conductor are being traversed by the coupler and tools connected by it.

The down-shift assembly 300 is illustrated in FIGURES 6-6G and 7-7B. The down-shift assembly is activated upon approaching each sliding sleeve valve in the production tubing, engages each sliding sleeve valve in an upper end position, moves the sliding sleeve downwardly to a lower end position, and disengages from the downwardly shifted sliding sleeve releasing the tool train to move downwardly to the next sliding sleeve. The down-shift assembly includes a monitor unit 301, which functions to release the down-shift assembly from a shifted sleeve, and a sleeve shifting unit 302, which engages the sleeve valve and moves it from an upper end position to a lower end position.

The monitor unit is illustrated in detail in FIGURES 6-6G. Referring particularly to FIGURE 6, the monitor unit is connected with a coupler 260 by its top connector socket 303 which is a hollow member having a locking chamber 304 open at its upper end through an upper end internal annular locking flange 305. The connector socket

has a lower reduced neck section 306 threaded on an upper end section 307 of a slider 308 which performs multiple functions of locking the trigger mechanism of the monitor unit and activating the locking key or slip mechanism of the shifting unit. The connector socket is held against rotation relative to the slider by a lock pin 309 introduced through a radial hole 309a in the socket into a corresponding hole in the upper end section of the slider.

The monitor unit includes a slider retainer cap 310 threaded into a tubular trigger housing 311 and held against rotation relative thereto by a locking wire 312 extending annularly around the retainer cap and having one short bent end 313 extending longitudinally through alignable shallow locking slots in the retainer cap and outer surface of the trigger housing. The trigger housing 311, illustrated in further detail in FIGURES 6B and 6C, is generally tubular in shape having a slightly inwardly converging tapered lower end section surface 314 and an internally threaded upper end section 315. The trigger housing is provided with an elongated, laterally opening blind chamber or slot 316 which extends substantially the length of the housing and laterally into the housing almost the depth of its diameter. The threaded bore 315a of the section 315 opens into the slot 316. The trigger housing is provided with a circular blind hole or recess 317 and a square blind hole or recess 318 which are spaced from each other, oriented laterally relative to the longitudinal axis of the trigger housing, and open into the back or base surface of the recess 316. As explained in more detail hereinafter, the recess 317 receives one end of the feeler biasing spring while the recess 318 receives one end of a monitor unit trigger. The trigger housing is also provided with pivot pin holes 319 and 320 each of which extends perpendicular to and spaced from the longitudinal axis of the trigger housing and perpendicular to and opening through a side wall of the recess 316. A reduced threaded end section 321 formed on the other end of the trigger housing is provided with a semispherical ball socket 322 adapted to receive a spherical ball unit to provide a universal connection between the monitor unit 301 and the sleeve shifting unit 302. A bore 323 having an axis coincident with the longitudinal axis of the trigger housing communicates the chamber 322 with the recess 316.

The slider 308 of the monitor unit 301 has a central body portion 324 which has substantially flat side faces 325, a semicylindrical base edge surface 326 and has one end section 327 which is enlarged to a substantially cylindrical shape. The body section 324 has a contoured front edge surface comprising a downwardly sloping end section 328, a central section 329, an upwardly sloping portion 330, and a downwardly sloping portion 331. The surface 331 is interrupted by a laterally extending slot 332 the bottom of which slopes slightly downwardly forward toward the longitudinal axis of the slider. A trigger sear 333 of a very hard material, such as tool steel, is positioned within the recess 332 and suitably connected with the slider by welding or soldering. The trigger sear has an upper front surface 334 extending at a slight angle and inwardly toward the longitudinal axis of the slider and a lower front face 335 which extends in a plane common with a downwardly sloping surface 336 of the slider central body portion. The front surface 334 of the trigger sear is spaced sufficiently from the slider body surface 331 that the top edge of the sear forms a stop shoulder 337. The central body portion of the slider has a laterally extending elongated slot 339 longitudinally positioned between the enlarged section 327 and the trigger sear and opening from and through both the back surface 326 and the front central surface. The opposite ends of the slot 339 are defined by a curved surface 340 adjacent the enlarged section 327 and a stepped curved surface comprising a section 341 connecting with the front face 329, a flat shelf-like surface 342 intermediate the front and back surfaces of the body section and a lateral surface 343 connecting with the back surface 326 of the body section.

A lower push rod 344 having a longitudinal axis coincident with the axis of the reduced threaded upper end section 307 is formed on the central body section of the slider. The diameter of the push rod 344 permits it to extend slidably through the bore 323 of the trigger housing 311 when the slider is positioned through the housing as in FIGURE 6. At the upper end of the slider an intermediate cylindrical section 345 is formed between the enlarged section 327 and reduced end section 307. The intermediate section 345 slidably extends through a bore 346 in the retainer cap 310. The outside diameter of the intermediate section 345 is substantially equal to the outside diameter of the reduced neck section 306 on the connector socket. The slider is movable longitudinally within the trigger housing with the bottom surface 326 of the slider being slidably supported on the base or back surface 316a of the slot 316 in the trigger housing.

A trigger 347, illustrated in detail in FIGURES 6D and 6E is pivotally supported in the recess 316 of the trigger housing on a pin 348 extending through a hole 349 in the trigger and correspondingly positioned holes 319 in the trigger housing. The trigger is generally L-shaped having a trigger locking leg 350 and a feeler locking leg 351. The feeler locking leg 351 is positioned longitudinally along the slider surfaces 330, 331, and connecting slider surfaces, while the locking leg 350 extends through the slot 339 of the slider into the blind hole 318 of the trigger housing. A surface 352 on the trigger locking leg is engageable with the surface 343 in the slider slot 339 to hold the trigger against counter-clockwise rotation about its pin 348 as viewed in FIGURE 6. The trigger functions between the slider and a laterally movable pivoted feeler 354 to release the feeler for lateral movement relative to the trigger housing and to lock the feeler against lateral movement. The feeler locking leg 351 of the trigger has a back face adjacent to the slider comprising contiguous surfaces 355, 356, and 357 which are sloped at angles such that the surfaces are generally complementary to the contiguous surfaces 330 through 336 on the slider. As best seen in FIGURE 6E the thickness of the feeler locking leg of the trigger is reduced to provide a section 358 which has a lateral trapezoidal opening 359. The width of the reduced portion 358 of the feeler locking leg is reduced to provide a downwardly extending toe 360. The reduced thickness of the trigger leg 351 near its back side is increased to provide side longitudinal ramp sections 361 along a portion of the reduced section 358. The back face of the trigger leg 351 has a recess 362 opening toward the slider for a laterally extending insert 363 formed of a suitable hard material, such as tool steel. The surface 364 of the insert extends generally in alignment with the surface 357 of the leg 351 which in the position of the trigger in FIGURE 6 also extends along and adjacent to the surface 336 on the slider. The insert 363 has a lower end locking surface or edge 365 which engages the slider insert locking edge 337 in a manner to be explained hereinafter to lock the slider at its activated or cocked position.

The feeler 354 which is illustrated in further detail in FIGURES 6F and 6G is movably positioned within the slot 316 of the trigger housing pivotally supported on a pin 366 extending through a lateral hole 367 in the feeler and the holes 320 of the trigger housing. The feeler has a longitudinal slot 368 extending downwardly from about midway between opposite ends of the feeler opening through its lower end. The slot 368 along a lower end section 368a opens only through the back face of the feeler while the slot opens completely through the feeler from front to back along its other section 368b to receive the reduced portion 358 of the trigger leg 351. A spring 369 is coiled around the pin 366 within the slot section 368a of the feeler. One free end section 370 of the spring engages a feeler surface 368c defining the front of the slot section 368a while the other end section 371 of the spring engages the front face of the toe 360 of the trigger

to bias the trigger clockwise relative to both the feeler and trigger housing. A stop pin 372 secured through aligned lateral holes 373 in the feeler extends through the slot section 368b of the feeler and the lateral recess 359 of the trigger so that the biasing effect of the spring 369 against the trigger toe 360 tends to rotate the trigger clockwise to hold the surface 359a of the trigger slot 359 against the pin 372 to limit the lateral outward movement of the feeler relative to the position of the trigger. When the trigger is held in the position shown in FIGURE 6, the pin 372 coacting with the trigger holds the feeler at its retracted, deactivated position. When the trigger is at the position shown in FIGURE 6A, the trigger is moved counterclockwise sufficiently allowing the pin 372 within the recess 359 to move laterally outwardly permitting the feeler to be expanded outwardly along its upper end section through the slot of the trigger housing. The upper free end section of the feeler has a blind hole 374 which opens inwardly through its back face to receive one end of a spring 375 the other end of which is received within the blind hole 317 of the trigger housing. The spring is positioned on a spring guide 376 and compressed between the feeler and the trigger housing for biasing the free end of the feeler laterally outwardly from the trigger housing about the pivot pin 366. The feeler upper free end section has a contoured outer shape or front face comprising the surfaces 377, 378, and 379 so that the free end of the feeler is received in a correspondingly shaped recess provided in a flow conduit through which the down-shift assembly is moving for releasing the down-shift assembly after it has performed its sleeve shifting function, as explained in more detail hereinafter.

The sleeve shifting unit 302 of the down-shift assembly is pivotally connected with the monitor unit 301 to facilitate the movement of the down-shift assembly through curved sections of a flow conduit. A connector ball 380 is held within the ball socket 322 of the trigger housing 311 by a socket cap 381 which is threaded on the reduced lower end section 321 of the trigger housing. A retainer wire 382 positioned in an external annular recess 383 of the socket cap has a short end section 384 which is bent to extend longitudinally relative to the monitor unit. The retainer wire end section is received in aligned recesses 385 and 385a of the trigger housing and socket cap to hold the socket cap against rotation relative to the trigger housing. The socket cap has a fragmentary inside spherical surface 386 adapted to mate with the surface of the ball 381 for holding the ball within the socket of the trigger housing. A bore 386 through the socket cap is defined by an annular downwardly divergent shoulder surface 387. A ball link 388 has a reduced threaded upper end neck portion 389 extending through the bore 386 of the ball cap and threaded into a threaded bore 390 of the ball 380. The divergent annular shoulder surface 387 allows the neck portion of the ball link limited pivotal movement about the center of rotation of the ball 380 providing a limited universal connection between the monitor unit and the sleeve shifting unit.

The ball link 388 has a pair of laterally extending oppositely positioned lugs 391 each of which is connected with a body or mandrel 392 of the sleeve shifting unit by opposite shear pins 393. Each of the lugs 391 has an upwardly and outwardly extending bore 394 which intersects the shear pin bore in the lug so that a suitable tool, such as a screwdriver, may be introduced into the bore 394 to remove the inward end section fragment of the shear pin from the lug if the pin is sheared as explained hereinafter.

The sleeve shifting unit mandrel 392 is generally tubular in shape and has a pair of laterally opening, oppositely positioned, rectangular key windows 395. The upper end section of the mandrel has a slightly tapered or inwardly convergent outside surface 396 connecting with a more sharply convergent external annular shoulder surface 397. The mandrel is internally threaded along a

lower end section 398 and has an upper end internal annular flange 399 defining a bore opening 399a into the upper end of the mandrel to receive a small end portion of the socket cap 381 while permitting the socket cap a limited degree of pivotal movement as the monitor unit pivots about the ball 380 when the down-shift assembly is traversing a curved section of a flow conduit.

A laterally expandable and contractable sleeve shifting key 400 is supported within the mandrel in each of the lateral windows 395. The keys 400 have aligned inwardly opening blind holes 401. A spring 402 around a spring guide 403 is positioned in each set of corresponding blind holes 401 biasing the keys apart and laterally outwardly through their respective windows 395. Each of the keys has a contoured outer surface adapted to mate with correspondingly shaped internal surfaces provided in each of the sliding sleeve valves in the production tubing. The outside surface of each key includes opposite end inwardly convergent surfaces 403 and 404, a longitudinal outside surface comprising a long section 405 and a shorter section 406 spaced by a recess 407 defined by an inwardly sloping cam surface 408, a longitudinal base surface 409, and an abrupt sleeve shifting or engaging shoulder 410. Each key is generally I-shaped in cross section, having a reduced longitudinally extending body portion 411 on which are formed longitudinally spaced and laterally extending operator lugs 412 and 413. The lugs 412 have longitudinally extending vertical locking surfaces 412a and inwardly sloping cam surfaces 412b. The lugs 413 have corresponding vertical locking surfaces 413a and end inwardly sloping cam surfaces 413b which function as explained hereinafter for retracting and locking the keys.

The radial movement of keys 400 is controlled by a pair of laterally spaced longitudinally movable key retractors 414 the outside surface of each of which is a fragmentary cylindrical surface and the inside surfaces of which are contoured mirror images of each other adapted to fit on opposite sides of the pair of keys 400. Each of the key retractors has an internal longitudinally extending recess 415 defined by inner parallel facing locking surfaces 416, inwardly convergent cam surfaces 417, outer parallel facing locking surfaces 418, inner parallel facing locking surfaces 419, inwardly convergent cam surfaces 420, and outer parallel facing locking surfaces 421. The key retractors are parallel with and laterally spaced from each other within the bore 392a of the mandrel on opposite sides of the keys 400 so that the lugs 412 and 413 of each of the keys are positioned within the key recesses 415 while the locking portion 400a of each of the keys is positioned laterally outwardly of the key retractors so that these locking portions may be expanded and retracted through the windows 395 of the body. The facing inside edge surfaces 414a of each of the key retractors fit in sliding relationship with the opposite longitudinal faces 411a of the central longitudinal body section 411 of each of the keys. The pair of key retractors is movable longitudinally within the body 492 relative to the keys so that the various cam and locking surfaces defining the recesses 415 of the key retractors coast with the locking and cam surfaces of the operator lugs for holding the keys retracted and limiting their radial expansion.

Each of the key retractors 414 has an inwardly opening semicylindrical recess 422 which communicates at its lower end into the recesses 415 and at its upper end with a reduced semicircular recess 423 defining an internal semiannular shoulder 424 at the upper end of the recess 422. A semiannular shoulder 425 defines the lower end of the recess 422. A lower portion of the ball link 388 is positioned between the key retractors which are laterally spaced in parallel relationship sufficiently for the lugs 391 of the ball link to extend to the wall of the bore 392a between the adjacent facing edge surfaces 414a of the two key retractors. The ball link has semi-

annular external flanges 426 which are circumferentially spaced from each other 180 degrees and are each positioned between and on opposite sides of the lugs 391 of the link at 90 degrees spacing from the lugs. The flanges 426 are each received within the recess 422 of the adjacent key retractors so that the key retractors are lifted by the ball link when each flange 426 engages the shoulder 424 of its key retractor upon upward movement of the ball link after the shearing of the pins 393 as explained hereinafter.

The ball link 388 has a longitudinal bore 427 which receives a key retractor push rod 428, the upper end of which projects above the upper end of the reduced neck section 389 of the ball link to engage the lower end of the push rod 344 on the slider 308. The lower end of the push rod 428 is enlarged providing a head portion 429 forming an external annular flange 430 around the push rod projecting into the recess 422 of each of the key retractors between the lower end of the ball link and the shoulders 425 of the key retractor so that the flange 430 on the push rod 428 engages the shoulders 425 of the key retractors to move the key retractors downwardly away from the ball link responsive to downward movement of the push rod through and relative to the ball link.

A key retractor spring 431 is confined on a combination spring guide and push rod 432 having an enlarged head section 433 provided with an external annular flange 434 which is engageable with the lower ends 414b of the key retractors for moving the key retractors upwardly to retract the keys 400 inwardly. The spring 431 is confined within a lower end section of the mandrel 392 and a tubular bore 435 of an end socket 436 having an internal annular flange 437 supporting the lower end of the spring. The end socket 436 has a reduced neck section 438 threaded into the end section 398 of the mandrel 392. A locking wire 439 fitted in an external annular recess 440 of the end socket has a bent end section 441 which extends through longitudinal alignable slots 442a and 442 in the end socket and mandrel 392, respectively, for holding the end socket against rotation relative to the mandrel. The end socket has a lower internal annular end flange 443 defining the lower end of a locking recess 444 extending upwardly to the flange 437 for receiving the locking flanges on the upper end of another connector 260 which secures the detent unit 700 with the down-shift assembly. The connector 260 has been previously described.

The down-shift assembly 300 normally traverses a flow conduit in a deactivated condition in which its sleeve shifting keys 400 and the feeler 354 of the monitor are held at their retracted positions. The primary function of the keys 400 is to engage and longitudinally shift the sliding sleeve of each sleeve valve 123 while the monitor unit deactivates and releases the keys after the sleeve has been properly shifted so that the down-shift assembly may continue its passage along the conduit.

The down-shift assembly is activated, that is, the keys and the feeler of the monitor unit are released and resiliently biased radially outwardly by holding the assembly against downward movement while applying a downward force to its connector socket 303. As will be explained in further detail hereinafter, the sleeve shifting unit of the down-shift assembly is held against downward movement by the detent unit 700 while the piston unit 200, responsive to a pressure differential across it, applies a downward force to the connector socket 303. Since the connector socket is rigidly secured on the neck section 307 of the slider 308, the slider is forced downwardly until the lower end of the connector socket engages the upper end of the end retainer 310. The lower end of the push rod 344 on the slider engages the upper end of the push rod 428 forcing it downwardly relative to the ball link 388 so that the head 429 is moved to a spaced apart relationship from the flange segments 426

below the lower end of the ball link. The external annular flange 430 on the head 429 engages the shoulder 425 in each of the slip retractors 414. The slip retractors are pushed downwardly within and relative to the mandrel 392 while the keys 400 are held against downward movement by the engagement of their lower end surfaces 400b with the lower end surface 395a of each of the lateral windows 395. The downward movement of the key retractors shifts the inner locking surfaces 416 and 419 downwardly relative to the key operator lug locking surfaces 412a and 413a, respectively. The key retractors are moved downwardly until the outer locking surfaces 418 and 421 are aligned with the key lug locking surfaces 413a and 412a, respectively releasing the keys for expansion through the windows 395. The keys 400 are each expanded outwardly by the expansion of the springs 402 until the outer surfaces of the keys engage the inside surface of the flow conduit through which the down-shift assembly is moving or until the key lug surfaces 413a and 412a engage the outer locking surfaces 418 and 421, respectively, of the key retractors. Under the operating conditions generally encountered within the system of the invention the keys will engage the inside wall of the flow conduit or the recess of a sliding sleeve prior to reaching their maximum expansion. Thus, the keys normally will reach their maximum expanded positions at which the key retractor locking surfaces 418 and 421 are engaged with the key lug surfaces 413a and 412a, respectively, only when the tool is not within a confining surface such as before insertion into the flow conductor.

The forcing of the key retractors downwardly by the push rod 428 also forces the push rod 432 downwardly due to the engagement of the lower ends of the key retractors with the flange 434 on the push rod. The spring 431 is compressed between the flanges 434 and 437.

The downward movement of the slider 308 not only releases the keys for lateral expansion but also releases the feeler 354 and releasably locks the slider at a downward position at which the keys and the monitor feeler remain resiliently biased outwardly until the slider is released and returned to its normal upper end position. The movement of the surface 343 of the slot 339 of the slider downwardly from the surface 352 of the trigger locking arm releases the trigger for counter-clockwise rotation about its pivot pin 348. Contact of the lower end section of the locking arm with the lower end wall of the recess 318 in the trigger housing limits the counter-clockwise rotation of the trigger while permitting the trigger to rotate to a sufficient extent to allow proper functioning of the feeler mechanism. The end section 371 of the spring 369 resiliently biases the trigger in a clockwise direction against the pin 372 which is secured to the feeler 354. The spring section 371 resiliently maintains engagement between the trigger and the feeler thus preventing slack between them while permitting their relative relationship to change. With the slider moved downwardly disengaging or freeing the trigger for counter-clockwise rotation the force of the compressed spring 375 against the upper free end of the feeler lifts the feeler about its pivot pin 366 moving the pin 372 laterally outwardly in an arcuate path about a point of rotation at the center of the pin 366. The lateral movement of the pin 372 lifts the feeler locking arm of the trigger causing the trigger to rotate counter-clockwise about its pin 348. The inside wall of a flow conduit through which the down-shift unit is moving generally limits the lateral outward movement of the feeler 354 to an intermediate position which will permit some further counter-clockwise movement of the trigger so that the trigger may perform its function of locking the slider at its lower end position. With the feeler stopped somewhat short of its maximum expanded position additional downward movement of the slider 308 relative to the trigger causes the surfaces 336 and the insert 333 of the slider acting along the surfaces 357 and 364 of the trigger to rotate the trigger farther counter-

clockwise about its pin 348 with the surface 359a of the recess 359 in the trigger being moved apart from the pin 372 against the force of the spring 369. When the edge 337 of the insert 333 on the slider has moved below the edge surface 365 of the trigger insert, the spring arm 371 causes the trigger to return clockwise with the trigger insert edge surface 365 moving into potential engagement with the slider insert edge surface 337 so that the two insert surfaces are ready to sustain the upward force of the compressed spring 431 acting through the key retractors and the push rod 428 against the lower end of the push rod 344 on the slider. So long as the trigger insert surface 365 is urged against the slider insert surface 337 with the spring end section 371 biasing the trigger clockwise, the slider is held locked at a downward position. The relative dimensions of the various components of the trigger and feeler assembly are such that when the trigger is so interlocked with the slider to hold it at its lower end position, the spring section 371 biases the trigger in a clockwise movement so that its recess edge surface 359a is near the pin 372 of the feeler 354.

The down-shift assembly is releasable from the above described activated condition by further lateral expansion of the feeler 354. As will be explained in more detail hereinafter, each sliding sleeve valve has recess means into which the feeler 354 expands when the sleeve shifting unit of the down-shift assembly has completed its sleeve shifting function. Thus, when the down-shift assembly moves to a position within a flow conduit where the feeler 354 may expand laterally outwardly a greater distance from the longitudinal axis of the assembly than permitted by the normal wall surface of the conduit, the spring 375 pivots the feeler 354 farther clockwise about its pin 366 causing the pin 372 acting on the trigger surface 359a within its recess 359 to rotate the trigger counterclockwise. The trigger insert surface 365 is moved laterally from the slider insert surface 337 disengaging the insert surfaces releasing the slider for upward longitudinal movement. The compressed spring 431 lifts the push rod 432 raising the key retractors whose shoulders 425 engage the flange 430 on the push rod 428. The push rod 428 is raised forcing the push rod 344 on the slider upwardly. The upward movement of the key retractors and the push rod substantially simultaneously retracts both the sleeve shifting keys 400 and the feeler 354 of the monitor unit.

The upward movement of the key retractors effected by the expansion of the spring 431 causes the key retractors to move relative to the keys 400 each of which is held against upward movement by the engagement of its upper end surface with the upper end surface of its window 395. As the key retractors move upwardly relative to the keys, the retractor cam surfaces 420 engage the key lug cam surfaces 412b while the retractor cam surfaces 413b retracting the keys laterally inwardly against the force of the springs 402. The spring 431 expands until the flange 327 on the upper end section of the slider engages and is held against farther upward movement by the cap 310 at the upper end of the monitor unit. When the slider has reached its upper limit the key retractors are positioned relative to the keys such that the retractor inner locking surfaces 419 and 416 are in alignment and engagement with the key lug locking surfaces 412a and 413a, respectively, thus fully retracting and locking the keys at their inward positions at which they are fully within the windows 395 in substantially parallel relationship with each other.

As the slider moves upwardly the insert 333 and adjacent slider surfaces move upwardly relative to the trigger 347 while the slider surface 343 in its recess 339 engages the trigger locking arm along its surface 352 forcing the trigger to rotate in a clockwise direction so that the surface 359a of the trigger recess 359 engages the pin 372 rotating the feeler in a counter-clockwise direction

around its pivot pin 366. Counter-clockwise rotation of the feeler compresses the spring 375 and retracts the feeler into the trigger housing recess 316. The spring 431 is of sufficient strength and is normally compressed to the degree necessary to hold the slider and the key retractor at their upper positions at which the down-shift assembly is deactivated with the keys and feeler all locked at their inward positions until the down-shift assembly is again compressed longitudinally sufficiently to reactivate it as described above.

If the shifting keys 400 encounter an obstruction at their expanded positions interlocked in a sliding sleeve such that the compressed spring 431 cannot apply sufficient force to the lower end of the retractors to withdraw the keys, the down shift assembly is releasable from the sleeve by application of an upward force to the top connector 303 either by use of a suitable fishing tool or additional piston units, as explained hereinafter. The upward force lifts the top connector to its uppermost position within the retainer cap 310 to apply an upward force to the monitor unit so that through the ball connector 380 the ball link 388 is lifted against the shear pins 393. When sufficient force is applied to sever the shear pins the ball link is released for upward movement relative to the mandrel 392. Upward movement of the ball link lifts the key retractors due to the interlocking relationship between the external flanges 426 on the ball link with the key retractors. The upward movement of the key retractors retracts the keys 400 inwardly in the same manner as described above. Such procedure for disengagement of the down-shift assembly from a sliding sleeve is resorted to only as an emergency measure when the spring 431 is not effective for release of the shifting keys.

The down-shift assembly is connected by means of another coupler 260 with the detent unit 700 which functions to releasably hold the tool train at predetermined location against movement within the production tubing for such purposes as activating the down and up-shift assemblies. The detent unit is adapted to engage recesses provided in the sleeve valves, as discussed hereinafter, to hold the tool train against movement until the force applied to the tool train by either the upper or lower piston unit is increased above a predetermined value during which time the particular sleeve shifting assembly between the driving piston and the detent unit is activated. When the predetermined force on the detent unit is exceeded by the driving piston, the detent unit releases from the recess with which it is engaged and permits the tool train to continue its travel within the production tubing.

The detent unit 700 is illustrated in detail in FIGURES 8 through 8K and FIGURE 9.

The detent unit 700 includes a tubular mandrel 701 on which are mounted a releaseable locking assembly 702 and a control assembly 703. A top socket connector 704 threaded on the upper end of the mandrel includes an internal annular flange 707 having a locking shoulder 708. The connector has a locking recess 710 to receive one end of the connector 260 for securing the detent unit to the down-shift assembly. A bottom connector 712 is mounted on the lower end of the mandrel by means of a screw 713 which has a shoulder 714 engaging a shoulder 715 of an internal annular flange 716 of the bottom connector. The bottom connector has an internal annular flange 712a having an annular locking shoulder 712b for holding the locking dogs on a connector 260 which secures the lower end of the detent unit to the up-shift assembly.

The locking assembly 702 includes a cage 725, longitudinally slidable on an intermediate portion of the mandrel, and a pair of locking dogs 728 and 728a. The cage includes a pair of upper and lower flange portions 732 and 733, spaced vertical side portions 734 and 735, and horizontal planar brace portions 736 and 737 which extend between the vertical side portions. The vertical side portion 734 has a horizontal outwardly extending flange portion 738. The top flange portion 732 and the flange portion

738 are provided with pairs of aligned apertures 744 and 745, respectively, which are aligned with one another and with a pair of upwardly opening bores 746 of the lower flange portion. Pivot pins or posts 748 and 748a extend through the apertures 744 and 745 and into the bores 746 and are rigidly secured by pins 751 which extend through suitable aligned apertures in the upper ends of the pins and the upper flange portion 732.

The locking dog 728 has horizontal top and bottom arms 761 and 762 which are positioned adjacent the upper and lower flanges 732 and 733, respectively, of the cage and arms 763 and 764 which are positioned above and below the middle flange portion 738 of the cage. The arms of the dogs 728 are provided with vertical apertures 767 which are aligned with the apertures of the flange portions of the cage through which the pivot pin 748 extends whereby the dog is pivotally movable about the vertical axis of the pin. The dog is biased in an outwardly direction, FIGURE 8, by a pair of springs 767a and 768a disposed about the pin, the spring 767a being disposed between the arms 761 and 763 and the spring 768a being disposed between the arms 764 and 762. One end portion of the spring 767a engages one edge surface of the vertical cage portion 734 and its other end is received in a bore of the dog 728. The lower spring 768a similarly has one end portion engaging a side of the vertical cage portion 734 and its other end portion is positioned in a bore of the dog 728.

The dog has a pair of internal horizontal upper and lower bosses 770 and 771, see FIGURE 8H whose function will be described below.

The dog 728a is similar in structure to the dog 728 and is similarly mounted on the cage and biased outwardly in a clockwise direction about the axis of the pin 748a. Elements of the dog 728a and its mounting and biasing means are provided with the same reference numerals, to which the subscript "a" has been added, as the corresponding elements of the dog 728 and its mounting and biasing means.

The cage 725 is vertically movably mounted on an intermediate portion of the mandrel which has a vertical side 775, vertical parallel sides 778 and 779 which extend perpendicularly from opposite edges of the side 775, and planar vertical surfaces 780 781, see FIGURE 8G, which extend convergently outwardly from the edges of the sides 778 and 779 to a central vertical planar surface 782 which lies parallel to the side 775. The vertical portion 734 of the cage has a configuration corresponding to the configuration of the vertical surfaces 780, 781 and 782 of the mandrel so that the cage is vertically slidable but non-rotatably mounted on the intermediate portion of the mandrel. The planar internal surface of the vertical portion 735 is engageable with the mandrel side 775 and the vertical internal surfaces of the vertical cage portion 734 being engageable with the mandrel surfaces 780, 781 and 782.

The vertical planar side 778 of the intermediate portion of the mandrel is provided with an upper pair of spaced horizontal recesses 791 and 792 in either of which is receivable the upper internal boss 770 of the dog 728 and with a lower pair of horizontal recesses 793 and 794 in either of which is receivable the lower internal boss 771. The vertical planar mandrel side 779 is provided with a similar upper pair of recesses 791a, 792a and a lower pair of recesses 793a and 794a in which are receivable the upper and lower bosses 770a and 771a, respectively, of the dog 728a. The dogs are movable inwardly to retracted positions when the cage, and therefore the dogs, is in an upper or lower position on the mandrel. The dogs are held locked in expanded positions when the cage is in an intermediate position on the mandrel due to the engagement of the bosses 770 and 771 of the dog 728 with the locking surfaces 796 and 797 of the mandrel side 778 between the upper and lower pairs of recesses and the engagement of the bosses 770a

and 771a of the dog 728a with the locking surfaces 796a and 797a of the mandrel side 779 between its pairs of recesses.

The cage 725 of the dog assembly is biased to its intermediate position by a pair of centering springs 801 which are disposed in the vertical passages 802 of the cage vertical portion 735. Each of the springs has an upper portion disposed about the reduced lower end portion 804 of an upper pin 805 which extends downwardly into its passage 802. The upper ends of the springs bear against the downwardly facing annular shoulders 807 of the upper pins. The lower portions of the springs 801 are disposed about the upper reduced end portions 810 of lower pins 811 which extend upwardly into the passages 802. The lower ends of the springs bear against the upwardly facing annular shoulder 812 of the lower pins. Longitudinal movement of the upper pins relative to the cage is limited by pins 814 which are secured to the cage and extend through the passages 802 and longitudinal slots 815 of the upper pins. Similarly, longitudinal movement of the lower pins 811 is limited by pins 817 secured to the cage which extend through the passages 802 and longitudinal slots 818 of the lower pins. The upper pins engage the bottom end surface of a spring retainer ring 820 mounted on the mandrel above the cage. Downward movement of the spring retainer ring on the mandrel is limited by the engagement of its bottom surface with the upwardly facing shoulder 821 of the mandrel at the top ends of its planar sides 775, 778 and 779. The lower ends of the pins 811 are rigidly secured as by welding to a foot plate 824. Downward movement of the foot plate 824 relative to the mandrel is limited by the engagement of the bottom surface of the foot plate with the upwardly facing external shoulder 825 of the mandrel at the lower end of its vertical planar side 775. The springs 801 tend to hold the cage in the intermediate position on the mandrel illustrated in FIGURES 8 and 8A wherein the internal bosses of the dogs are in expanded positions and locked against inward pivotal movement to their retracted positions by the engagement of their internal bosses with the locking surfaces of the mandrel. The outward swing of the dogs beyond their expanded positions at which the bosses 770 etc. are clear of the locking surfaces 796 etc., is limited by horizontal projections 763b and 764b coming in contact with the surface of the side 734 of the cage.

The control assembly 703 includes a control sleeve assembly 830 mounted on the mandrel as shown in FIGURES 8D, 8E, and 8J. The control sleeve assembly includes a collet ring 831 having a plurality of resilient upwardly extending collet fingers 832 provided at their upper ends with radially inwardly extending lugs 833 which are selectively receivable in the bottom, middle and top external annular recesses 835, 836 and 837 of the mandrel for releasably latching the control assembly in a bottom, middle or top position on the mandrel. The inner ends of the collet lugs have inwardly convergent upper and lower cam shoulders 843 and 844 and the shoulders of the mandrel defining the top and bottom sides of each latch recess are outwardly convergent whereby the camming engagement of the lug shoulders 843 with the downwardly facing shoulders defining the upper end of the bottom and middle latch recesses moves the collet fingers resiliently outwardly to permit upward movement of the control sleeve assembly from its bottom position to its middle position and from its middle position to its top position. Similarly, the camming engagement of the bottom lug shoulders 844 with the shoulders of the mandrel defining the lower ends of the top and middle latch recesses moves the collet fingers outwardly to permit downward movement of the control sleeve assembly from its top position to its middle position and from its middle position to its bottom position. The control sleeve assembly includes a pair of sleeve sections 851 and 852 disposed in the collet ring and rigidly se-

cured thereto by welding in a way not to affect the resiliency of the collet arms 832. The control sleeve section 852 is provided with recesses 854 in its vertical sides between upper and lower locking surfaces 856 and 857 provided by its vertical sides. The top and bottom ends of the recesses are defined by the outwardly convergent upper and lower cam shoulders 860 and 861, respectively, which are engageable with the cam bosses 864 of a trigger link 865, see FIGURE 8I, to cause the trigger link to be pivoted in a counter-clockwise direction, FIGURE 8A, about the horizontal axis of the pins 870 by means of which the upper end of the trigger link 865 is pivotally connected to the cage, to its inoperative position upon movement of the control assembly from its middle position illustrated in FIGURE 8B to either its top or bottom position. The engagement of the cam bosses 864 of the trigger link with the upper locking surfaces 856 of the control sleeve section 852 holds the trigger link in its inoperative position when the control sleeve assembly is in its bottom position on the mandrel and their engagement with the lower locking surfaces 857 of the control sleeve section 852 holds the trigger link in its inoperative position when the control assembly is in its top position on the mandrel. The sleeve section 851 cooperates with the control sleeve section 852 to help hold the control sleeve assembly in properly centered position on the mandrel.

Downward movement of the control sleeve assembly on the mandrel is limited by a plurality of circumferentially spaced pins 871 whose lower ends bear against the top end surface 872 of the connector 712. The outer portions of the pins are disposed in vertical internal circumferentially spaced recesses 873 of the horizontal flange 844 of a spring retainer ring 875 disposed on the mandrel and their inner portions are disposed in vertical external recesses 876 of the mandrel which are aligned with the recesses 873. All of the pins, such as the pin 871a, except a single pin 871b, are short and their upper ends bear against the bottom surface of the control section 851 or 852. The upper end portion of the long pin 871b extends into and is secured as by welding in an internal recess 877 so that it is rigid with the control sleeve assembly and thus prevents rotation of the control sleeve assembly relative to the mandrel.

Since the passages 873 are of somewhat larger diameter than the pins 871 and since only one of the pins 871b is rigidly secured to the control sleeve, vertical movement between the control assembly and the housing may take place while rotation of the control sleeve is prevented.

Upward movement of the spring retainer ring 875 on the mandrel is limited by the engagement of its flange 874 with the downwardly facing shoulder 880 of the mandrel. The spring retainer ring 875 is rigidly secured to the mandrel by a pin 876a which extends through aligned apertures of the ring and the mandrel and a slot 877a of the screw 713. The connector 712 is yieldably biased downwardly by a spring 882 whose upper portion extends into the spring retainer ring with its top end bearing against the bottom surface of its flange 874 and whose lower portion extends about the upper section of the connector and bears against the upwardly facing annular shoulder 886 of the connector. Upward movement of the connector, and therefore of the pins 871 on the mandrel is limited by the engagement of the top end surface 872 of the connector with the annular bottom end surface 888 of the mandrel.

The trigger link 865 comprises a pair of substantially vertical legs 891 and 892 which are connected at their upper ends by a connector portion 893. The upper end portion of the leg 891 is received between a pair of parallel dependent legs 894 of the cage 725 and is pivotally secured thereto by a pivot pin 870 which extends through suitable aligned apertures in the legs. Similarly, the upper end portion of the leg 892 extends upwardly

between the dependent pair of spaced legs 895 of the cage and is pivotally connected thereto by a pivot pin 870. The pivot pins are provided with enlarged heads which limit inward movement of the pins due to their engagement with the outer surfaces of the trigger link legs. The pins are held against outward movement by split lock rings 896 whose outer portions are received in internal annular recesses 897 of the outer legs 894 and 895.

The lower end portions of the trigger link legs have aligned vertical slots 899 in which are received the outer end portions of a vertical trigger plate 900 which extends between the legs and through aligned vertical slots 902 of the mandrel. The trigger plate is secured to the legs by a pair of pins 904 which extend through suitable aligned apertures 904a in the trigger plate and in the trigger link legs. The trigger plate has an upwardly opening upper slot 906 which provides an upwardly facing planar horizontal catch surface 908 which is adapted to engage the downwardly facing edge or shoulder 909 of an upper sear plate 912 disposed in a lateral recess 914 of the lower trigger head 915 threaded to a control rod 916. The trigger plate, FIGURE 8L, on either side of its upper slot 906 has upwardly facing cam shoulders 920 which are engageable with the upwardly and inwardly sloping upper cam surfaces 922 of the mandrel at the slots 902 thereof. The trigger plate also has a downwardly opening lower slot 925 which provides a downwardly facing planar horizontal catch surface 926 which is adapted to engage the upwardly facing horizontal shoulder 928 of a lower sear plate 925 disposed in the lateral recess 914 of the control rod. The trigger plate on either side of the lower slot 952 has downwardly facing cam shoulders 930 which are engageable with the downwardly and inwardly sloping lower cam surfaces 931 of the mandrel at the slots 902 thereof. The upper and lower sear plates are rigidly secured to the trigger head 915, as by welding, with a vertical space between their respective sear faces 909 and 928 greater than the width of the trigger plate between its sear faces 908 and 926.

The trigger link is biased in a counter-clockwise direction, FIGURE 8A, about the axis of its pivot pins 870 toward its operative position wherein the sear faces 908 and 926 are between and in position to engage the sear faces 909 and 928 respectively, of the sear plate by three springs 935 whose lower end portions are disposed in upwardly opening bores 936 of the connector portion 893 of the trigger link and whose upper end portions bear against the bottom of the lower flange portion 733 of the cage.

The trigger head 915 is disposed in the lower enlarged bore 940. The enlarged upper portion of the control rod 916 slides in the bore 941 of the mandrel and has an upper longitudinal slot 950 which is aligned with longitudinal slots 951 of the mandrel and with transverse slots in the top spring retainer ring 954. A cross pin 952, fits closely in the ring 954 traversing the slots 950 and 951 which extend vertically more than the width of the pin 952. The top retainer ring is biased upwardly on the mandrel by an outer spring 957 whose top end bears against the bottom surface of the annular external flange 958 of the top retainer ring and whose bottom end bears against the top surface of the bottom spring retainer ring 820. The stem of the control rod also has a longitudinal slot 960 which is aligned with the lower longitudinal slot 961 of the mandrel and a cross pin 964 extends through the control rod slot 960 and the mandrel slots 961. The cross pin 964 is biased downwardly and away from the top spring retainer ring 954 by an inner spring 966 whose top end bears against the bottom annular shoulder 968 of the top spring retainer ring and whose bottom end bears against top surface of a lower spring retainer ring 969 which is formed integral with the retainer ring 820.

The outer and inner springs yieldably hold the control rod in its intermediate position illustrated in FIGURES

8 and 8A since the upper cross pin is held in engagement with the downwardly facing surface 971 of the control rod stem defining the upper end of the stop slot 950 and the lower pin is held in engagement with the upwardly facing surface 972 of the control rod defining the lower end of the lower slot 960. The sear plates when the control rod is in its intermediate position are in position to receive the trigger link plate therebetween when the trigger link is pivoted in a counter-clockwise direction.

The detent unit 700 functions in the tool train to engage an appropriate recess at each sliding sleeve valve to releasably restrain the tool train while the desired sleeve shifting assembly, depending upon the direction of travel of the tool train, is activated for shifting the sleeve valve.

Prior to installing the detent unit in the tool train, it is equipped with pins 871a in its control assembly 703, FIGURE 8B, which are short enough that when the connector 712 is forced against the mandrel bottom surface 888 the control assembly collet 830 is not shifted on the mandrel. The control assembly functions only to lock the detent unit trigger at an inactive position if it is desired that the unit run freely in one direction in a tubing string. In installing and removing gas lift valves in accordance with the invention, the detent unit is active in both directions. Therefore the control assembly is placed with its collet heads 833 in the middle groove 836 on the mandrel. Thus, the trigger remains active and the control assembly is not shifted when the tool train hits the pin collar 126.

The external bosses 990 and 990a of the dogs 728 and 728a, FIGURE 8, are longer than any internal recess of the production tubing 104 other than the recesses of the sliding sleeves in which it is desired they be received and they are substantially shorter than such recesses. The bosses 990 and 990a have outwardly convergent top and bottom shoulders 991, 992, 991a and 992a. As the detent unit 700 is inserted into the conduit section 114a, the mandrel is moved downwardly relative to the cage and the dogs against the resistance of the centering springs 801 to align the internal dog bosses 770, 770a, 771 and 771a with the recesses 791, 791a, 793 and 793a, respectively, of the mandrel. The dogs 728 and 728a are then pivoted inwardly to their retracted position against the resistance of the springs which bias them outwardly. The trigger link is pivoted in a clockwise direction prior to the movement of the cage to its inoperative position in order that the force of the springs 957 and 966 be ineffective to resist this movement. The catch edge or shoulder 908 of the trigger link plate is now above the edge 909 of the upper sear plate 912 and the trigger link is held in its outer inoperative position by the engagement of the cam shoulders or edges 920 of its plate with the vertical surfaces 993 defining upper portions of the sides of the mandrel slots 902 above the upper cam shoulders 922. The dogs are then held in their inner retracted positions by the engagement of their external bosses with the internal surfaces of the tubing. Since the bosses of the dogs are considerably greater in length than any internal recess of the production tubing other than the recesses of the sliding sleeves, the dogs can move outwardly to their expanded positions only when their bosses move into alignment with the desired recesses. When the detent unit reaches a sleeve to be shifted and the dogs of the detent unit move into alignment with the sliding sleeve recess, the dogs are moved laterally outwardly by the springs 767a and 768a. As soon as the internal bosses of the dogs move out of the upper recesses of the pairs of mandrel recesses, the centering springs 801 move the cage, and therefore the dog and the trigger link downwardly relative to the mandrel and the control rod to the position illustrated in FIGURES 8, 8A, 8B, and 8G. This downward movement of the cage relative to the mandrel occurs prior to the engagement of the bottom shoulders 992 and 992a of the dogs with the bottom annular shoulder of the recess, the length of the recess being considerably greater than that of the external bosses of the dogs to permit this down-

ward movement of the dogs relative to the mandrel and the mandrel and the nipple while the downward movement of the train of tools and of the mandrel through the tubing continues. The inner bosses then engage the locking surfaces between each pair of recesses so that the dogs are then held against movement to their retracted positions. The downward movement of the trigger link relative to the mandrel and the control rod causes the cam shoulders 920 of the trigger link plate to move downwardly and below the mandrel cam shoulders 922 and the trigger link is pivoted by the springs 935 to its operative position illustrated in FIGURES 8A and 8B wherein its plate 900 is disposed between the sear plates of the control rod. Continued downward movement of the detent unit then causes the bottom shoulders 992 and 992a of the dogs to engage the bottom shoulder of the recess and further downward movement of the dogs, and therefore of the cage and the trigger link is arrested. As the downward movement of the mandrel and the control rod continues, the bottom edge 909 of the upper sear plate 912 engages the top edge 908 of the trigger link plate whereupon downward movement of the control rod is arrested. The lower cross pin 964 is also held against downward movement since it engages the surface 972 of the control rod defining the lower end of the slot 960 thereof and the lower cross pin in turn holds the lower retainer ring against downward movement. As the mandrel continues to move downwardly, the upper cross pin 952 moves downwardly therewith since it is secured to the top retainer ring 958 which in turn is engaged by the annular bottom end shoulder of the socket connector section 704. Downward movement of the mandrel therefore is now resisted by the centering springs 801, and the inner and outer springs 966 and 957 which are compressed between the upper and lower retainer rings.

As the mandrel continues to move downwardly, before the mandrel lock surfaces 796, 796a, 797 and 797a move out of engagement with the inner dog bosses 770, 770a, 771 and 771a, the cam shoulders or edges 920 of the trigger plate are engaged by the cam shoulders 922 of the mandrel and the trigger link is pivoted in a clockwise direction, FIGURE 8A. The top edge 908 of its plate 900 is moved out of engagement with the bottom edge 909 of the upper sear plate 912. The control rod is thus released suddenly for downward movement relative to the mandrel and is moved downwardly by the force of the springs 957 and 966. The downward movement of the mandrel relative to the cage and the dogs is now accelerated and, as the upper recesses of the pairs of mandrel recesses now move into alignment with the internal bosses of the dogs, the camming engagement of the bottom shoulders 992 and 992a of the dogs with the bottom shoulder of the sliding sleeve recess pivots the dogs inwardly, the dogs move out of the recess and the cage and the dogs then continue to move downwardly with the mandrel. It is during this holding step while the detent unit dogs are resisting inward movement to free the unit for continued travel that the sleeve shifting assembly between the driving piston 200 and the detent unit is compressed and activated. This sequence of operation of the detent unit is repeated each time the detent unit passes downwardly through a sliding sleeve 123.

The detent unit functions similarly when moving in an upward direction in the production tubing. As the train of tools moves upwardly and the detent unit moves into a sliding sleeve valve, the dogs are moved outwardly into its sleeve recess, the centering springs move the cage to its intermediate position on the mandrel wherein the dogs are again locked against movement toward their retracted positions, and the trigger link is moved to its operative position. As the upward movement of the unit continues, the top shoulders 991 and 991a of the dogs engage a top internal shoulder of the sliding sleeve recess.

When the upward movement of the dogs and the cage is thus arrested and the upward movement of the mandrel

continues, the top edge 928 of the lower sear plate 929 engages the bottom catch edge 926 of the trigger link plate and upward movement of the control rod is now arrested. Continued upward movement of the mandrel due to the engagement of the bottom spring retainer ring 820 by the mandrel shoulder 821 and the lower cross pin 964 causes the bottom retainer ring and the lower cross pin to move upwardly with the mandrel and relative to the control rod. The upper cross pin 952, and therefore the top spring retainer ring 954, is now held against upward movement due to the engagement of the upper cross pin with the surface 971 of the control rod stem defining the upper end of the upper slot 950. The upward movement of the mandrel and therefore of the train of tools is now resisted by the combined force of the two springs 957 and 956, as well as of the centering spring. Increased force from the lower piston unit 200 overcomes the resistance of the springs. As the mandrel moves upwardly relative to the cage and the control rod, before the lock surfaces of the mandrel move out of engagement with the dog bosses, the lower cam shoulders 931 of the mandrel at the slots 902 thereof engage the trigger link plate lower cam shoulders 930 and the trigger link is pivoted in a clockwise direction to move the lower edge 926 of its plate 900 out of engagement with the edge of the lower sear plate 929. The control rod is thus suddenly released for upward movement and is moved upwardly by the force of the springs 957 and 956. The upward movement of the mandrel continues and, as the lower recesses of the pairs of recesses of the mandrel move into alignment with the internal bosses of the dogs, the camming engagement of the top shoulders 991 and 991a of the dogs with the top shoulder of the sleeve valve recess pivots the dogs inwardly and the dogs move out of the recess and move upwardly with the mandrel. This sequence of operation of the detent unit is repeated each time the detent unit passes through a sleeve valve recess.

Further details of the detent unit are illustrated and described in my copending United States patent application Ser. No. 499,358, filed Oct. 21, 1965, now Patent No. 3,381,750, wherein it is generally referred to as a pressure signal generator.

The up-shift assembly 1000 includes a sleeve shifting unit 1040 which when activated is engageable with a sliding sleeve for moving the sleeve longitudinally upwardly and a monitor unit 1041 which functions to deactivate the up-shift assembly by effecting retraction of its sleeve shifting keys and monitor feeler. The up-shift assembly is connected with the detent unit by another coupler 260 which provides an articulated connection between the detent unit and the up-shift assembly thereby permitting the detent unit and up-shift assembly while remaining interconnected with each other to traverse a curved section of a flow conduit.

The sleeve shifting unit 1040 of the up-shift assembly is illustrated in detail in FIGURES 10-10B. The unit has a top connector socket 1042 providing an upwardly opening locking recess 1043 and having an internal annular end locking flange 1044 for receiving the lower end locking flanges of the coupler 260 whereby the top connector socket is loosely secured with the coupler. The connector has a reduced lower end section or neck portion 1045 which is telescopically received within a shear pin sleeve 1046 to which it is secured by a laterally extending shear pin 1047 inserted through the sleeve and the connector socket neck portion. A pointed cap screw 1048 is threaded through a longitudinal bore 1049 of the socket stem against the shear pin to prevent its center portion from falling out after shearing. The socket stem has a further reduced section 1050 providing a downwardly facing external annular shoulder 1051. Below the reduced section 1050 the socket stem has a still further reduced section 1052 between a downwardly and inwardly sloping annular shoulder 1053 on the lower end of the section 1050 and a lower upwardly facing abrupt shoulder 1054 on

the upper face of an enlarged lower end flange 1055. The shear pin sleeve has a lower end external annular flange 1056. When the connector 1042 and sleeve 1046 are at their upper end position, FIGURE 10, the flange 1056 is received within an internal annular recess 1057 in the lower end of a retainer cap 1058 threaded into the upper end of a tubular body or mandrel 1059. The retainer cap is held against rotation relative to the body 1059 by a locking wire 1060 positioned annularly around the retainer cap in an external annular recess 1061. The locking wire has a bent end section 1062 which is received in the longitudinal recesses 1063 and 1063a of the retainer cap and the body 1059, respectively. A longitudinally split sleeve 1064 comprising two identical half sections is telescopically fitted within the shear pin sleeve over the lower end section of the socket stem. The sleeve 1064 has an upper internal annular flange 1065 which fits around the socket stem section 1052. The sleeve 1064 also has a lower end external annular flange 1066 the function of which is explained hereinafter.

The body 1059 of the sleeve shifting unit 1040 is provided with a pair of longitudinally extending rectangular key windows 1067 spaced 180 degree relationship from each other around the body. A pair of laterally expandable and retractable sleeve shifting keys 400a are mounted within the body 1059 in back-to-back relationship, one key being adapted to be expanded and retracted through each of the windows 1067. The keys are identical with the previously described sleeve shifting keys 400 employed in the down-shift assembly. Thus, the various cam and shoulder surface features of the keys 400a shall be designated by the same reference numerals used for the keys 400, the detailed description of which is set out hereinabove. The upshift keys 400a are, however, oriented a direction opposite to the keys 400 so that their sleeve shifting shoulders 410 face in an upward direction permitting them to engage and move each of the sleeve valves in an upward direction. The keys 400a are biased laterally outwardly from each other by the springs 402 which are positioned within the aligned bores 401 within the keys around the spring guides 402a.

The lateral expansion and retraction of the up-shifting keys 400a is controlled by a pair of key retractors 1069 and 1069a, FIGURE 10B, which are positioned in parallel spaced relationship for longitudinal movement within the body 1059 on opposite sides of the keys 400a. The key retractors have identical features, being mirror images of each other, and function identically as the key retractors 414 hereinabove described in the down-shift assembly. Each of the key retractors has an upper end internal flange 1070 defining the upper end of a semi-annular recess 1071. The flange 1066 on the split sleeve 1064 is received in the recess 1071 of each of the key retractors. Each of the key retractors has a longitudinally extending recess 1072 which receives the operator lugs 412 and 413 of the keys 400a, the lugs on one side of both of the keys being received in the recess of one of the key retractors while the lugs on the other side of both of the keys are received in the longitudinal recess of the other of the key retractors. The longitudinal recess 1072 in each of the key retractors is defined by upper outer vertical internal locking surfaces 1073, upper downwardly and inwardly convergent cam surfaces 1074, upper inner vertical locking surfaces 1075, lower outer vertical internal locking surfaces 1076, lower downwardly and inwardly convergent cam surfaces 1077, and lower vertical inner locking surfaces 1078. The operator lugs of the keys are engaged by the various cam and locking surfaces of the key retractors for holding the keys at their retracted and expanded positions and for camming the keys or retracting them inwardly from their expanded positions. Specifically, when the keys are held at their retracted positions, as illustrated in FIGURE 10, the upper inner locking surfaces 1075 are engaged with the operating lug surfaces 413a while the lower inner locking surfaces

1078 are engaged with the key operating lug surfaces 412a. When the keys are at maximum expanded positions, the upper outer locking surfaces 1073 of the key retractors are engaged with the key operating lug surfaces 413a while the lower outer locking surfaces 1076 are engaged with the key lug surfaces 412a. The keys are cammed from their expanded positions to their retracted positions by coaction between the cam surfaces 1074 and 1077 of the key retractors with the cam surfaces 413b and 412b, respectively, of the keys.

The top face of the flanges 1070 on each of the key retractors is engageable with the lower face of the flange 1056 on the lower end of the sleeve 1046 so that when the socket connector 1042 along with its stem and the shear pin sleeve are telescoped through the retainer cap into the body 1059 the key retractors are forced downwardly relative to the keys. A spring 1079 is confined within the shear pin sleeve between the flange 1065 on the split sleeve 1064 and the shoulder 1051 on the stem of the socket connector biasing the split sleeve downwardly relative to the socket connector stem and shear pin sleeve. The biasing force of the spring 1079 is applied through the split sleeve to the key retractors.

The body 1059 of the sleeve shifting unit has a reduced lower externally threaded end section 1080. The body has a transverse lower flange portion 1081 defining a shoulder 1081a provided with a bore 1082 having axis coincident with longitudinal axis of the body. A lower push rod 1083 having an upper enlarged head section 1084 is slidably positioned within the body below the key retractors with its rod section extending through the bore 1082. The head 1084 of the push rod is engageable with the lower ends of the key retractors for moving the retractors from lower end to upper end positions. Downward movement of the push rod head 1084 is limited by the shoulder 1081a. The lower end section of the body has a downwardly opening ball socket 1085 in which a ball 1086 is retained by a socket cap 1087 threaded on the body end section. The socket cap has an external annular recess 1088 for a lock wire 1089 having a short end section 1089a bent transverse to the annular portion of the wire extending longitudinally through a recess 1088a in the socket cap and into a short aligned recess 1090 in the body for holding the socket cap against rotation relative to the body. The end cap has an internal annular semispherical recess 1091 adapted to conform to the contour of the ball 1086 so that the internal surface of the socket cap fits in sliding relationship around the ball to hold the ball within the socket 1085.

The ball 1086 has a lower threaded stem 1092 which extends through the bore 1093 of the socket cap for connection with the monitor unit 1041. The bore 1093 is defined by a downwardly facing divergent annular shoulder surface 1094 so that the bore 1093 is somewhat larger than the stem 1092 to permit the pin and ball limited rotation around the axis of revolution of the ball within its socket thus providing a universal joint between the monitor and sleeve shifting units. The ball 1086 and its stem have a longitudinal bore 1095 to receive an upper push rod 1096 on a slider 1097 of the monitor unit so that the upper end of the slider push rod is engageable with the lower end of the key retractor push rod 1083.

The monitor unit 1041, FIGURE 11, has an upper body mandrel or trigger housing section 1098 having an upper internal threaded bore 1099 into which the stem 1092 of the ball 1086 is engaged for connecting the monitor and sleeve shifting units. The socket cap 1087 has a lateral hole 1087a alignable with a corresponding blind hole 1086a in the ball 1086 for the insertion of a suitable tool, such as a screw driver, to hold the ball against rotation while connecting the stem section of the ball into the threaded bore 1099 of the mandrel 1098. The external surface of the upper end section of the mandrel includes upwardly and inwardly convergent surfaces 1100 and 1101 which function to facilitate the move-

ment of the monitor unit through a flow conduit by minimizing the probability of its upper end section becoming lodged against an obstruction within a conduit.

The mandrel 1098 has a longitudinally extending rectangular parallelepiped shaped slot 1102 which extends laterally entirely through the housing opening through its outer wall on opposite sides thereof. A short longitudinal recess 1103 extends from the upper end of the mandrel parallel to and spaced laterally from the bore 1099 opening into the slot 1102. The mandrel has an internally threaded bore 1104 along a lower end section opening into the lower end of the slot 1102. A laterally extending pin 1105 is positioned through the mandrel and the stem 1092 of the ball 1086 for holding the stem against rotation relative to the mandrel so that the monitor unit will not become accidentally unscrewed from the sleeve shifting unit.

The slider 1097, FIGURES 11B and 11C, includes the upper push rod section 1096, a central body section 1106, and a lower push rod section 1107. The back surface of the slider body has formed therein a shallow recess 1108 to receive the spring anchor 1109 which is secured thereto by a socket head screw 1110 threaded into a lateral bore 1111 in the slider body. The front of the slider body has a longitudinally extending recess 1112 having curved end sections 1112a and 1112b. The recess 1112 is provided in the slide to receive a trigger 1113, the details and the function of which are discussed hereinafter. The curved upper end section 1112a of the recess joins a vertical surface 1113 which connects with an upwardly and outwardly sloping surface 1114 joining a vertical surface 1115 on an insert lock member 116 secured within a recess 1117 of the slider body. The surface 1115 of the insert is laterally spaced from an upper end vertical surface 1118 on the slider body providing a horizontal locking shoulder 1119 on the upper end of the insert. The slider body has a lower end external annular flange 1120 which forms a downwardly facing external annular spring retainer shoulder 1121 engaged by the upper end of a main reset spring 1122 held at its lower end by an internal annular flange 1123 provided within the lower connector socket and spring retainer 1124 threaded along its upper reduced end section 1125 into the lower end section 1104 of the mandrel 1098. The connector 1124 is held against rotation relative to the mandrel by an annular lock wire 1126 disposed in the connector annular recess 1127. A bent end section 1128 of the lock wire extends through a short longitudinal recess 1129 opening through the end of the connector into an aligned recess 1130 in the mandrel to hold the connector against rotation relative to the mandrel.

The trigger 1113 is pivotally secured at its lower end within the slot 1102 on a pin 1131 extending through the trigger into aligned holes 1132 in opposite side sections of the mandrel 1098 extending along and defining the slot 1102. The upper free end of the trigger has a reduced end section 1133 providing a vertical surface thereon 1134. Spaced downwardly from the free end of the trigger is a laterally extending rectangular slot 1135 which receives a lateral pin 1136 secured in a feeler member 1137, further details and the function of which are discussed below. The back vertical face of the trigger has secured therein an insert lock member 1138 of a hardened substance such as tool steel secured in a vertical recess 1139 of the trigger. The back vertical face 1140 of the insert is laterally spaced inwardly from a vertical surface 1141 on the trigger providing a downwardly facing lock shoulder 1142 on the lower end of the insert adapted to interlock with the lock shoulder 1119 on the insert 1116 of the slider for releasably locking the slider at a lower end position as discussed below. The trigger insert has a vertical upper end back face 1143 which slopes upwardly and outwardly at substantially the same angle as the back face 1114 on the slider body and joins an upwardly and outwardly sloping back face

1144 on the trigger so that downward movement of the slider relative to the trigger effects relative sliding motion between faces 1113 and 1114 of the slider body along the insert and upper end back faces of the trigger so that the free end of the trigger is smoothly cammed laterally outwardly to allow the slider insert to pass below the trigger insert.

The feeler 1137 functions to detect certain recesses in the production tubing and responds to its movement into such recesses by releasing the trigger assembly of the monitor unit for disengagement of the sleeve shifting keys. The feeler is pivotally supported within the slot 1102 of the mandrel 1098 on a lateral pin 1145 secured through lateral aligned holes 1146 in the feeler into corresponding lateral holes 1147 in the vertical sides of the mandrel on opposite sides of the slot. The feeler 1137 has a generally longitudinally extending main body section 1147 and laterally extending parallel spaced arms 1148. The front free end surface 1149 of the body section of the feeler has a family of adjoining generally downwardly and inwardly sloping faces 1149a, 1149b, and 1149c providing a contour to the feeler which permits it to smoothly slide into and out of the various recesses along the inside surface of the production tubing as the monitor unit traverses the tubing. The particular shape of the recess engaging free end portion of the feeler is not provided to particularly conform to the configuration of any special recess but rather so the feeler will move smoothly into and out of recesses during longitudinal motion of the monitor unit. The body portion of the feeler has interconnecting longitudinally extending lower and upper recesses 1150 and 1151 for receiving, respectively, the upper free end section of the trigger and the trigger biasing spring 1152 which encircles the pivot pin 1145 pivotally supporting the feeler within the slot of the mandrel. One free end 1152a of the spring 1152 engages an inside surface of the feeler body defining an upper end section of the recess 1150 while the other free end section 1152b of the spring engages the surface 1134 on the reduced end section 1133 of the trigger biasing the trigger in a counterclockwise direction about its pivot pin 1131 as viewed in FIGURE 11. The upper end section 1153 of the feeler body has an internal vertical foot section 1153a which is engageable with a vertical surface 1154 defining the back vertical face of the slot 1103 for limiting the counterclockwise rotation of the feeler about its pivot pin 1145.

A pair of longitudinally extending feeler biasing springs 1153 are supported at their upper ends on a pin 1154 extending through aligned holes 1155 in the parallel arms 1148 of the feeler. The lower ends of the feeler springs are received in longitudinal upwardly opening slots 1155 in the spring anchor 1109 on a lateral pin 1156 secured between upwardly extending end sections 1157 defining the upwardly opening slots of the anchor. The feeler arms 1148 straddle the push rod 1096 of the slider 1097 and are engageable along their downwardly facing edge surfaces 1158 with upwardly facing shoulder surfaces 1097a on the upper end of the body portion of the slider. The springs 1153 bias the feeler counterclockwise about its pivot pin 1145 thereby biasing the lower sleeve-engaging end section 1147 of the feeler laterally outwardly. The upper end surfaces 1097a of the slider body engage the downwardly facing arm surfaces 1158 on the feeler holding it against counterclockwise rotation at its retracted position when the slider is positioned as shown in FIGURE 11.

The bottom connector 1124 of the monitor unit has an internal annular flange 1159 providing an upwardly facing downwardly and inwardly convergent annular shoulder surface 1160 defining the lower end of a locking recess 1161 extending upwardly to the flange 1123 to receive the upper end locking flanges of another connector 260 by which a lower piston propulsion unit 200 is connected with the up-shift assembly.

The up-shift assembly functions during upward travel of the tool train to shift the sliding sleeve valves 123 from their lower end to their upper end positions in a manner which is generally similar to the operation of the down-shift assembly. In its normal or deactivated condition at which the up-shift assembly travels through the production tubing the up-shift keys 400a and the feeler 1137 are held at their inward retracted positions by the slider 1097 which is resiliently biased at an upper end position, FIGURES 10 and 11, by the spring 1122. The upper end surfaces 1097a on the body of the slider engage the downwardly facing surfaces 1158 on the feeler arms 1148 locking the feeler against counter-clockwise rotation about its pivot pin 1148 with its recess engaging lower end section 1147 being held retracted within the recess 1102 of the mandrel 1098. The spring section 1152b bearing on the surface 1134 of the trigger biases the trigger counter-clockwise with its sear plate surface 1140 engaging the surface 1113 of the slider body. The upper end of the push rod 1096 on the slider engages the lower end of the push rod 1083. The upper face of the head 1084 on the push rod 1083 engages the lower ends of the key retractors 1069 and 1069a holding the retractors at their upper end position as illustrated in FIGURE 10 at which the inward locking surfaces 1075 and 1078 within each of the retractors engage the locking surfaces 413a and 412a, respectively, on the operator lugs of the keys 400a thereby holding the keys at their retracted positions within their respective windows 1067. The flange 1066 on the split sleeve 1064 is within the recesses 1071 of the key retractors while the flange 1056 on the shear pin sleeve 1046 is engaged with the upper end faces of the key retractors. The spring 1079 bearing downwardly on the upper ends of the split sleeve is compressed. The upper connector 1042 along with its related components, including the shear pin sleeve 1046, is at its upper end position with the flange 1056 on the sleeve in the internal annular recess 1057 of the retainer cap 1058.

When the top socket connector 1042 of the up-shift assembly is held against upward movement, such as by the releasable engagement of the detent unit 700 within one of the sliding sleeves 123 in the production tubing, and an upward force is applied to the up-shift assembly by imposing a fluid pressure differential across the lower piston unit, relative motion is effected between the top connector and the sleeve shifting unit to activate the up-shift assembly. The ball connection between the sleeve shifting unit 1040 and the monitor unit 1041 while permitting pivotal movement between the lower end of the sleeve shifting unit and the upper end of the monitor unit does not provide slack between the units. Therefore, the upward force of the piston applied through the connector 260 to the lower end of the monitor unit telescopes the sleeve shifting unit mandrel 1059 upwardly over its shear pin sleeve 1046 until the annular shoulder 1042a on the top connector engages the upwardly facing annular shoulder 1058a on the retainer 1058. The lower end flange 1056 on the sleeve 1046 engages the top ends of the key retractors 1069 and 1069a forcing the key retractors downwardly relative to the keys 400a which are each held against downward movement by the engagement of its lower end with the lower end surface 1067a of its respective window 1067. The key retractors are moved downwardly relative to the keys until the outer key locking surfaces 1073 and 1076 are aligned with the locking surfaces 413a and 412a, respectively, of the keys. The springs 402 bias the keys apart toward their outward expanded positions until the outer faces of the keys engage the inside surface of the production tubing through which the assembly is moving. This is an intermediate position between the fully retracted and fully expanded positions of the keys so that when the keys are aligned with the appropriate recess of a sleeve valve to be shifted they move farther outwardly to their expanded engaged position for shifting the valve sleeve. Thus, the keys are

resiliently held by their springs 402 against the inside surface of the production tubing.

The relative downward movement of the key retractors which releases the keys as described above also effects downward movement of the push rod 1083 due to the engagement of the lower ends of the key retractors with the top surface of the head 1084 of the push rod. The push rod 1083 forces the slider 1097 downwardly compressing the spring 1122 between the shoulder 1121 on the push rod and the internal annular flange 1123 within the bottom connector 1124. The downward movement of the slider 1097 performs a dual function of releasing the feeler 1137 and biasing its lower end section resiliently outwardly while locking the slider at a lower end position with the trigger 1113. The downward movement of the slider relative to the feeler and trigger moves the upper end slider surfaces 1097a downwardly relative to the surfaces 1158 on the feeler arms while the springs 1153 connected between the free ends of the arms 1148 and the slider resiliently biases the arms downwardly so that the feeler is resiliently biased counter-clockwise relative on its pivot pin 1145. The lower free end section 1147 of the feeler moves outwardly until it engages the inside surface of the production tubing. The resilient biasing of the feeler counterclockwise by the springs 1153 with the slider at its downward position permits some pivotal movement of the feeler so that surface irregularities encountered by the feeler within the production tubing may rotate the feeler slightly about its pivot pin under the influence of the springs 1153. As the feeler 1147 moves from its innermost retracted position to contact with the inside wall of the flow conductor, the pin 1136 is then in a free position within the trigger recess 1135 and both feeler and trigger are free relatively for limited clockwise and counter-clockwise movement. As the slider progresses downwards relatively, its sloping surfaces 1113, 1114, 1115 progressively move underneath the surfaces 1144, 1140 of the trigger which is biased toward them by the action of the spring 1152. Before the completion of the relative downward movement of the slider 1097, the upper face 1119 of its sear plate 1116, passes the lower face 1142 of the trigger sear plate 1138. The trigger is then swung anticlockwise by its spring 1152 until the sear face 1140 touches the face 1118 of the slider while the inner surface 1135a of the rectangular slot 1135 of the trigger approaches more closely to the pin 1136 of the feeler 1137 but does not make contact so long as the feeler head 1149b continues to ride on the internal wall of the pipe. As the tool train is driven upwards, the resistance of the detent unit 700 is overcome and the force which moved the slider 1097 downwards relative to the monitor 1041 closes. The spring 1122 then urges the slider upwardly relatively but movement is stopped and held by contact between the faces 1119 and 1142 of the sears 1116 and 1138 of the slider 1097 and the trigger 1113 respectively.

When the various components of the monitor unit are positioned as described above, the slider is locked at its lower end position, the feeler is biased outwardly with the biasing force being supplied by the springs 1153, and the surfaces 1097a of the slider are spaced below the surfaces 1158 of the feeler arms so that when the feeler section 1147 is aligned with the desired recess within the sliding sleeve the feeler may move farther outwardly. Also, at this intermediate position of the feeler its relationship with the trigger is such that the pin 1136 is sufficiently close to engagement with the trigger within its recess 1135 that farther outward movement of the feeler into the desired recess will move the trigger sufficiently clockwise to disengage it from the slider. Thus, when the up-shift assembly is activated its sleeve shifting keys are released and biased outwardly such that when they arrive at the desired recess they may move to expanded positions, the slider is locked at its lower end position with the spring 1122 compressed, and the feeler is biased out-

wardly to a position at which it engages the inner wall of the production tubing and may move farther outwardly at a desired recess for deactivating the up-shift assembly to release it from the sleeve.

After activation, the up-shift assembly travels in the production tubing until its sleeve shifting keys reach recesses shaped and sized to receive their outer surfaces so that their shoulders 410 may engage a shoulder provided in a sleeve valve to shift its sleeve upwardly. Upon reaching the recess adapted to receive the keys, the springs 402 of the keys force them laterally outwardly into the recess so that further upward movement of the assembly effects upward shifting of the sleeve valve. As explained hereinafter in further detail, the sliding sleeve units are so designed that when the sleeve has been properly shifted the feeler of the monitor unit is aligned with a recess adapted to receive its free end section 1147 for releasing the up-shift assembly.

When the feeler of the monitor unit is aligned with the desired recess in the sliding sleeve valve its recess engaging lower end portion 1147 is expanded into the recess by the springs 1153 which effect counter-clockwise rotation of the feeler about its pivot pin 1145. As the feeler revolves counter-clockwise its pin 1136 engaging the trigger recess surface 1135a pivots the trigger clockwise about its pin 1131 causing the trigger sear plate 1138 to be moved outwardly relative to the slider sear plate 1116 until the trigger sear plate locking surface 1142 is disengaged from the slider sear plate locking surface 1119 at which time the compressed spring 1122 expands forcing the slider abruptly upwardly relative to the mandrels of the monitor and sleeve shifting units. The upper end of the slider push rod 1096 engaging the lower end of the push rod 1083 forces its head against the lower ends of the key retractors moving the key retractors upwardly relative to the keys. The cam surfaces 1074 and 1077 of the key retractors engage the lower cam surfaces 413b and 412b, respectively, of the key operator lugs forcing the keys laterally inwardly retracting each of them against the force of its springs 402 into its window 1067 and thus disengaging the keys from the shifted valve sleeve. Simultaneously with the retraction of the keys and responsive to the upward movement of the slider, the upwardly moving surfaces 1097a on the slider at the base of its stem 1096 engage the feeler arm surfaces 1158 pivoting the feeler clockwise about its pivot pin 1145 retracting its recess engaging lower end section 1147 laterally inwardly into the mandrel slot 1102. The force of the spring 1122 holds the slider at its upper end position until the previously discussed sequences are repeated to reactivate the up-shift assembly.

If the up-shift assembly becomes jammed in a sliding sleeve valve unit such that its spring 1122 is not effective for releasing or deactivating the assembly, the assembly may be released by application of an upward force on its top connector 1042 of sufficient magnitude to sever the shear pin 1047. It will be obvious that upward force on the top connector below that sufficient to sever the shear pin will not release the up-shift assembly. The connector along with its shear pin sleeve 1046 and its stem 1045 down through and including the lower end flange or head section 1055 may be moved upwardly relative to the split sleeve 1064, which, in the absence of an upward force on the slider from its main spring 1122, normally remains at a downward position with the key retractors when the keys are expanded outwardly into locked position in a sliding sleeve. The connector thus is movable upwardly until the flange 1056 engages the shoulder 1057 within the retainer cap 1058. With the top connector and the shear pin sleeve so telescoped upwardly on the split sleeve the flange 1056 on the shear pin sleeve is spaced apart above the upper end flanges on the slip retractors so that the spring 1079 maintains the split sleeve at its downward position thus preventing accidental upward shifting of the key retractors and the split sleeve. The slip retractors may

be lifted from above only by the split sleeve which may be raised from above only the flange 1055 which cannot be lifted sufficiently to engage the split sleeve until the shear pin 1047 is severed. When the shear pin 1047 is severed the top connector with its stem including its lower end flange 1055 is lifted relative to the shear pin sleeve so that the flange 1055 engages the internal upper annular flange 1065 of the split sleeve. The split sleeve is lifted pulling the slip retractors upwardly causing the slips or the keys to be retracted inwardly as previously described. The top connector is lifted until the upper end flanges of the key retractors are returned upwardly to the relationship shown in FIGURE 10 so that the keys are fully disengaged and retracted inwardly. Of course, the top connector with its stem is telescoped upwardly from the shear pin sleeve with the flange 1055 being engaged with the flange 1065 of the split sleeve and the spring 1079 in an expanded condition.

The upward movement of the lower ends of the key retractors responsive to the lifting force on the top connector which severed the shear pin generally permits the spring 1122 to expand returning the slider to its upper end position and effecting retraction of the feeler. If, however, the mechanism is so jammed that the spring 1122 cannot return the slider upwardly, the up-shift assembly is still readily withdrawn from the production tubing since the feeler is cammed inwardly to pass any obstruction encountered by its lower end section as the up-shift assembly is returned to the surface through the production tubing. The clockwise camming of the feeler is effected by surfaces encountered as the up-shift assembly travels causing the feeler to be forced inwardly against the biasing effect of the springs 1153 so long as the slider is at its lower end position. The feeler is resiliently movable against the force of the springs 1153 between its maximum expanded position and its retracted position within its slot 1102 since the shoulders 1097a on the feeler are sufficiently spaced below the feeler arm surfaces 1158 to allow maximum pivotal movement of the feeler.

During the upward movement and functioning of the up-shift assembly the down-shift assembly moves freely along the flow conduit as its down-shift keys and monitor unit feeler are held at their retracted positions by the slider of the assembly which is held at an upper end position by its main operator spring, as explained in detail above. The down-shift assembly is not activated during upward movement since the detent unit is below the assembly and thus restrains only the up-shift assembly for activation during upward travel of the tool train.

The up-shift assembly 1000 is connected with a lower piston propulsion unit 200 by a coupler 260. The lower piston unit is a double-acting pressure responsive propulsion unit identical to the upper piston unit and is connected at its lower end by another coupler 260 to the articulated probe 1200 which is of a length necessary to support the bottom circulating valve and the required number of gas lift valves with their respective latch units.

The flexible probe is illustrated in FIGURES 12 through 17 in assembled relationship within the latch units and bottom circulating and gas lift valves and is separately illustrated in detail in FIGURES 18 through 18C.

The flexible probe has a head assembly 1210 which includes a top sub or mandrel 1211 having an upwardly opening locking socket 1212. An internal upper end flange 1213 provides a downwardly facing internal annular locking shoulder 1214 for the engagement of the locking dogs on the lower end section of a coupler 260 which is received within the locking socket 1212. The mandrel 1210 has a reduced externally threaded lower end section 1215 having a downwardly opening semispherical recess 1216. An annular retainer 1217 is threaded on the reduced section 1215 and has a lower end semispherical section 1218 providing an internal semispherical upwardly facing recess 1219 communicating with a lower end bore 1220. The recesses 1216 and 1219 combine to form a generally

spherical recess which receives a spherical ball member 1221 having an internally threaded axial bore 1222.

A top link 1223 having a reduced upper end section 1223a is threaded into the bore of the ball member and locked by a pin 1221a inserted through opposite holes 1221b in the retainer 1217. The top link has an external annular flange 1224 providing an upwardly and inwardly convergent annular shoulder 1225 adapted to be engaged by a locking cleat in the latch unit supporting the uppermost gas lift valve, as discussed hereinafter. The lower end section of the top link is bifurcated providing a pair of dependent fork members 1226 in laterally spaced parallel relation defining a downwardly opening slot 1227 which receives a male member 1228 which is pivotally connected within the recess between the fork members 1226 by a linking pin 1229. The male member 1228 is formed on a circular body section or flange 1230 which has formed thereon a downwardly extending male member 1231 identical to the male member 1228 and oriented along the same longitudinal axis and rotated therefrom 90 degrees. An intermediate female link section 1232 is pivotally secured by a link pin 1233 at its upper end to the downwardly extending male member 1231. The female has identically shaped and oriented upper and lower bifurcated end sections comprising laterally spaced parallel fork members 1234. The upper member 1234 are pivotally connected with the male member 1231 by a link pin 1233. The lower end section of the female link is pivotally connected with another male link 1228 by a link pin 1235. The combination of each of the male links with the adjoining bifurcated link sections connected thereto forms a universal joint in the articulated probe. For example, the top link 1223 and the intermediate female link 1232 are both pivoted on mutually perpendicular axes which are also perpendicular to the longitudinal axis of the probe. The movement of each of the probe links relative to the male member is limited by the configuration of the end surfaces of the bifurcated and male members of the links which have engaging surfaces contoured to permit the maximum bending required in the probe to permit it to traverse curved sections within the production tubing, particularly at the surface end of the tubing where the tubing generally turns from generally horizontal orientation to vertical. The bifurcated end sections 1234 have inwardly convergent upper end surfaces 1234a which engage with the surfaces 1230a on the body or flange portion of the male link. The spacing between the surfaces 1234a and the surface 1230a, and the angularity of the surfaces 1234a determine the degree to which the bifurcated members 1234 may rotate about their pivot pin 1233 relative to the male link. For example, by making the surfaces 1234a a single curved surface about a center point coincident with the axis of the link pin the female link may revolve about its pivot pin relative to the male link more than 180 degrees.

Selected intermediate female links are provided with an external annular flange 1224 having an upwardly facing annular shoulder 1225 to permit the releasable engagement of each latch unit on the probe for supporting a gas lift or bottom circulating valve. Thus, a female link provided with such a locking flange is included in the probe at each location along its length at which a gas lift or bottom circulating valve latch unit is to be positioned. The probe is employed for both installing and removing the gas lift and bottom circulating valves of a gas lift system embodying the invention.

When functioning as a running probe for installation of gas lift and bottom circulating valves, the probe has a bottom link 1235 provided with an external annular flange 1236 and a bottom enlarged section 1237 providing an upwardly facing external annular locking shoulder 1238 which is engageable by a bottom release assembly on the bottom circulating valve, as described in detail hereinafter. While the running probe employed in installing gas lift and bottom circulating valves of each system embody-

ing the invention includes a top link 1223 and a bottom link 1235, the number of intermediate male and female links incorporated in the probe is dependent upon the number of gas lift valves to be supported on the probe. The links are combined to position a universal joint section the probe at each pivotal connection in the valves and between the valves and latch units to provide a fully articulated assembly of probe and valve-latch unit combinations. Also, as previously stated each female link to be located at a valve latch unit is provided with an external annular locking flange for the releasable locking of the latch unit on the probe.

When the flexible probe is employed for removing the bottom circulating and gas lift valves, it is equipped with a bottom pulling link 1239 which is substituted in the probe for the bottom link 1235. Near its lower end the pulling link has a longitudinally extending lateral slot 1240 which extends entirely through the probe and communicates with a short small bore 1241 opening through the bottom end of the link. A pair of laterally movable dogs 1242 are pivotally supported within the recess on a pin 1243 with their free upper end sections being biased laterally outwardly by a spring 1244 confined along opposite end sections in a blind hole 1245 in the head section of each of the dogs. The head section 1246 of each dog has a plurality of parallel teeth 1247 each of which has an upwardly facing shoulder surface 1248. Each tooth is in the shape of a segment of an annular flange so that the outer surface of the head section of each dog is receivable within annular recesses provided within the release assembly of the bottom circulating valve, as described in detail hereinafter, for engaging the valve and retrieving it along with the gas lift valves. Each of the dogs has a reduced upper end lip section 1249 which extends within and engages the inside surface of a retainer ring 1250 which limits the lateral movement or expansion of the dogs about their pivot pin 1243. The spring 1244 biases the two dogs apart with their end flanges 1249 engaging the retainer ring. The head ends of the dogs may be pressed laterally inwardly compressing the spring 1244 to permit the pulling link to be inserted into the bottom release assembly of the bottom circulating valve. Each of the dogs has a longitudinal centrally positioned slot 1242a, a laterally extending portion 1242b through which the pivot pin 1243 extends, and an enlarged lower end section 1242c. When the head sections of the dogs are engaged in the bottom release assembly of the bottom circulating valve, the dog head sections are forced inwardly by inserting a screw driver into the hole 1241 between the lower end sections 1242c of the dogs.

A latch unit 1300 is releasably secured on the top link 1223 of the flexible probe for supporting a gas lift valve on the probe. The latch unit is illustrated in detail FIGURES 13 through 13J. As shown on the probe, FIGURE 13, the latch unit is at its fully locked position with its locking dogs fully retracted. The latch unit has a mandrel 1320 provided with a longitudinally extending central bore 1321 which receives the flexible probe during the running and pulling of the latch unit and through which fluid flows while the latch unit is locked in production tubing as in the gas lift system of the invention. The mandrel is provided in the upper end section 1322 with a plurality of longitudinal circumferentially spaced upwardly opening blind holes 1323 and a longitudinal rectangular slot 1324 extending laterally entirely through the wall of the head section and opening upwardly through the upper end of the mandrel. The mandrel is reduced along a major central section 1325 which, FIGURE 13B, has a vertical planar back face 1326, vertical side faces 1327 on opposite sides of and convergent laterally toward the back face 1326, and vertical planar side faces 1328 which are divergent toward and join the surfaces 1327. The mandrel has a vertical front face 1329 in the form of a longitudinal section of a cylindrical surface. The

mandrel faces 1326, 1327 and 1328 extend between a downwardly facing shoulder 1330 defining the lower end of the mandrel head section 1320 and an upwardly facing fragmentary annular shoulder 1331 on a flange 1332 extending partially around the mandrel between the side edges of the surface 1329. The central section of the mandrel along which the surface 1329 extends is provided with a longitudinal shallow front slot 1333 oriented along an axis parallel with the longitudinal axis of and opening at its upper end into the slot 1324. Intermediate its opposite ends the slot 1333 is enlarged providing lateral facing recesses 1334. Between the lower end of the slot 1333 and the lower end of the central section of the mandrel the mandrel has an internally threaded lateral hole 1335 surrounded by circular recess 1336 opening through the mandrel surface 1329 to receive a head of a screw threaded into the bore 1335. The mandrel has a lateral backwardly extending upper flange portion 1337 on its head section 1320 provided with a longitudinal bore 1337a, a central lateral flange portion 1338 having a longitudinal bore 1338a and extending from the central section of the mandrel perpendicular to the surface 1326, and a lower lateral flange portion 1339 having a longitudinal bore 1339a and projecting from the lower flange 1332. The flange portion bores 1337a, 1338a, and 1339a are aligned along a common longitudinal axis to receive a hinge pin for supporting laterally expandable and retractable locking dogs on the mandrel. The mandrel is reduced along a lower end section 1340 below the flange 1332. The section 1340 has a vertical half-cylinder surface 1341 extending 180 degrees around the mandrel aligned symmetrically with its back face 1326. The mandrel section 1340 has vertical parallel side faces 1342 which are spaced apart less than the diameter of the half-cylinder surface 1341. The mandrel section 1340 also has vertically extending side surfaces 1343 adjoining the surfaces 1342 and convergent forwardly toward each other adjoining a vertical front face 1344 extending parallel to along and on an opposite side of the mandrel from the back face 1326. The lower ends of the surfaces 1341, 1342, 1343 and 1344 are defined by an upwardly facing external annular shoulder 1345 on an annular flange 1346 having an external annular recess 1347. The lower end section 1348 of the mandrel is reduced in external diameter and provided with a lower end external annular flange 1349. The lower face of the flange 1346 along with the upper face of the flange 1349 defines an external annular recess extending around the end section 1348 of the mandrel.

A pair of laterally expandable and retractable locking dogs 1351 and 1352 are secured to the upper, middle, and lower flange portions along the back face of the mandrel by a longitudinally extending hinge pin 1353 received in the flange portion bores 1337a, 1338a, and 1339a and locked by lateral pin 1354 in a lateral bore 1350 of the flange 1338 and received within an external annular recess 1356 in the hinge pin. The locking dogs have identically shaped upper and lower external locking bosses 1357 and 1358. The surface contour and the longitudinal spacing of the locking bosses adapt the keys to be received only within similarly shaped locking recesses within the landing nipples included in the production tubing. Each of the locking dogs has an upper end inwardly sloping chamfered surface 1359, which, as explained hereinafter, facilitates inward camming or retraction of the locking dogs. The locking dogs each have identical longitudinal adjacent inside surfaces 1360 and 1361 which are similar to the side faces 1328 and 1327, respectively, on the central section of the mandrel 1320. As best seen in FIGURE 13B, the locking dogs are each fully retractable against the central section of the mandrel between its flange surfaces 1330 and 1331. The locking dog 1351 has a plurality of lateral, longitudinal, spaced, parallel hinge arms 1362, 1363, 1364, and 1365 while the locking dog 1352 similarly has longitudinally spaced parallel hinge arms 1366, 1367,

1368 and 1369. The locking dog 1351 has parallel, inwardly opening, longitudinally spaced, rectangular recesses 1370, 1371, and 1372 which receive, respectively, the free ends of the hinge arms 1367, 1368 and 1369. Similarly, the locking dog 1352 has parallel, longitudinally spaced, inwardly opening, rectangular slots 1373, 1374, and 1375, which receive, respectively, the free ends of the hinge arms 1362, 1363, and 1364. The locking dog 1351 has a lower end inwardly opening rectangular recess 1366a which receives the hinge arm 1366 of the locking dog 1352 while, similarly, the locking dog 1352 has an upper end recess 1374a which receives the hinge arm 1365 at the upper end of the locking dog 1351. When assembled on the mandrel, the locking dog hinge arms are intermeshed or interlocked with each other and with the locking flanges on the mandrel, as illustrated in FIGURE 13J. The hinge arm 1366 on the dog 1352 is positioned adjacent to and above the lower hinge flange portion on the mandrel while the hinge arm 1362 of the dog 1351 is adjacent to and immediately above the hinge arm 1366. The hinge arms 1363 and 1368 of the dogs 1351 and 1352, respectively, are connected below and above the central hinge flange portion 1338 of the mandrel. The hinge arm 1365 of the dog 1351 is secured adjacent to and below the mandrel flange portion 1337 while the hinge arm 1369 of the dog 1352 is adjacent to and immediately below the hinge arm 1365. The single hinge pin 1353 extends through all of the hinge arms of both of the locking dogs and the flange portions along the back face of the mandrel thereby pivotally securing both of the locking dogs along a common longitudinal axis parallel to the axis of the mandrel. A plurality of springs 1376, 1377, 1378, and 1379 are coiled around and spaced along the hinge pin between the hinge arms of the locking dogs with one end bearing on the locking dog 1351 biasing it counterclockwise while the other end of each spring is bearing on the locking dog 1352 bearing it clockwise. The free ends of each of the springs are bent at an angle with the axis of the wire forming the spring and hooked into holes, not shown, provided in the hinge arms of the locking dogs to bias the locking dogs outwardly to expanded positions relative to the mandrel. The opposite ends of each spring are so connected into adjacent hinge arms of opposite locking dogs that the cumulative forces of the springs bias the dogs apart outwardly on the mandrel.

A cage or sleeve 1380 is telescopically positioned over the mandrel 1320 and adapted to move longitudinal relative thereto between upper and lower end positions for controlling the lateral expansion and contraction of latch unit locking dogs. The sleeve includes a generally tubular head section 1381 having an upwardly and inwardly convergent outside upper end surface 1381a and an internal upper end flange 1382. The upper end surface 1383 of the flange 1382 is an inwardly facing annular concave spherical surface contoured to fit the generally spherical lower end surface of the retainer 1218 on the head of the probe so that when the probe link 1223 pivots relative to its head assembly the sleeve 1380 may pivot relative to and while remaining in engagement with the retainer. The lower face of the flange 1382 provides an internal downwardly facing annular shoulder 1384. The bore through the head section 1381 of the sleeve is enlarged along a lower end section providing an internal downwardly facing annular shoulder 1385 to limit the upward movement of the mandrel within the sleeve. The sleeve has a downwardly extending finger 1386 in the shape of a longitudinal cylindrical segment encompassing circumferentially approximately 90 degrees of the portion of the mandrel along which the sleeve finger extends. The finger is enlarged circumferentially along a lower end section 1387 encompassing approximately 180 degrees of the mandrel. The finger section 1387 is reduced along an end section 1388 providing an inwardly extending flange 1389 and a downwardly facing shoulder portion 1390. The section 1388 has an external locking ring recess 1391 below the

shoulder 1390. Since the lower end section 1387 extends circumferentially about 180 degrees the internal flange 1388 and the shoulder 1390 with the recess 1391 similarly extend the same circumferential distance in degrees partially around the reduced section 1343 of the mandrel 1320. The finger has a lower longitudinal recess 1392 aligned with the hole 1335 in the mandrel so that the head of a cap screw 1393 engaged in the hole of the mandrel is received within the recess 1392 to prevent relative rotation between the mandrel and the sleeve 1380 while allowing relative axial movement. The sleeve finger has an upper longitudinal recess 1394 alignable with the recess 1333 of the mandrel for a purpose explained hereinafter. The sleeve is also provided with a hole 1395 above the recess 1394 the function of which is described hereinafter.

The flange 1389 of the lower end section of the sleeve finger supports a dog lock member 1396 which is slidable along the lower end section 1340 of the mandrel to lock the dogs 1351 and 1352 at their outward expanded position when the lock member is at an upper end position on the mandrel. The lock member, FIGURE 13I, is generally half circular in shape to extend around 180 degrees of the reduced mandrel section and has an outside cylindrical surface 1397 between end flanges 1398 and 1399. The internal annular flange section 1388 of the sleeve fits in contact with the surface 1397 of the lock member between its end flanges 1398 and 1399 holding the lock member against longitudinal movement relative to the sleeve so that it moves with the sleeve. The inside of the lock member is semi-octagonal in shape defined by parallel side surfaces 1400 which engage the surfaces 1342 on the mandrel, FIGURE 13H, adjoining convergent surfaces 1401 which engage the similarly convergent surfaces 1343 of the mandrel, and a surface 1402 corresponding to and engageable with the surface 1344 on the mandrel. The lock member thus slides along and is held against rotation on the mandrel reduced lower end section. A pair of parallel, longitudinal, upwardly extending lock fingers 1403 are formed on the lock member. The lock fingers have inside parallel surfaces which are coincident with and adjoin the surfaces 1400 within the lock member. When the lock member is at an upper end position with its upper end surface 1404 engaged with the downwardly facing shoulder 1332a on the mandrel, the lock fingers extend along the mandrel surfaces 1342 with their upper ends extending above the upper face of the flange 1332 behind the expanded locking dogs 1351 and 1352 to hold the dogs at their outward locked position.

As best seen in FIGURE 13BB the flange 1388 on the lower end of the sleeve finger 1386 encompasses about 180 degrees of the mandrel while the lock member 1396 fitted on the flange encompasses 180 degrees of the lower reduced end section of the mandrel 1320. The other 180 degrees around the mandrel reduced section is encompassed by a semiannular spacer 1405 having an inside semicylindrical surface 1406 corresponding to and slidable along the semicylindrical surface 1341 on the reduced mandrel section. The outside surfaces of the spacer are shaped to be aligned with and conform generally with the outside surfaces of the lower end section of the finger on the sleeve. Thus, the spacer has a half-circular external flange 1407, a reduced section 1408 corresponding with the flange section 1388 of the sleeve finger, and a lock ring recess 1388a aligned with and corresponding to the lock ring recess 1391. A continuous annular retainer ring 1409 is engaged around the flange section 1388 of the sleeve finger and the corresponding section 1408 of the retainer 1405 to hold the retainer on the semicylindrical reduced section of the mandrel with its opposite ends 1410 engaged with the opposite ends 1396a of the lock member 1396. The retainer ring 1409 is held against downward movement on the finger flange section and the spacer 1405 by a suitable split lock ring 1411 positioned within the lock ring recess 1391 and the corresponding

recess 1388a on the spaced 1405. Thus, the lock member 1396 and the spacer 1405 combine to completely encircle the reduced lower end section of the mandrel and are held together by a combination of the retainer ring 1409 and the lock ring 1411 so that the lock member and the spacer member slide on the mandrel section between an upper end position at which the lock fingers on the lock member are inserted behind the locking dogs to hold them outwardly and a lower end position at which the lock fingers are disengaged from behind the locking dogs to allow them to retract. When the locking dogs are retracted inwardly, FIGURE 13B, the upper end faces 1403a of the lock fingers 1403 engage the lower ends of the locking dogs thereby limiting upward movement of the lock member and thus the sleeve 1380.

A latch clear ring 1412, FIGURE 13E, is positioned within the sleeve 1380 with its top face 1413 biased toward the internal annular shoulder 1384 of the sleeve head section. The ring 1412 is C shaped extending through an arc of approximately 330 degrees and having parallel opposite end surfaces 1414 spaced laterally defining a gap approximately the same width as the width of the slot 1324 in the mandrel. The latch cleat ring is oriented within the sleeve so that the ring end faces 1414 are aligned with the side surfaces of the slot 1324. The cleat ring has downwardly opening circumferentially spaced blind holes 1415 corresponding in size and position to the upwardly opening blind holes 1323 in the upper end section of the mandrel 1320. A spring 1416 on a guide 1417 is within each set of corresponding holes 1323 in the mandrel and 1415 in the latch cleat ring so that the latch cleat ring is biased upwardly against the shoulder surface 1384 in the sleeve head section and the mandrel is biased downwardly from the latch cleat ring and sleeve 1380. The opposite end sections of the latch cleat ring each has an upwardly and outwardly opening recess 1414a. A locking cleat 1418, FIGURES 13C and 13D, is pivotally supported from the latch cleat ring extending downwardly therefrom. The latch cleat is adapted to pivot about an axis at its upper end between inward locked and outward unlocked positions for releasably interlocking the latch unit on a section 1223 of the flexible probe. The latch cleat has opposing lateral arms 1419 and 1419a at its upper end which are received within the recesses 1414a of the latch cleat ring for pivotally supporting the latch cleat. The top end face 1420 of the latch cleat slopes downwardly and outwardly from a fulcrum 1421 with the plane of the surface 1420 being at an angle in excess of 90 degrees with a longitudinal axis of the cleat extending along the front face 1422 of the cleat. The lower end inside edge 1423 is chamfered to correspond with the upper shoulder of the locking flange on the flexible probe link so that the edge 1423 of the cleat engages an upwardly facing shoulder 1225 on the flange of the probe link 1223 when the cleat is pivoted to its inward position, FIGURE 13. At its locked position the top face 1420 of the cleat is at an acute angle with the downwardly facing shoulder surface 1384 within the sleeve while the fulcrum 1421 of the cleat is engaged with the shoulder surface 1384. The bottom outside corner edge 1424 of each cleat arm engages a bottom face 1414b of its recess 1414a so that a moment arm force is created between the edges 1424 and the fulcrum 1421 on the cleat by the force of the springs 1416 biasing the latch cleat ring toward the surface 1384 along its free end sections with the latch cleat ring being pivoted slightly about its corner center edge 1412a. The cross sectional configuration of each of the latch cleat arms 1419 and 1419a is such that when the latch cleat is pivoted laterally inwardly to its locked position, FIGURE 13, the surface 1420 extends at the angle shown with the sleeve shoulder surface 1384, the surface 1420 pivoting about the fulcrum 1421 on the latch cleat and the free end sections of the latch cleat ring are held spaced downwardly from the surface 1384 about the pivot edge 1412a on the cleat ring so that the

cleat ring is positioned at a slight angle relative to the sleeve shoulder 1384. At its locked position the lower free end section of the cleat is held laterally inwardly by engagement of its front face 1422 along its lower end section with the upper end section 1425 of a latch cleat locking pin 1426. The locking pin includes a pair of parallel flexible prongs 1427 formed on and extending downwardly from an upper end section 1425. Each of the prongs has a lateral locking boss 1428. The locking pin is positioned within and longitudinally movable along the recess 1333 of the mandrel 1320. The locking bosses 1428 have upper locking shoulders 1428a and lower inwardly convergent cam surfaces 1428b. The prongs 1427 are laterally flexible and thus compressible toward each other. The bosses 1428 are receivable within the lateral recesses 1334 opening into the recess 1333 so that the locking pin 1426 is releasably lockable at the position illustrated at which its upper end section 1425 is positioned within the recess 1324 of the mandrel between the front face 1422 of the latch cleat and the inner surface of the sleeve 1380 whereby the free lower end section of the latch cleat is held inwardly at its locked position with the probe link. The hole 1395 and the recess 1394 in the sleeve permit access to the latch cleat locking pin for manipulating it, as described hereinafter, when releasably engaging the latch unit on the flexible probe. During relative longitudinal movements of the mandrel 1320 and its sleeve 1380, the locking pin 1426 remains latched in the position shown in FIGURE 13A with its locking and unlocking relationship with the latch cleat 1418 being determined by the relative positions of the mandrel and sleeve. The latch pin is manually moved within its recess only when connecting the latch unit on the probe.

The dogs 1351 and 1352 are held at their fully retracted position by the telescopic engagement of the upper end section of the sleeve 1380 over the upper end sections 1359 of the dogs which relationship is effected by the longitudinal compression of the mandrel 1320 into the sleeve 1380 to the position shown in FIGURE 13 when the latch is assembled on the probe. At such position the lower end of the head section of the sleeve substantially engages the upper end surface of each of the bosses 1357 on the locking dogs. At such position, also, the upper end section 1425 of the latch cleat lock pin 1426 is at its upper end position relative to the mandrel between the sleeve 1380 and the outer face 1422 of the latch cleat 1418 holding the latch cleat laterally inwardly in engagement with the flexible probe link. At such maximum telescoped compressed condition between the mandrel and sleeve the springs 1416 also are compressed tending to bias the sleeve and mandrel in opposite directions.

As indicated above, the latch unit 1300 is releasably secured on the flexible probe 1200 with the sleeve 1380 telescoped downwardly over the mandrel 1320 to the position shown in FIGURE 13. Preparatory to insertion of the probe through the latch unit the latch cleat lock pin 1426 is moved downwardly in the recess 1333 by introducing a suitable tool, such as a screw driver, through the hole 1394 in the sleeve head section, engaging the upper end section of the pin 1426, and applying a downward force on the pin causing its cam surfaces 1428b to compress its prongs 1427 inwardly thereby moving the bosses 1428 inwardly out of the lateral recesses 1334 thus freeing the pin for downward movement in the recess. The pin is moved downwardly to a lower end position in the recess so that its upper end section 1425 is below the lower free end of the latch cleat 1418. The force of the springs 1416 press the latch cleat ring 1412 toward the internal annular shoulder 1384. The latch cleat is pivoted counter-clockwise about the edge 1421 moving the lower free end of the latch cleat laterally outwardly until its outer surface 1422 engages the inside surface of the head section of the sleeve 1380. The latch unit is placed on the flexible probe and moved upwardly

until the upper end surface 1383 on the head section of the sleeve is in engagement with the spherical lower end surface of the retainer member 1218. The lower locking edge 1423 of the latch cleat is thus moved to a position permitting the flexible probe to be inserted through the latch unit until the locking flange 1225 on a probe link 1223 is moved below the latch cleat locking edge 1423. The mandrel 1320 of the latch unit is pressed upwardly telescoping it farther into the sleeve against the force of the springs 1416 until the latch cleat moves above the locking flange on the flexible probe link. When the cleat is in the proper position above the shoulder, a suitable tool, such as a screw driver is inserted through the hole 1395 depressing the lower free end of the latch cleat laterally inwardly against the upper shoulder of the locking flange on the probe link. The lower end of the latch cleat lock pin 1426 is engaged with a suitable tool inserted through the longitudinal slot in the sleeve 1380 in the finger section 1386 of the sleeve moving the lock pin upwardly until its bosses 1428 are aligned with and expand outwardly into the lateral recesses 1334 of the mandrel to releasably lock the lock pin at its upper end position, FIGURE 13. With the lock pin 1426 positioned, the latch cleat is held laterally inwardly in engagement with the locking flange on the probe link. The latch unit mandrel is held at its upper end position as shown in FIGURE 13 by suitable means to be described hereinafter releasably interlocking the flexible probe and the lower end of the mandrel whereby the mandrel may not move downwardly on the flexible probe from the position of FIGURE 13 until release is effected. At the position of FIGURE 13, the sleeve 1380 is fully telescoped downwardly over the upper end sections of the locking dogs 1351 and 1352 with the lower end of the sleeve engaging the surfaces 1359 on the locking dogs.

When the tool reaches a desired location in the tubing through which it is traveling, such as the lower end of the production tubing 104, and release is effected between the flexible probe and the mandrel of the latch unit, as described in detail hereinafter, the springs 1416 at the upper end of the latch unit expand moving the mandrel 1320 downwardly until the lower ends of the dogs 1351 and 1352 engage the upper ends 1403a of the fingers 1403 on the lock mandrel 1396 thereby holding the mandrel against further downward movement through the lock member which is held by the downwardly extending sleeve finger 1386. The downward movement of the mandrel relative to the sleeve 1380 positions the mandrel at an intermediate longitudinal position relative to the sleeve when the dogs engage the upper ends of the lock member fingers. At such intermediate position the latch pin 1426 which moved downwardly with the mandrel due to its engagement with the lateral recesses 1334 of the mandrel is still at a position at which its upper end section 1425 holds the latch cleat 1418 at an inward position in locking relationship with the locking flange on the flexible probe. At this intermediate position of the mandrel relative to its sleeve the upper end sections 1359 of the locking dogs are withdrawn from within the head section of the sleeve 1380 freeing the dogs for lateral expansion by pivoting about their hinge pin 1353. The springs 1378 pivot the locking dogs outwardly from the mandrel until their internal bosses 1357 and 1358 engage the inside surface of the flow conductor in which the latch unit is moving. The wall of the flow conductor is engaged by the locking dogs at intermediate lateral positions which do not sufficiently space the dogs from the mandrel to allow the upwardly extending fingers 1403 on the lock member 1396 to be inserted behind the dogs. Thus the mandrel is held at its intermediate longitudinal position at which, for reasons previously explained, the latch cleat is restrained against lateral movement and maintains the latch unit locked on the running tool probe.

When the latch unit moves to a position within the

flow conduit through which it is traveling at which the bosses on the locking dogs **1351** and **1352** are aligned with internal recesses in the conduit adapted to receive the bosses, the springs on the hinge pin of the locking dog expand the dogs laterally into the locking recesses of the conduit. The additional expansion of the locking dogs spaces their inner surfaces **1360** from the mandrel side surfaces **1342** sufficiently for the fingers **1403** on the lock member **1396** to be moved between the mandrel and the locking dogs to hold them at their outward expanded positions. With sufficient space for the fingers of the lock member to be moved between the mandrel and the locking dogs, the springs **1416** further expand simultaneously lifting the sleeve **1380** along with the locking member **1396** relative to the mandrel and locking dogs until its locking fingers **1403** are inserted between the mandrel and the locking dogs **1351** and **1352** until the upper end surface **1404** of the lock member engages the lower face **1332a** of the flange **1339** on the mandrel limiting further upward movement of the sleeve and lock member and moving the latch cleat ring **1412** upwardly during the lifting of the sleeve thereby raising the cleat until its lower free end section is above the upper end section **1425** of the latch cleat lock pin. When the latch cleat moves above the lock pin the force of the springs **1416** against the latch cleat ring pivots the latch cleat counterclockwise about its pivot line or edge **1421** moving the cleat laterally away from the locking shoulder on the link of the probe thereby disengaging the latch unit from the probe.

With the latch unit disengaged from the probe, the springs **1416** bias the mandrel and sleeve in opposite longitudinal directions to maintain the fingers **1403** on the lock member **1396** at their upward positions behind the locking dogs **1351** and **1352** thereby holding the dogs at their expanded outward positions locking the latch unit within the conduit. The latch unit remains so locked until relative motion is effected between the mandrel and the sleeve **1380** to withdraw the lock fingers **1403** downwardly from within the locking dogs. Such relative movement is effected by a downward force on the upper end of the sleeve **1380** in a manner to be explained in more detail hereinafter. A downward force suitably applied to the upper end of the sleeve telescopes the sleeve downwardly over the mandrel thereby moving the finger **1386** of the sleeve along with its lock member **1396** downwardly withdrawing the locking fingers **1403** from between the locking dogs and the side surfaces **1342** of the mandrel. With the fingers so withdrawn the locking dogs are cammed inwardly by the cam surfaces on their bosses **1357** and **1358** coacting with similar shoulder-like cam surfaces at the ends of locking recesses within the conduit. So long as the sleeve **1380** is maintained at a downward position relative to the mandrel to keep the fingers **1403** from being reinserted between the mandrel and the locking dogs the latch unit will remain at its released position and may be moved in either direction through the conduit. Further described procedures and equipment permit the sleeve and mandrel to be maintained in the proper relationship for withdrawal of the latch unit from the conduit. As previously pointed out, the latch cleat lock pin **1426** remains releasably locked in its recess until the release of the latch unit from its locked position within the conduit. As the sleeve **1380** is moved downwardly to effect release, the lower end face **1423a** contacts the upper end face **1425a** of the cleat lock pin head **1425** and forces it downwardly relative to the mandrel. The lobes **1428** of the lock pin **1426** are cammed inwardly and take a friction grip on the side walls of the lower portion of the slot **1333** in the mandrel; the lock pin remains there, out of action, until the latch is again manually assembled on a probe at the surface and the cleat **1418** remains likewise inactive in its outermost position.

As illustrated in FIGURES 13-15, a gas lift valve **1500** is pivotally supported from the latch unit **1300**.

The gas lift valve is an articulated unit having an upper packing section **1520**, a central valve section **1521**, and a lower packing section **1522**. The gas lift valve is supported from the latch unit by a universal coupling **1523** which includes two pair of identical spider members **1524** interconnected by a swivel crosshead **1525**. Each of the spider members has a semicircular body section **1526** provided with an internal semiannular flange **1527** and an arcuate finger section **1528** provided with a hole **1529** having an axis on a radius of the arcuate section. The swivel crosshead **1525** comprises a ring member **1530** having four radial round lugs **1531** evenly spaced around the ring member at 90 degree intervals. The outer spherical surface portion **1530a** of the ring member substantially mates with the internal spherical surface portion **1528a** of the arcuate finger on each of the spider members. A pair of the spider members **1524** are supported on the lower end section of the latch unit mandrel in 180-degree spaced relationship with their internal flanges **1527** received within the external annular recess **1548** at the lower end of the mandrel. The spider members are held on the mandrel section by an annular retainer ring **1532** having an internal outwardly downwardly divergent surface **1532a** engageable with the outwardly divergent surfaces of the spider members holding the ring against downward movement while the ring is held against upward movement on the mandrel by a split lock ring **1533** positioned within an external annular lock-ring recess **1547** on the mandrel lower end section. The arcuate fingers **1528** of the two spider members supported on the mandrel are positioned on opposite sides of the crosshead **1525** with a lug **1531** on the crosshead being received in the hole **1529** of each of the spider members. The pair of oppositely positioned spider members pivot relative to the crosshead along an axis extending through the centers of the opposing lugs **1531** which are positioned within the holes **1529** of the arcuate sections of the spider members. A pair of downwardly extending spider members **1524** are disposed on the other two opposing identical sides of the swivel crosshead spaced or intermeshed between the spider members secured to the latch unit. The lower spider members **1524** are secured on the upper end section of a mandrel **1534** of the packing assembly **1520** by another annular retainer ring **1532** which is held on the packing assembly mandrel by another split lock ring **1533** positioned within an external annular recess **1535** around the packing assembly mandrel. The internal flanges **1527** of the spider members **1524** are received in an external annular recess **1536** of the packing assembly mandrel. The lower spider members are spaced 180 degrees from each other at 90 degree spacing between the upper spider members and secured in an identical manner on the swivel crosshead with a crosshead lug **1531** extending through the hole **1529** in each spider member. The packing assembly **1520** is movable pivotally about an axis extending through the centers of the oppositely positioned crosshead lugs along a line at a 90 degree angle to the line about which the spider members on the latch unit are pivotally supported on the crosshead. Thus, with both the lower end of the latch unit and the upper end of the upper packing assembly on the gas lift valve being pivotally connected for movement about axes which intersect at 90-degree angles in a plane perpendicular to the longitudinal axes of the latch unit and packing assembly when they are coincident universal-joint action is permitted between the latch unit and the packing assembly allowing the units while coupled to traverse curved portions of a flow conduit. Suitable external annular packing **1536** is supported on the mandrel **1534** between an upper retainer ring **1537** threaded on the mandrel and held against rotation by a roll pin **1538** and a lower retainer ring **1539** telescoped downwardly over a split lock ring **1540** positioned within an external annular locking ring recess **1541** around the mandrel. The upper packing assembly section **1520** of

the gas lift valve is pivotally connected with the valve section 1521 by a universal joint 1542 enclosed within a flexible tubular sleeve 1543. The universal joint 1542 is similar to the universal joint 1523 and includes a swivel crosshead 1525 connected within and between two pairs of oppositely positioned intermeshed spiders 1544 each of which is similar to the spiders 1524 differing therefrom only in the provision of an external annular section arcuate recess 1545 around each of the spiders to facilitate compression and tension folding of the flexible tubular sleeve 1543. An internal arcuate flange section 1545a within each spider 1544 on the lower end section of the mandrel 1534 is received within an external annular recess 1546 around the lower end section of the mandrel 1534. An upper end section 1543a of the flexible sleeve 1543 is telescoped over the packing assembly mandrel extending upwardly thereon to a position adjacent to the retainer ring 1539 and clamped on the mandrel by a tubular compression sleeve 1547 placed over the sleeve and annularly crimped to form the external annular recesses 1547a which aid in holding the compression sleeves on the flexible sleeve. The flexible sleeve 1543 serves the double purpose of locking the universal joint spiders 1544 into their respective assembled positions and, assisted by the application of a suitable adhesive sealant, such as "Larkin" epoxy cement, on its interfaces, of preventing leakage of gas from the exterior to the central flow passage through the valve.

The valve section 1521 of the gas lift valve includes an inner bellows assembly 1548, an outer bellows assembly 1549 telescopically engaged over the inner bellows assembly, and a dome chamber assembly 1550 telescoped along its lower end section over an upper end section of the outer bellows assembly. The inner bellows assembly includes an upper tubular mandrel 1551 which is provided along its upper end section with external annular longitudinally spaced flanges 1552 and 1553 defining an external annular recess 1554 which receives the arcuate internal flanges sections 1545a on the two sets of spider members 1544 of the universal joint 1542. The mandrel 1551 is enlarged along a lower end section 1555 which is externally threaded and provided with a longitudinally extending external recess 1556 along its threaded section to conduct dome gas, as explained hereinafter. An internal sleeve 1557 is slidably fitted telescopically into the enlarged lower end section 1555 of the mandrel and is provided with an external annular flange 1558. A longitudinally collapsible and extendable inner bellows 1559, formed of a material such as metal, is secured around its upper end to the lower end of the mandrel section 1555 and around its lower end to the upper face of the flange 1558 on the sleeve 1557. The bellows extends and contracts as the sleeve 1557 telescopes into and out of the lower end of the mandrel 1551. The outer bellows assembly 1549 includes a tubular mandrel 1560 having an internally threaded upper end section secured on the enlarged lower end section 1555 of the upper mandrel 1551. The mandrel 1560 has an externally threaded reduced lower end section 1562 provided with an internal annular lower end flange 1563 which fits in sliding relationship over the sleeve 1557 below its external annular flange 1558. A longitudinally extendable and contractable bellows 1563a, which may be formed of a suitable material such as metal, is secured around its upper end to the lower face of the flange 1563. A valve ring 1564 is fitted telescopically over a lower end section of the sleeve 1557 and secured around its upper end face to the lower end of the bellows 1563. The ring 1564 has a reduced lower end section 1565 which is substantially the same diameter as the sleeve 1557 and provides an upwardly facing internal annular shoulder 1566 which is engageable with the lower end of the sleeve 1557. The valve ring is suitably secured, as by silver soldering around an annular groove 1567, to the sleeve 1557.

The dome chamber assembly 1550 includes a tubular body section 1568 having an upper reduced end section

1569 provided with an internal annular upper end flange 1570 which fits over the flange 1553 on the mandrel 1551 and is sealed thereto as by silver soldering around an annular groove 1571 carried by the flange 1570. A lower end section of the flexible sleeve 1543 fits telescopically over the reduced upper end section 1569 of the member 1568 and is secured thereon by cement and the lower compression sleeve 1547 which is annularly crimped in the same manner as the upper compression sleeve 1547 to secure the lower end section of the compression sleeve in sealed relationship around the flexible sleeve over the upper end section of the member 1568. A lower slightly reduced end section 1572 fits over the upper reduced end section 1561 of the outer bellows mandrel 1560 and is sealed thereto by soldering around internal annular recesses 1573 within the section 1572. A radially spaced concentric relationship between the tubular member 1568 and the tubular mandrel 1551 provides an annular dome chamber 1574 for dome gas employed to bias the gas lift valve downwardly toward a closed position. A plug member 1575 secured in the tubular member 1568 is provided with internal threaded bore 1576 reduced in diameter along its lower end section 1576a and opening through the inward end opening into the dome chamber for the introduction of dome gas. The bore of the plug member is closable by a threaded removable core 1577. A gasket 1577a seals between the inward end of the core and the plug member 1575 in the bore section 1576a.

A tubular valve body 1578 is threaded along an upper end section over the lower end section 1562 of the outer bellows mandrel 1560. A ring seal 1579 in an external annular recess in the bellows mandrel 1560 seals between the bellows mandrel and the upper end section of the valve body. The valve body has a plurality of longitudinally spaced lateral slots 1580 admit lift gas into the valve from around the valve when the valve is functioning in the system of the invention. The valve body is reduced along a lower end section 1581 providing an external downwardly facing annular shoulder 1581a and an internal upwardly facing annular shoulder 1581b below the slots 1580.

A tubular valve seat member 1582 is supported concentrically within the valve body 1578. The valve seat member has an enlarged lower end section 1583 received within the reduced lower end section 1581 of the valve body. A ring seal 1584 positioned within an external annular recess around the enlarged section of the valve seat member seals between the valve body and valve seat member. An annular split retainer 1585 is supported in concentric relationship around the valve seat member 1582 within the tubular valve body 1578 along its slots 1580 for retaining a flexible annular sleeve type check valve 1586 clamped along a lower end section between the retainer and the valve seat member. The retainer, FIGURE 15a, is an annular member having a lower end internal annular flange 1587 and is outwardly flared or outwardly and upwardly divergent along its upper end section which comprises a plurality of circumferentially spaced upwardly and divergently extending fingers 1588 which defined a plurality of upwardly opening slots 1589 through which lift gas flows into the valve from the valve body slots 1580. The side edge surfaces 1590 on the head ends of the fingers 1588 engage the inner surface defining the bore through the valve body 1578 above its slots 1580 providing radial support for the fingers. The internal flange 1587 of the retainer is received within an external annular recess 1591 of the valve member at the upper end of its enlarged section 1583 while the annular end surface of the retainer flange engages the internal annular shoulder 1581b of the valve body 1578 so that the retainer is clamped between the valve seat member and the valve body and holds the valve seat member against downward movement within and relative to the valve body 1578.

The flexible check valve 1586 is tightly clamped along

its lower end section 1592 between the retainer 1585 and the valve seat member 1582 with an internal annular portion of the check valve being squeezed into an external annular recess 1593 to aid in holding the check valve in position between the retainer and valve seat. An upper free end portion 1583 of the check valve element is expandable and contractable between the external surface of the valve seat member and the internal edge surfaces 1594 of the fingers on the retainer 1585. The valve element 1586 functions as a check valve to prevent back flow from within the valve outwardly through the lateral slots 1580. Outward flow past the check valve element toward the slots 1580 biases the upper free end section of the check valve radially outwardly into seated relationship over the inside edges 1594 of the fingers 1588 thereby shutting off flow from within the valve into the slots 1589 between the fingers 1588. The upper free end section 1583 of the check valve extends above the fingers 1588 sufficiently to seat on the inside surface of the valve body 1578 above the fingers. Flow into the valve through the slots 1580 passes through the slots 1589 between the fingers collapsing the check valve inwardly as shown in FIGURE 15b so that the check valve permits flow into the gas lift valve but prevents flow outwardly from within the valve.

The valve seat member 1582 has an upper outwardly divergent or flared end section 1595 which is concentrically positioned within and spaced apart from the surface defining the bore through the valve body 1578 to permit flow around the valve seat member within the bore of the valve body. The outside surface of the valve member along its upper end section provides an inside support for the check valve element when it is contracted inwardly to permit upward fluid flow through the valve around the valve seat member. The valve member has an annular upper end seat surface 1596 which is engageable by an annular valve face member 1597 which is supported within and longitudinally movable with the valve ring 1564 of the outer bellows assembly between the engaging closed relationship of FIGURE 15 and the spaced open relationship of FIGURE 15b. The valve face member is supported around the reduced end section 1565 of the valve ring 1564 by an annular retainer sleeve 1598 the outer surface of which is slidable within the bore of the valve body 1578. A retaining wire 1599 is confined between the upper end section of the retainer 1598 and the valve ring 1564 to secure the retainer on the valve ring. The retaining wire is inserted into its recess in the retainer through a tangential slot in the retainer opening into the wire recess.

An annular spacer or back-up member 1600 is positioned around the section 1565 of the valve ring 1564 within the retainer 1598 between the top surface of the valve face member 1597 and the enlarged upper end section of the valve ring. The spacer 1600 is especially adapted to permit precision fitting of the valve face member 1597 with the upper end seat surface 1596 on the seat member 1582 after assembly of the gas lift valve. The spacer comprises a ring shaped core 1601 of a low melting point metal encased within a covering 1602 of a suitable rubber or plastic which resists the chemical action and operating temperatures of the fluids, such as oil and gas, to which the member is exposed. For example, the core 1601 may be formed of a metal such as bismuth alloy sold under the trademark "Cerrolow 136" which has a melting point of about 136 degrees F. The spacer is manufactured by forming an annular ring of the low melting point metal at a temperature below its melting point, wrapping the core with the uncured outer coating material and suitably curing the coating material as by pressure and heat to form the impermeable flexible covering 1602 encasing the core. The casing is preferably formed of the flexible material in the form of a cord or string which is tightly wound about the core so that during the curing and until the casing material is melted into a continuous sheath,

the metal core which may be heated above its melting point will remain confined within the casing material.

The spacer 1600 performs its basic function of adjusting the relationship between the seat member 1597 and the surface 1596 on the valve seat member after the valve section 1521 of the gas lift valve is completely assembled. The valve assembly is heated to a temperature above the melting point of the core 1601 of the spacer so that the core is transformed from the solid to the liquid state. With its core in the liquid state, the deformability of the spacer is appreciably increased. The valve is biased toward its closed position as by injection of dome gas into the dome chamber 1574. With the spacer in the semifluid state the seat member 1597 assumes an optimum seated relationship with the seat surface 1596 and the spacer due to its deformability conforms to the shape of the space between the seat member and the enlarged section of the valve ring around the valve ring within the sleeve 1598. With the spacer so conformed to the proper shape to allow the seat member to assume full-seated engagement with the seat surface on the valve seat member, the temperature of the valve assembly is reduced allowing the core of the spacer element to return to its solid state and preserve optimum engagement between the valve face member 1597 and the valve seat surface 1596 on the valve seat member 1582. It will be seen that the spacer may be adjusted simply by heating the valve assembly at any time disassembly and reasonably of the valve is required for parts replacement or repair. When assembled, the spacer 1600 is virtually incompressible.

The following valve components are movable longitudinally as an assembly or unit for positioning the valve face member 1597 between its open and closed positions relative to the upper seat surface 1596 of the valve member 1582: the valve seat member 1597, the retainer 1598, the spacer 1600, the valve ring 1564, the inner valve sleeve 1557, and the lower end portion of the bellows 1559 and 1563a. During upward movement of these components as a unit, the inner sleeve 1557 telescopes into the mandrel lower end section 1555 while the inner and outer bellows 1559 and 1563a, respectively, are compressed. Conversely the group of components moves downwardly as a unit to position the face member 1597 in closed relationship with the seat surface 1596 while the bellows 1559 and 1563 are expanding. The dome gas chamber effectively includes the space around the sleeve 1557 within the outer bellows 1563, the space around the inner bellows 1559 within the mandrel 1560 and the gas passage 1556. Dome gas may flow from the chamber 1574 through the flow passages 1556 formed along the threads 1561 around the inner bellows 1559 within the mandrel 1562, past the flange 1563 around the sleeve 1557, within the outer bellows 1563, and along the surface of the sleeve 1557 to the joint 1567 within the valve ring 1564.

The lower seal assembly section 1522 of the gas lift valve is pivotally connected with the valve section 1521 by a lower universal joint 1542a which is identical to the previously described universal joint 1542 and includes the swivel crosshead 1525 with the two pairs of spiders 1544. The arcuate internal flange sections 1545 of the upper set of spider members 1544 are received within an external annular recess 1603 in the lower end section 1583 of the valve seat member 1582. The spider members function not only as a part of the universal joint 1542a between the valve and lower packing assembly sections but also their upper end surfaces are engageable with the lower end surface of the valve body 1578 holding the valve seat member against upward movement relative to the valve body.

The lower packing assembly has a tubular mandrel 1604 provided with a reduced upper end section 1605 having an external annular recess 1606 which receives the flanges 1545 on the lower set of spider members 1544 of the joint 1542a. The universal joint 1542a is covered to make it fluid tight and its spider members are held on the

cross-head 1525 and the valve seat member and seal assembly mandrel respectively by a lower flexible sleeve 1543a confined around the reduced lower end section 1581 of the valve body 1578 by the crimped compression sleeve 1547. The lower end section of the flexible sleeve is similarly secured on the mandrel 1604 by another crimped compression sleeve 1525. A lower packing 1536a identical to the upper packing element 1536 is supported on the mandrel 1604 below an upper retainer ring 1539a which is held against upward movement on the mandrel by a split lock ring 1540a received in an external annular recess 1607 of the mandrel 1604. The packing is limited against downward movement on the mandrel by the upper end surface 1608 on the retainer 1609 threaded on the lower reduced threaded end section 1610 of the mandrel 1604. The retainer 1609 has an internal upwardly facing annular shoulder 1611 which engages the lower end surface 1612 of the packing assembly mandrel limiting upward movement of the retainer on the mandrel. The retainer has a bore 1613 which is substantially the same diameter as the bore through the mandrel 1604 and is flared downwardly and outwardly along a section 1614 to accommodate a portion of a universal joint of the flexible probe. The retainer has a substantially spherical external lower end surface 1615 which is engaged by the internal annular arcuate surface 1383 of another latch assembly 1300 which is connected with the bottom circulating valve 1700. The relationship between the lower end surface of the retainer 1609 and the upper internal arcuate surface on the upper end of the latch unit 1300 permits the latch unit and the lower packing assembly of the gas lift to move pivotally relative to each other while a universal joint of the flexible probe is positioned within the connection between the latch unit and the gas lift valve.

The gas lift valve 1500 is operable responsive to the pressure within its central bore. Prior to installation of the valve its dome chamber 1574 is charged with gas introduced through the bore of the plug 1575 and sealed therein by engagement of the core 1577 within the threaded section of the bore of the plug. The dome gas is introduced into the chamber until its pressure within the chamber is at a desired predetermined value to control the opening pressure of the valve. The dome gas introduced into the chamber 1574 flows downwardly through the longitudinal flow passages 1556 in the threaded section 1555 of the mandrel 1551, around the mandrel within the mandrel 1562 around the inner bellows 1559, around the tubular member 1557 within the flange 1563 into the outer bellows 1563a so that the dome gas chamber in effect extends downward around the inner bellows mandrel and the tube 1557 within the outer bellows to the solder joint 1567. The pressure of the dome gas is applied over an effective annular area determined by the difference between the areas of circles having diameters equal, respectively, to the mean effective diameters of the outer bellows and the inner bellows. Since the outer bellows is larger than the inner and below the inner bellows, the valve sleeve 1557, the member 1597 and related components are biased downwardly by a force determined by the dome gas pressures applied over this effective annular area. The force tending to bias the valve toward the open position is produced by the pressure within the central bore of the valve applied over the same effective annular area when the valve is at its open position. When closed the pressure in the valve bore acts on an annular area equal to the difference between the area of the circular line of sealing engagement between the seat member 1597 and the seat surface 1596 and a circle having a diameter equal to the effective diameter of the inner bellows. So long as the dome pressure is sufficient to overcome the pressure of fluid within the valve, the valve remains closed.

When the pressure within the valve bore increases to a sufficient value, the force resulting from the pressure on the movable valve elements moves the valve upwardly

to an open position. The valve tube 1557 moves upwardly with its upper end telescoping into the lower end section 1555 of the mandrel 1551 which remains fixed longitudinally and thus the inner bellows 1559 is compressed. The tube 1557 slides upwardly within the flange 1563 raising the retainer ring 1598, the valve face member 1597, the spacer 1600, and the valve ring 1564 to compress the outer bellows 1563. The valve face member is lifted to a spaced relationship above the seat surface 1596 of the valve seat member 1582. The spaced relationship of the valve face member above the valve seat member allows fluid flow inwardly through the lateral ports 1580 collapsing the check valve member 1586 inwardly along its upper end section 1593 around the upper end section of the valve seat member allowing inward flow through the ports 1580 upwardly around the valve seat member and inwardly between the upper end surface of the valve seat member and the lower end surface of the valve face member into the central bore of the valve. So long as the fluid pressure around the valve exceeds the fluid pressure within the central bore of the valve and such pressure is of sufficient magnitude to overcome the dome gas pressure the valve is held at its upper open position.

When the pressure within the central bore of the valve drops to a value insufficient to overcome the dome gas pressure, the dome gas pressure acting around the inner bellows downwardly within the outer bellows to the joint 1567 forces the tube 1557 downwardly expanding the inner and outer bellows and moving the valve face member 1597 back to seated relationship on the seat surface 1596 of the valve seat member. The check valve element 1592 prevents back flow of fluids from within the central bore of the valve outwardly from the valve through its lateral ports 1580. Any flow toward the ports 1580 expands the upper end section 1593 of the check valve outwardly against the inside edges of the fingers of the seat member 1585 shutting off flow through the longitudinal slots defined between the fingers of the member.

One gas lift valve 1500 with a latch unit 1300 is provided on the probe for each sliding sleeve valve in the production tubing. The gas lift valves and their latch units are arranged in end-to-end array on the flexible probe. Each latch unit below the one on the uppermost gas lift valve is engaged with the lower end of the gas lift valve on the probe immediately above it as illustrated in FIGURE 15.

Below the lowermost gas lift valve supported on the probe, a bottom circulating valve 1700 with a latch unit 1300 is releasably supported by the lower end section of the flexible probe. A bottom release assembly 1720 connected on the lower end of the bottom circulating valve releasably engages the bottom circulating valve on the flexible probe.

The bottom circulating valve 1700 is a modified gas lift valve 1500 adapted to permit fluid circulation in either direction through the side ports 1580 between the central bore of the valve and the annular space around the valve within the production tubing. The gas lift valve 1500 is modified by substitution of a tubular valve seat 1721 for the valve seat 1582 and removal of the flexible check valve 1586 and its retainer seat member 1585. As explained below, the gas lift valve adapted as a bottom circulating valve is also modified by addition of the bottom release assembly on the lower end of the valve in place of the retainer 1609. The valve seat member 1721 has a lower external annular recess 1722 which receives the flanges 1545 of the spider member 1544 on the upper end of the universal joint 1542a. The valve seat member has an upper external annular recess 1723 to receive the ring seal 1584 for sealing around the valve seat member within the lower reduced end section 1581 of the valve body 1578. An external annular flange 1724 is provided on the valve seat member providing a downwardly facing external annular shoulder 1725 which engages the

internal annular upwardly facing shoulder 1581b within the valve body 1578 thereby limiting the downward movement of the valve seat member. The valve seat member has an upper end external annular spherical seat surface 1726 which coacts with the concave spherical seat surface on the valve member 1597 for opening and closing the bottom circulating valve. With the exception of the substitution of the valve seat member 1721 for the seat member of the gas lift valve and the removal of the check valve and its retainer, all other components of the bottom circulating valve are identical to those of the gas lift valve 1500 described above.

The bottom circulating valve functions exactly as the gas lift valve responsive to fluid pressure within the tubing which applies an upward force on the movable components of the valve raising the valve member 1597 to a spaced relationship above the valve seat surface 1726 and permitting fluid flow between the bore of the valve and the annular space around it through the lateral ports 1580. So long as the pressure remains at a sufficient value, the valve remains at its upper open position permitting fluid flow in either direction since no check valve is included. Generally, the bottom circulating valve is inflated to a dome pressure higher than the maximum limit of the normal range of gas-lift pressure variations so that the valve will remain closed during all normal gas-lift operations. This dome pressure, however, is considerably under what the ambient pressure will be when either the casing on the tubing of the well is filled with fluid and operations with a pumped tool train are commenced requiring an open circulating system.

The bottom release assembly 1720, illustrated in FIGURES 17 through 17B, has a mandrel 1727 having an internally threaded upper end section 1728 secured on the lower reduced section 1610 of the bottom packing assembly 1604 on the bottom circulating valve. The mandrel 1727 has a thick-walled central section 1729 provided with a plurality of internal annular locking recesses 1730 which are adapted to receive locking flanges or teeth on a pulling link on the flexible probe, as explained hereinafter. The mandrel has a longitudinal rectangular slot 1731 which communicates at its upper end with a shallow outwardly opening recess 1732. A locking key 1733 is pivotally supported within the slot 1731 on a pin 1734 extending laterally through the mandrel perpendicular to the longitudinal axes of the mandrel and the locking key. Opposite end sections of the pin are received in holes provided in the mandrel on opposite sides of the slot. The outer face of the locking key comprises convergent edge surfaces 1735 and 1736 which converge from opposite ends of the key toward each other at a slight angle with each other joining along a line spaced slightly longitudinally below the pivot pin 1734. A leaf spring 1737 is secured along its lower end section 1738 in contact with the edge surface 1736 of the locking key by a pair of longitudinally spaced rivets 1739. The leaf spring is normally slightly curved or bent along its longitudinal axis to substantially conform to the contour of the outer edge face of the locking key so that when the key is in the position illustrated in FIGURE 17, the upper end section 1740 of the spring, which is prestressed inwardly, engages the mandrel surface 1732a defining a vertical inside face of the recess 1732 thereby biasing the key in a clockwise direction about its pivot pin 1734.

The locking key 1733 has an upper internal boss 1741 providing a downwardly facing lock shoulder 1742, a central internal boss 1743 providing an upwardly facing lock shoulder 1744, and a lower internal boss 1745 providing an upwardly facing lock shoulder 1746. A tubular bottom stop member 1747 telescoped into the lower end section of the mandrel bore is biased downwardly by a coil spring 1748 confined between the lower end surface 1749 of the mandrel and an upwardly facing external annular shoulder 1750 on a lower enlarged end section 1751 of the stop member. The tubular body section 1752 of

the bumper member has an upper rectangular longitudinal slot 1753 and a lower rectangular slot 1754. The upper end of the upper slot 1753 is defined by a downwardly facing lock surface 1753a, which at the position of the key illustrated in FIGURE 17, engages the lock shoulder 1744 on the central boss of the key to hold the bottom stop in the mandrel against the force of the compressed spring 1748. Also, at the position shown in FIGURE 17, the outer surface 1752a of the body 1752 of the bottom stop engages the inner face 1745a of the bottom boss on the locking key holding the key against clockwise rotation by its leaf spring. At such position, the upper boss 1741 on the key extends laterally inwardly above the upper end of the tubular member 1752 into the bore of the mandrel 1727 with the locking shoulder 1742 on the key engaging the locking shoulder 1238 on the bottom link 1235 of the flexible probe thereby releasably locking the release assembly on the bottom link of the flexible probe.

The assembly 1720 is releasable from the bottom link of the flexible probe by application of an upward force to the bottom stop 1747. Such an upward force compresses the spring 1748 telescoping the tubular body 1752 of the bottom stop into the mandrel until the upper edge surface 1754a defining the upper end of the lower slot 1754 is raised above the locking shoulder 1746 on the lower boss 1745 of the locking key. The spring 1737 pivots the locking key clockwise with the upper end of the locking key being moved laterally outwardly out of engagement with the locking flange shoulder 1238 on the bottom link of the probe and the bottom boss 1745 of the locking key being received within the lower slot 1754 of the tubular body section 1752 of the bottom stop. Depending upon the extent to which the spring 1748 is compressible, the bottom stop may telescope upwardly sufficiently for the upper end of the body 1752 to engage the surface 1742a on the upper boss of the locking key to cam the key clockwise aiding the spring 1737. When the force telescoping the bottom stop into the mandrel relaxes, the spring 1748 expands slightly biasing the bottom stop downwardly with the surface 1754a of the bottom slot 1754 engaging the locking surface 1746 on the lower boss of the locking key holding the bottom stop at its upper position against the spring 1748 and holding the locking key in its unlocked position within the recess 1731 disengaged from the bottom probe link. Subsequent to engagement with the pin collar in the production tubing which stops the tool train's downward movement and telescopes the bottom stop 1747 into the mandrel 1727, the bottom stop remains locked at its upward position by the key which is held at its vertical retracted position within the recess 1731. The locking key and bottom stop thereafter serve no further function unless the bottom circulating valve is subsequently removed and reinstalled in the tubing. As described in detail hereinafter the internal annular recesses 1730 in the mandrel 1720 receive a pulling tool for removing the bottom circulating valve from the tubing.

A sliding sleeve valve assembly 124 and its landing or locking nipple 125 in which each of the gas lift valves is positioned and locked by its latch unit is illustrated at its upper open position in FIGURES 19-19A and at its lower closed position in FIGURES 20-20A. Each sleeve valve and landing nipple unit comprises a section of the production tubing string 104 at each depth within the well at which a gas lift valve is desired in the gas lift system. Referring particularly to FIGURES 19-19A, an upper tubular mandrel 1820 and a lower tubular mandrel 1821 are connected together by a central sleeve or mandrel 1822. The upper mandrel has an internally threaded upper end section 1823 adapted to receive a lower threaded end section on the production tubing section immediately above the mandrel and the mandrel is further provided with an externally threaded lower end section 1824. The lower mandrel 1821 has a reduced externally threaded lower end or pin section 1825 for connection of the portion of the production tubing extending below the sliding

sleeve valve and reduced externally threaded upper end section 1826. The lower end section of the upper mandrel and the upper end section of the lower mandrel are threaded into the upper and lower end sections, respectively, of the central mandrel 1822.

The upper mandrel 1820 has an internal annular upper locking recess 1827 defined between a downwardly divergent upper shoulder 1828 and a lower upwardly divergent shoulder 1829 and a lower locking recess 1830 defined between an upper downwardly divergent shoulder surface 1831 the lower upwardly divergent shoulder surface 1832. The upper and lower locking recesses 1827 and 1830 are adapted to receive the locking bosses 1357 and 1358, respectively, on the locking dogs of a latch unit 1300. The locking recesses are longer than the dog bosses recesses sufficiently for the latch unit dogs to move outwardly into the recesses as the tool train moves so that the recesses will not be missed by the dogs. The shape and sizes of the latch unit dog bosses and the locking recesses are correlated so that the locking recesses 1827 and 1830 are the only combination of recesses in the production tubing which will receive the dog bosses so that the latch units are lockable only at the desired depth locations in the production tubing.

A longitudinally slidable sleeve 1833 extends through the central end portions of the upper and lower mandrels. The sleeve slides between an upper open position shown in FIGURES 19-19A and a lower closed position illustrated in FIGURES 20-20A. The sleeve has a plurality of longitudinal circumferentially spaced slots 1834 which are alignable with a plurality of longitudinal circumferentially spaced slots 1835 in the central mandrel 1822 when the sleeve is at its upper end position. The central mandrel has an internal annular packing 1836 for sealing around the sliding sleeve above the slots 1835. The packing 1836 is held against downward movement in the mandrel by engagement of its lower end surface with an internal annular upwardly facing shoulder 1837 provided in the mandrel and is limited against upward movement by engagement with the lower end surface 1838 on the reduced lower end section 1824 of the upper mandrel. A ring seal 1839 is received within an external annular recess 1840 around the lower reduced end section of the upper mandrel below its threads to prevent leakage along the connection between the upper and central mandrels. A ring seal 1841 is positioned below the slots 1835 between annular upper and lower female adapter 1842 and 1842a. The upper adapter is held against upward movement within the central mandrel by an internal downwardly facing annular shoulder 1843 provided in the mandrel. Below the lower female adapter an internal annular split ring 1844 is positioned within an internal annular recess 1845 of the central mandrel. The split ring comprises an annular ring structure having a radially inwardly extending flange 1846 for holding an internal annular packing 1847 within the central mandrel against upward movement and to prevent force applied to the packing 1847 by a pressure differential from being applied to the ring seal 1841. The packing 1847 is held against downward movement by the upper end surface 1848 on the reduced upper end section 1826 of the lower mandrel. A ring seal 1849 within an external annular recess 1850 of the reduced upper end section of the lower mandrel seals against leakage along the connection between the central and lower mandrels.

The sleeve 1833 includes a plurality of upwardly extending longitudinal circumferentially spaced locking fingers 1851 comprising its upper end section. Each of the locking fingers has an external transverse recess 1852. The recesses 1852 are in longitudinal alignment for receiving a snap ring 1853 positioned in an internal annular recess 1854 of the upper mandrel to releasably lock the sleeve at a lower closed position. Upward movement of the sleeve is limited by the engagement of the upper ends

1855 of the locking fingers with an internal annular downwardly facing shoulder 1856 provided in the upper mandrel. An internal annular recess 1857 is defined within the upper mandrel between the shoulder 1856 and a lower annular downwardly and inwardly convergent shoulder surface 1858. Below the shoulder surface 1858 a plurality of longitudinal recesses 1859 extend above and below the lock ring recess 1854 to provide passage for the dispersal of possible silt accumulation in the snap ring groove 1854 when the sleeve is shifted and the snap ring expanded into its groove.

The sliding sleeve has an external annular locking recess 1860 near its lower end to receive a snap ring 1861 supported in an internal annular recess 1862 in the lower mandrel for releasably locking the sliding sleeve at its upper open position. A plurality of longitudinal circumferentially spaced internal silt dispersing recesses 1863 are provided in the lower mandrel extending downwardly from the snap ring recess 1862 and opening at their lower end through a downwardly divergent shoulder surface 1864 defining the upper end of an internal annular recess 1865 which extends downwardly to an internal annular upwardly facing shoulder 1866. The lower end surface 1867 of the sliding sleeve is engageable with the shoulder 1866 limiting the downward movement of the sleeve.

The upper end of each of the collet fingers 1851 on the sliding sleeve has an internal downwardly and inwardly sloping cam surface 1868. The lower end of the sliding sleeve is provided with an upwardly convergent internal annular cam surface 1869.

The sliding sleeve 1833 has a set of upper internal annular recesses 1870 and 1871 which are adapted, respectively, to receive the bosses 405 and 406 on the shifting keys of the down-shift assembly for moving the sliding sleeve from its upper end position to its lower end position. The internal annular recess 1870 is defined between an upwardly and inwardly convergent cam surface 1872 and a lower internal annular shifting or lock shoulder 1873 which is engageable by the shifting shoulder surface 410 on the shifting keys. The recess 1871 is defined between an upwardly and inwardly convergent cam surface 1873 and a downwardly and inwardly convergent cam surface 1875.

The sleeve 1833 has a lower set of sleeve shifting recesses 1876 and 1877 which receive the bosses 405 and 406, respectively, on the up-shift keys of the up-shift assembly for moving the sleeve from its lower to its upper end positions. The recess 1876 is defined between a lower downwardly and inwardly convergent cam surface 1878 and an upper downwardly facing internal annular sleeve shifting shoulder 1879 adapted to be engaged by the sleeve shifting shoulder 410 on the up-shift keys. The recess 1877 is defined between a lower downwardly and inwardly convergent annular surface 1880 and an upwardly and inwardly convergent annular surface 1881.

At the upper end position of the sliding sleeve 1833 it is releasably secured against downward movement by the radially inwardly biased snap ring 1861 which is received in the annular snap ring recess 1860 of the sleeve. At this upper position fluid may flow in either direction between space around the central mandrel and the bore 1833a through the sliding sleeve assembly. Fluid flows through the central mandrel slots 1835 and the sliding sleeve slots 1834 which at this upper end position are longitudinally aligned with each other. At its lower end position the sleeve 1833 is held against downward movement by the engagement of its lower end surface 1867 and the lower mandrel shoulder 1866 while it is releasably locked against upward movement by the snap ring 1853 which is biased radially inwardly into the locking recesses 1852 on the locking fingers 1851. At such lower end position the sleeve slots 1834 are positioned below the packing 1847 thereby preventing communication through the slots 1835 into the central bore of the sliding sleeve.

The sleeve 1833 is provided with upper and lower reduced bore portions 1833b and 1833c to receive the upper and lower packing 1536 and 1536a, respectively, of the gas lift valve assembly 1500 and are so longitudinally spaced in relation to the latch dog recesses 1827 and 1830 that when the sleeve 1833 is in the upper, open position and the latch assembly 1300 locked in the nipple 1821, the packing 1536 and 1536a are wholly accommodated along the surfaces 1833b and 1833c, respectively.

The recess 1857 in the upper mandrel 1821 of the sleeve valve assembly is of sufficient bore and length to let the feeler 354 of the monitor unit 301 of the down-shift assembly swing outwardly and effect the release of its trigger mechanism.

Similarly the enlarged bore 1865 in the lower nipple 1822 is adequate to effect the release of the trigger mechanism of the up-shift assembly.

The bottom circulating nipple 124 is included in the production tubing to support the bottom circulating valve 1700 and permit circulation in either direction between the production tubing and the annulus 111. The bottom circulating nipple, FIGURES 20 and 20A, includes an upper tubular section 1900 and a lower tubular section 1901. The upper section has an upper end internally threaded box section 1902 to receive the lower end of the production tubing section above the nipple and a lower end externally threaded pin section 1903 threaded into an upper internally threaded box section 1904 of the lower section which has a reduced lower end externally threaded pin section 1905 for connection of a production tubing string section extending downwardly from the nipple. The section 1900 has a pair of longitudinally spaced internal annular latch recess 1907 and 1907a for receiving the locking bosses on the latch unit 1300 of the bottom circulating valve. The locking recesses 1907 and 1907a correspond in configuration and size to the previously described locking recesses 1827 and 1830 of the sliding sleeve valve.

The lower section 1901 of the bottom circulation nipple has a plurality of longitudinal circumferentially spaced slots 1908 along an enlarged bore section 1901a to permit fluid communication between the bore of the nipple and the space surrounding the nipple. The bore of the upper section of the nipple is reduced along a long end section to provide an internal tubular seating surface 1909 adapted to receive the upper annular packing 1536 on the bottom circulating valve while the bore of the lower section of the nipple is reduced along a lower end section providing a similar internal tubular seating surface 1910 to receive the lower annular packing 1536a on the bottom circulating valve so that seals are effected within the nipple above and below the valve side ports 1580 and the nipple ports 1908, when the latch assembly 1300 on the valve is latched at the recesses 1907 and 1907a. Fluid thus flows to and from the valve side ports through the nipple ports 1908.

The bottom circulation nipple is positioned within the production tubing above the pin collar 126 at a distance which permits the bottom stop member on the bottom release of the bottom circulating valve to strike the pin collar while the upper propulsion piston unit in the tool string is above the circulation slots 1908 in the bottom circulation nipple so that fluid may be pumped into the slots of the circulation nipple will lift the tools upwardly.

The first phase in the installation of the gas lift valves 1500 and the bottom circulating valve 1700 is a gas lift system embodying the invention is the assembly of the tool train 140 to prepare it for insertion into the lubricator section 114a of the flow conduit connected with the production tubing 104. The flexible probe 1200 is assembled by interconnecting a plurality of the various links illustrated in FIGURES 18 and 18A, the uppermost link 1223 being secured with the head assembly 1210 of the probe with the bottom link comprising a running link 1235. A sufficient number of intermediate links are installed in the probe between its top and bottom links to adapt it to the combined length of the total number of gas lift valves

1500 with their latch units 1300 and a bottom circulating valve 1700 with its latch unit oriented in end-to-end array. An intermediate link having a locking collar 1225 for engagement with the latch cleat of each latch unit is positioned in the probe at the location to be occupied by each latch unit when the gas lift and bottom circulating valves are all installed on the probe. Also, the various probe links are interconnected to provide a universal joint connection, as by inclusion of a probe link 1230, aligned within each of the universal joint connections within the gas lift and bottom circulating valves and between the valves and their latch units. In other words, at each location along the probe where bending occurs within and between the components supported on the probe the probe itself must be adapted to bend accordingly.

The desired number of gas lift valves and their latch units are sequentially positioned and releasably locked on the probe with the bottom circulating valve and its latch unit being the last of the assembly to be placed on the probe. The first gas lift valve with its latch unit positioned on the probe adjacent to the head assembly 1210 is the valve which is last removed within the well and thus occupies the top or uppermost sliding sleeve valve within the well tubing.

The dome chamber 1574 of each gas lift valve is charged with a gas introduced through the plug member 1575 until the desired pressure is established within the chamber at which time the enclosure plug 1577 is threaded into the plug 1575 to seal the dome gas within the chamber. The dome gas chamber is charged to the pressure required to permit the opening of the gas lift valve by the hydrostatic pressure in a liquid column of a predetermined height above the valve within the production tubing.

The first gas lift valve and its latch unit are releasably locked on the probe in the following manner. The latch unit dogs 1351 and 1352 are compressed manually inwardly around their support mandrel 1320 while the sleeve or cage 1380 of the latch unit is telescoped downwardly over the upper end sections of the dogs until the lower end of the head section of the sleeve engages the upper ends of the upper bosses 1357 on the dogs to hold them in their retracted position for movement through the well production tubing. The latch cleat lock pin 1426 is manually positioned within its slot 1333 at a lower end location so that the latch cleat 1418 may be pivoted laterally outwardly to permit passage of the flexible probe through the bore of the latch unit. The lock pin 1426 is manipulated by insertion of a tool such as a screwdriver through the hole 1395 and the longitudinal slot 1394 in the sleeve. After the latch pin is moved to its lower end position within its recess the biasing force of the springs 1416 against the latch cleat ring 1412 pivots the latch cleat about its line of contact 1421 with the sleeve head section with the free end of the cleat being moved laterally outwardly until it engages the inside surface of the head section of the sleeve 1380. The gas lift valve with its latch unit is placed over the free lower end of the flexible probe and moved along the probe until the spherical end surface 1383 on the head section of the sleeve of the latch unit engages the spherical end surface of the retainer 1218 on the head assembly of the flexible probe. The locking shoulder 1225 on the top link of the probe is located below the lower end locking surface 1423 of the latch cleat. The latch cleat is pivoted inwardly by insertion of a suitable tool, such as a screwdriver, through the hole 1413 engaging the latch cleat with the locking shoulder 1225 on the top link of the probe. The latch cleat locking pin 1426 is moved upwardly in its recess until its bosses 1428 on its flexible prongs 1427 spring outwardly into the lateral or side recesses 1334 thereby releasably locking the latch cleat 10 at its upper end position at which its end section 1425 is positioned between the free end of the latch cleat and the inside surface of the head of the latch unit sleeve holding the latch cleat in locking engagement with the

flexible probe and thereby releasably locking the latch unit and its gas lift valve on the flexible probe.

The next gas lift valve and its latch unit are prepared for placement on the probe in the manner described above with the dome chamber of the valve being charged to the required pressure for the depth at which it will function in the production tubing. With the latch unit of the gas lift valve being introduced on the probe first the latch unit and the gas lift valve are moved along the probe until the upper end spherical section surface 1383 on the latch unit sleeve is engaged with the lower end spherical section surface 1615 on the bottom retainer 1609 of the first gas lift valve installed on the probe. The locking of the latch unit by its latch cleat to an intermediate link of the probe by engaging the latch cleat with the locking shoulder 1225 on such probe link is completed in exactly the same manner as the installation of the first gas lift valve and its latch unit.

It will be recognized with respect to each latch unit, and as explained in detail in connection with the detailed description hereinabove of the latch unit, that in its locked position on the probe the latch unit mandrel 1320 is at its compressed upper end position relative to its sleeve 1380 at which position the upper ends of the lock fingers 1403 on the lock member 1396 are spaced below the lower ends of the locking dogs of the latch unit as illustrated in FIGURE 13. When all of the gas lift valves and their latch units have been releasably locked on the flexible probe, the bottom circulating valve 1700 is similarly releasably locked on the probe with the bottom circulating valve being held at an upper position on the probe to maintain the mandrel of its latch unit compressed telescopically upwardly into its sleeve by the releasable engagement of the bottom release assembly 1720 with the bottom link of the flexible probe. The bottom stop 1747 is telescoped into the lower end of the mandrel 1727 until the locking key 1733 is pivoted clockwise with its lower end boss 1745 moving into the lower window 1754 of the stop. The stop is held at its inward position by engaging the locking surface 1746 on the boss 1745 with the upper locking surface 1754a at the upper end of the slot 1754 in the stop. With the key 1733 so positioned, the upper boss 1741 on the key is positioned in the mandrel longitudinal slot 1731 such that the bottom circulating valve is compressed upwardly until the locking surface 1742 on the lower end of upper boss 1741 of the locking key is slightly above the locking shoulder 1238 on the bottom link of the flexible probe. The bottom stop 1747 is then compressed slightly inwardly to release the key 1733 which is manually rotated about its pivot pin 1734 with its upper end moving laterally inwardly until its locking surface 1742 engages the locking shoulder 1238 on the bottom link of the probe. The bottom stop is released with the expansion force of its spring 1748 forcing the stop outwardly from the mandrel 1727 until the locking surface 1753a at the upper end of the window 1753 in the stop engages the locking shoulder 1744 on the upper end of the central boss 1743 of the locking key so that the locking key is locked on the bottom link of the flexible probe. The surface 1752a on the bottom stop engages the inside surface 1745a on the lower boss on the locking key thereby holding the locking key at its locked position against pivotal movement about its pivot pin 1734. Thus, the flexible probe with the desired number of gas lift valves and a bottom circulating valve releasably locked thereon is prepared for coupling with the remainder of the tool train and insertion into the production tubing of the well bore.

Alternatively, all of the gas lift valves and the bottom circulating valve with their latch units may be placed on the probe in the desired order, compressed longitudinally, and locked on the probe by the bottom stop. The latch cleat of each latch unit 1300 is then moved inwardly and locked by the pin 1426 to lock the latch unit on the probe.

The remainder of the tool train including one or more

upper piston propulsion units 200, the down-shift assembly 300, a detent unit 700, the up-shift assembly 1000, and one or more lower piston propulsion units 200 are interconnected together with couplers 260 in the relationship illustrated in FIGURE 1.

Prior to connection of the piston units 200 in the tool train the valve assembly 204 of each of the units is adjusted by selection and installation of its springs 215 which hold the valve at its closed position until a desired predetermined pressure differential is applied across the piston unit. As previously discussed, the piston units are adjustable to permit them to generate a desired amount of thrust responsive to a fluid pressure differential applied across them and to permit fluid to bypass through them when such pressure differential is exceeded to minimize the probability of tool damage if obstructions are encountered in the conduit through which the piston units are moving. Also, the tool train during its upward movement will span sliding sleeve valves which permits circulating fluid to pass into the production tubing between the upper and lower piston units. Since the lower piston units are below the up-shift assembly in the tool train each sliding sleeve valve is moved to its open position after passage of the upper piston units and before arrival of the lower piston units leaving an open sleeve between the upper and lower piston units. The upper piston unit or units are therefore adjusted to provide a sufficient amount of thrust in excess of the thrust developed by the lower piston unit or units to lift the tool train upwardly past each of the sliding sleeve valves after the valve has been returned to its open position, as explained in detail hereinafter. For example, in one particular application of a tool train in accordance with the invention, the upper piston unit 200 was provided with valve springs permitting it to generate 704 pounds of thrust under operating conditions while the lower piston unit was provided with valve springs permitting it to generate approximately 535 pounds of thrust under the same operating conditions. Also, the detent unit 700 is adjusted by selection of a main spring which permits the detent unit to releasably hold the tool train against upward and downward movement against a force sufficient to effect activation of the down-shift and up-shift assemblies. Also, the detent unit resistance must obviously be less than the maximum thrust applied by each piston unit so that the tool train is moved against the holding resistance of the drag unit. In the above cited specific examples of the thrust adjustments of the upper and lower piston units, the detent unit is provided with springs to provide approximately 500 pounds of resistance to both upward and downward movement of the tool train.

The piston units are interconnected with the up-shift and down-shift assemblies which are connected with the detent unit by the couplers 260. Specifically the upper piston unit is connected with the down-shift assembly by a coupler 260. The down-shift assembly is connected with the detent unit and the detent unit with the up-shift assembly by couplers 260. The up-shift assembly is then secured with the lower piston unit or units which are in turn secured with the head assembly of the flexible probe by couplers 260.

As previously explained in detail, a connection is made with a coupler 260 by longitudinally shifting the two coupler elements 261 and 262 in opposite directions relative to each other with the coupler members each being moved so that the longitudinal male member or boss on one of the members moves toward the female recess 284 of the other member at the end to be connected with the socket chamber of the particular tool train unit in question. When the members of the coupler are shifted a sufficient distance relative to each other the adjacent ends of the members at the end of the coupler at which the male boss moves into the female recess are compressed together so that the locking lugs or bosses 269 and 277 are closer together and are inserted into the socket cham-

ber of the unit of the tool train to which the coupler is being connected. The coupler members are then released allowing their spring to realign them so that the male boss moves out of the female recess expanding the locking flanges on the coupler end in the socket chamber of the tool train unit. After the portion of the tool train has been assembled extending from the top piston unit through the lower piston unit, the lower end of the lower piston unit and the head assembly of the flexible probe are interconnected by a coupler 260.

The entire assembly of the tool train may be carried out with the various tools resting in a trough or tray, not shown, positioned adjacent to the lubricator section 114a of the flow conduit. For example, such a tray may comprise a half cylinder structure such as a longitudinally split section of pipe having a sufficient diameter to accommodate the largest of the units of the tool train. Preferably an end of the tray is supported at and aligned with the end of the lubricator on which the cap 120 is secured. When the tool train is completely assembled as described above and with the valve 122 and 115 closed to isolate the lubricator, the end cap 120 is removed and the tool train is inserted into the lubricator with the bottom circulating valve being the first of the units to be introduced and the uppermost piston unit being the last. The dogs of the detent unit 700 when in the open air, are expanded from which position an axial thrust of 500 pounds is normally required before the dogs will swing in and allow the unit to slide freely inside the conduit. To avoid this necessity on entering the surface lubricator, the trigger assembly 703 of the detent unit can be manually deflected until its trigger sear 900 is clear of the sears 912 and 914 when the dog cage and dogs can be manually slid along the mandrel recesses until the clog bosses 770 and 771 drop into the mandrel recesses 791 through 794. The dogs can then be manually held in this contracted position while being entered into the lubricator. After the tool train is introduced into the lubricator, the end cap 120 is reinstalled on the open end of the lubricator and the valves 115 and 122 are opened to permit circulation into the lubricator behind the tool train. Fluid is pumped through the conduit 121 into the lubricator to displace the tool train from the lubricator into the conduit 114 and through the conduit 114 into and downwardly through the production tubing string 104. The pressure of the fluid being pumped into the system through the conduit 121 is raised to a value sufficient to establish a pressure differential across the piston units at a value high enough to effect a thrust which overcomes the frictional resistance of the keys 728 and 728a on the detent unit and the seat assemblies on the piston units. The locking dogs on the latch units 1400 and the shifting and monitoring keys of the up-shift and down-shift units are locked at their inward positions and thus do not affect the resistance to the movement of the tool train through the conduit 114 and the production tubing. Of course, along the entire length of the tool train its various units slide along different surfaces in the flow conduit causing some frictional resistance to movement of the tool train. As stated, however, the principal resistance to movement of the tool train is provided by the detent unit keys and the seal assemblies of the piston units.

For purposes of this discussion of the installation of the bottom circulating and gas lift valves, the sliding sleeve 1833 of each of the sliding sleeve-valve units 123 shall be presumed at its upper open position. Therefore, to maintain circulation behind the tool train to pump it to its lowermost position in the production tubing each of the sleeve valves must be closed as the tool train passes each sleeve valve. Otherwise, the propelling fluid circulates outwardly behind the tool train from the production tubing through the ports of the sleeve valve thus bypassing the tool train so that it is not moved by the fluid. The tool train moves downwardly through the production tubing until it arrives at the uppermost sliding sleeve valve 123

with the array of gas lift and bottom circulating valves on the flexible probe moving downwardly through the sliding sleeve valve. The lower piston unit or units and the up-shift assembly also pass through the sliding sleeve valve. The tool train units up to the detent unit are so free to pass the sleeve valve since all of the locking dogs on the latch units of the bottom circulating and gas lift valves along with the shifting keys and monitoring keys on the up-shift assembly are fully retracted.

When the detent unit arrives at the uppermost sliding sleeve valve it moves downwardly through the sleeve valve until the bosses are aligned with the internal annular recess 1865 below the lower end of the upwardly positioned sleeve 1833.

The external bosses 990 and 990a on its dogs 728 and 728a pass the various annular recesses in the sleeve valve above the recess 1865 since they are longer than such recesses. The detent unit dogs 728 and 728a, which have been sliding along and held against further outward expansion by the inside surface of the various production tubing sections through which the tool string is pumped, spring outwardly when they are aligned with the locking recess 1865. The bottom cam surfaces 992a on the lower ends of the detent unit dogs engage the internal annular shoulder 1866 at the lower end of the locking recess 1865 and due to the outward expansion of the detent unit dogs its mandrel is shifted until the inner bosses 770 and 770a are aligned with the mandrel bosses 796 and 796a at the upper end of the dogs and the inner dog bosses 771 and 771a at their lower ends are aligned with the mandrel bosses 797 and 797a thereby holding the locking dogs in their outward locked position so that the entire tool train is releasably held against further downward movement by the locking dogs on the drag unit. The holding of the tool train by the detent unit is detectable at the surface by a pressure increase in the fluid being pumped to displace the tool train. The pressure of the fluid being pumped into the production tubing is increased to increase the pressure differential across the upper piston unit 200 causing the piston unit to apply more downward force on the tool train which, of course, is being held by the drag unit by engagement of its locking dogs in the recess at the lower end of the uppermost sliding sleeve valve. The application of downward force by the upper piston unit and the opposition of such downward force by the detent unit forces the piston unit toward the detent unit to reduce the slack between the piston unit and the detent unit with the end sections of each of the couplers 260 telescoping into their respective end socket chambers so that an essentially solid relationship is established between ends of connected adjacent units of the tool train. For example the upper end of the down-shift assembly and the lower end of the piston 200 are connected substantially solidly through the members 261 and 262 of the couplers by engagement of the lower end surface of the bottom socket 205 of the piston with the shoulders 267 and 275 on the coupler member while the upper end of the top socket 303 on the down-shift assembly is engaged by the bottom shoulder surfaces 267 and 275 on the coupler members. After the slack within the tool train between the upper piston unit and the detent unit is so reduced, the downward force of the piston unit compresses the down-shift assembly. Downward force on the top connector socket 303 of the assembly telescopes the reduced neck section 306 downwardly through the retainer cap 310 to activate the down-shift assembly as previously described in detail. While the lower end of the down-shift assembly is held against downward movement, the reduced section 306 forces the slider 308 downwardly against the spring 431 compressing the spring until the slider sear plate 333 is below the trigger sear plate 363 with the trigger biasing spring 371 forcing the trigger and its sear plate into locking engagement with the slider to hold the slider at such lower end position. The downward movement of the slider releases the keys 400 which are biased outwardly by their springs 402. Also,

the downward movement of the slider from the trigger arm 350 permits the trigger to pivot counter-clockwise which releases the monitor feeler 354 to be biased outwardly by its spring 375, as previously explained, against the inner surface of the tubing and sliding sleeve valve assembly. Thus, the down-shift keys 400 and the monitor feeler 354 of the down-shift assembly are released and biased outwardly against the inside surfaces of the sliding sleeve while the entire tool train is held against downward movement by the dogs on the detent unit. At this stage the keys 400 are above the sliding sleeve of the sleeve valve and thus have not yet engaged it.

After the socket 303 of the down-shift has been fully compressed downwardly against the retainer 310 of the monitor unit 301, the tool train is not further compressible between the piston propulsion unit and the detent unit and thus the thrust applied by the piston unit is transmitted through the several units in the tool string to the dogs of the detent unit. The pressure differential across the upper piston unit is further increased to increase the thrust to the value required for releasing the detent unit. The springs 957 and 966 of the detent unit are compressed along with the movement of the trigger mechanism of the detent unit to its inoperative position to release its control rod which is suddenly shifted downwardly by its springs to align its upper mandrel recesses with the inner bosses of its dogs at which time the shoulder 1866 of the sliding sleeve valve assembly engaging the lower end cam surface 992 and 922a on the detent unit dogs cams the dogs inwardly releasing the detent unit for further downward movement. This release of the detent unit occurs when the downward thrust on the unit exceeds the value for which the drag unit is adjusted, such, for example, as the previously mentioned valve of 500 pounds.

Upon release of the detent unit by the inward camming of its dogs, the entire tool train resumes downward movement and when the down-shift key bosses 405 and 406 on each of the downshift keys are aligned with the recesses 1870 and 1871, respectively, of the sleeve 1833, the springs 402 biasing the keys outwardly expand the keys into the sleeve recesses effecting engagement of the down-shift shoulder 1873 of the sleeve by the down-shift shoulders 410 on the keys. The downward movement of the tool train is now resisted by the sleeve 1833 by virtue of the engagement of the sleeve by the down-shift keys. When the sleeve snap ring 1861 is cammed radially outwardly from its recess 1860 farther into the mandrel recess 1862 and the resistance of the packing around the sleeve within the mandrels is overcome, the sleeve moves downwardly to its lower end closed position, FIGURES 20-20A, at which its lower end surface 1867 approaches the shoulder 1866 in the lower mandrel. Before the sliding sleeve reaches its lower end position, its snap ring 1853 snaps inwardly into the locking recesses 1852 on the collet fingers 1851 at the upper end of the sliding sleeve to releasably lock the sliding sleeve at its lower position.

The downward movement of the sleeve uncovers the recess 1857 of the upper mandrel above the upper end of the sleeve while simultaneously the downward movement of the down-shift assembly with the sliding sleeve aligns the feeler 354 of the monitor unit 301 with the uncovered recess 1857 so that the outwardly biased feeler is pivoted laterally clockwise about its pivot pin 366 by the spring 375 moving the upper end section of the feeler into the recess 1857. The pin 372 of the feeler lifts the trigger 347 pivoting it counter-clockwise about its pivot pin 348 disengaging the trigger seat plate 363 from the slider seat plate 333 thereby releasing the slider 308 to be returned to its upper end position by the expansion of the compressed spring 431. The spring 431 expands moving the slider upwardly lifting the down-shift key retractors 414 retracting the keys 400 into their windows 395 thereby disengaging them from the sliding sleeve 1833 and locking them inwardly against their springs 402. The upward movement of the slider also pivots the

trigger 347 clockwise so that it engages the pin 372 of the feeler 354 pivoting the feeler counterclockwise back into its window 316 against the spring 375 to its fully retracted position completing the deactivation of the down-shift assembly and the downward movement of the sliding sleeve 1833. The slots 1834 of the sliding sleeve are at their lower closed position below the annular packing 1847. After the downward shifting of the sliding sleeve and the de-activation of the down-shift assembly by disengagement of its down-shift keys from the sliding sleeve, the tool train is thus free to resume its downward travel and it accordingly continues downward until the dogs 728 and 728a of the detent unit are aligned with and expand outwardly into the recess 1865 of the next sliding sleeve valve down the production tubing where the above described procedure of compressing the down-shift assembly to activate it, engaging the down-shift assembly with the sliding sleeve, moving of the sliding sleeve to its lower closed position, and the subsequent deactivation and disengagement of the down-shift assembly is once again repeated. This sequence of operation of the detent unit and the down-shift assembly is carried out each time the tool train passes through a sliding sleeve valve.

If, during its downward travel, the tool train moves into a sliding sleeve valve whose sleeve is already at its downward closed position the detent unit dogs expand into the recess 1857 at the upper end of the downwardly positioned sliding sleeve causing the tool train to be restrained against downward movement and effecting compression and activation of the down-shift assembly. In accordance with the previous description of its operation, the detent unit releases after the down-shift assembly is activated and the tool train resumes downward movement until the down-shift keys of the down-shift assembly are aligned with and expand into the sleeve recesses 1870 and 1871. Since the sleeve 1833 is already at its downward position, the recess 1857 is uncovered and the sleeve cannot be moved farther downwardly. Thus, simultaneously with the expansion of the down-shift keys into their recesses of the sliding sleeve the feeler on the monitor unit expands into the recess 1857 to effect immediate retraction of the down-shift keys and deactivation of the down-shift assembly so that the tool train is immediately released to resume downward movement. Thus, the encountering of a previously down-shifted sliding sleeve by the tool train merely effects only momentary interruptions in the downward movement of the tool train while the down-shift assembly is activated and subsequently deactivated without disturbing the position of the closed sliding sleeve.

After the tool train has sequentially passed through and closed each of the sliding sleeves in the production tubing it continues downward travel until its bottom stop 1747 on the release assembly of the bottom circulating valve engages the pin 130, FIGURE 2, of the pin collar 126 limiting further downward movement of the entire tool train and telescoping the stop into the mandrel 1727 compressing the spring 1748 and moving the tubular section of the stop upwardly aligning its slot 1754 with the inner boss 1745 of the key 1733. The key is pivoted about its pin 1734 in a clockwise direction by the spring 1737 and the camming action of the upper end surface of the tubular member 1752 with the cam surface 1742a of the key disengaging the locking shoulder 1742 on the key from the lock shoulder 1238 on the bottom link of the flexible probe. The locking surface 1746 on the bottom boss of the key 1733 engages the surface 1754a in the lower slot of the tubular member 1752 locking the bottom stop at its upper position while the key remains deactivated in the recess 1731.

The abrupt stoppage of downward travel of the tool train causes a pressure increase in the production tubing above the tool train transmitting a pressure pulse to the surface thereby indicating arrival of the tool train at

its lower end position at which time the fluid flow direction is reversed by manipulation of the necessary valves to connect the conduit 112 into an input conduit with fluid return coming from the production tubing above the tool train through the conduits 114 and 121 so that the tool train may be pumped upwardly in the production tubing. Fluid is thus pumped downwardly in the casing around the production tubing, inwardly through the slots 1908 in the nipple 124, and upwardly to the surface through the production tubing.

The release of the bottom release assembly 1720 from the bottom flexible probe link frees the bottom circulating valve 1700 for downward movement on the probe to an intermediate locked position of its latch unit. The bottom circulating valve 1700 and its latch unit 1300 are interconnected by the universal joint at the upper end of the bottom circulating valve so that the latch unit and valve function together as an assembly with the latch unit serving to releasably lock the assembly in the bottom circulation nipple. Thus, the release of the valve from the probe frees the mandrel of the latch unit to move downwardly since the upper spider members of the universal joint at the lower end of the latch unit have inner flanges engaged with the latch unit mandrel which holds the latch unit mandrel compressed upwardly so long as the bottom circulating valve is locked on the bottom link of the probe. Thus, the springs 1416 are biasing the sleeve 1380 and the mandrel 1320 of the latch unit longitudinally in opposite directions so that with the release of the compressive force holding the bottom circulating valve and the mandrel of the latch unit telescoped upwardly with respect to the sleeve of the latch unit, the latch unit mandrel and bottom circulating valve are held downwardly by the springs 1416 relative to the sleeve while the reverse fluid circulation lifts the tool train along with the flexible probe causing the sleeve 1380 of the latch unit along with the latch cleat ring 1412 and its interconnected latch cleat 1418 to move upwardly relative to the latch unit mandrel until the upper ends of the lock fingers 1403 on the lock member 1396 of the latch unit strike the lower end of the latch unit dogs 1351 and 1352. The relative upward movement of the sleeve 1380 releases the latch unit dogs which are biased outwardly into engagement with the inside wall of the tubing while the latch unit remains locked on the probe. Since the bottom circulating valve and its latch unit are in the production tubing below the bottom circulation nipple 124 the latch unit dogs may not move to their maximum expanded position as their bosses 1757 and 1758 engage the inner surface of the production tubing. Therefore, with the latch unit dogs held at an intermediate inward position, by the tubing wall when the sleeve of the latch unit moves upwardly relative to the latch unit mandrel lifting the locking member 1396, the fingers of the locking member strike the lower ends of the latch unit dogs limiting the further movement of the latch unit sleeve to its intermediate position at which the upper end section of the sleeve is telescoped from the upper end sections of the dogs but the lock pin 1426 of the latch cleat 1418 remains at an intermediate longitudinal position holding the cleat in the locked position with respect to the link of the flexible probe on which the latch unit is releasably secured. Therefore, the latch unit dogs are biased outwardly against the inside wall of the production tubing while the latch unit sleeve is held by the fingers 1493 to an intermediate position which retains the latch unit in its locked relationship on the probe.

With the bottom circulating valve and its latch unit now at their intermediate locked position on the flexible probe, the tool train is lifted.

If the lower end position of the tool train in the production tubing is at a location at which the lower piston is below the bottom circulation nipple, the tool train may still be pumped upwardly. The valve in the upper piston unit moves to its bypass position at a pressure differential

substantially above the bypass pressure of the lower piston so that when fluid is injected between the units at a pressure above the bypass pressure of the lower unit the upper piston develops an upward thrust exceeding the downward thrust of the lower piston unit to lift the tool train.

The tool train moves upwardly passing through the bottom circulation nipple until the bosses 1357 and 1358 on the dogs of the latch unit of the bottom circulation valve are aligned with the locking recesses 1906 and 1907, respectively of the bottom circulation nipple. The latch unit dogs expand laterally outwardly from their mandrel releasing the latch unit from the flexible probe and locking the latch unit in the bottom circulation nipple. The outward movement of the locking dogs spaces them sufficiently laterally from the mandrel of the latch unit mandrel to allow the fingers 1403 on the lock member 1396 to be inserted between the dogs and the mandrel to both lock the dogs outwardly and permit the necessary longitudinal movement between the mandrel and the sleeve of the latch unit for release of the latch cleat from the flexible probe. With the locking dogs expanded outwardly into the bottom circulation nipple recesses, the springs 1416 exert a downward force on the upper end of the mandrel 1320 holding the mandrel along with its locking dogs against upward movement while the upward movement of the tool train including the flexible probe lifts the sleeve 1380, the latch cleat ring 1412, and the latch cleat 1408 upwardly relative to the mandrel of the latch unit with the lower end of the latch cleat moving above the latch cleat lock pin 1426 which is held by its bosses 1428 against upward movement in the mandrel. When the lower end section of the latch cleat is above the upper end section of the latch cleat lock pin, the springs 1416 acting on the latch cleat ring pivot the latch cleat about its pivot line of contact with the inside shoulder of the sleeve at its upper end moving the lower free end of the latch cleat laterally outwardly out of engagement with the locking flange 1225 on the flexible probe releasing the flexible probe from the latch unit. The tool train continues upward travel in the production tubing withdrawing the flexible probe from the bottom circulation valve and its latch unit leaving the latch unit releasably locked in the bottom circulation nipple and the bottom circulating valve supported from the latch unit with its upper and lower packing assembly positioned in the seat sections 1909 and 1910 of the bottom circulation nipple and the valve assembly of the bottom circulation valve aligned with the slots 1908 to permit fluid circulation through the slots into the bottom circulating valve through its valve assembly. The force provided by the springs 1460 continuously biases the mandrel and the sleeve of the latch unit on the bottom circulating valve in the opposite longitudinal directions so that the fingers 1403 on the lock member 1396 connected with the sleeve are held between the locking dogs and the latch unit mandrel to lock the latch unit in the bottom circulation nipple.

When the latch unit of the bottom circulation valve is fully released from the probe the latch unit holding the lowermost gas lift valve 1500 on the probe is released to its intermediate locked position as the upper end surface 1383 at the upper end of the latch unit on the bottom circulating valve is no longer in engagement with the lower end surface 1615 on the lower end of the lowermost gas lift valve. Thus, the lowermost gas lift valve drops on the probe until the lower ends of its latch unit dogs engage the upper ends of the lock fingers 1403 at which position the dogs are released to expand against the inside wall of the tubing while the latch unit sleeve and mandrel are held at a position which retains the latch unit locked on the flexible probe until the latch unit arrives at the lowermost sliding sleeve valve.

As previously indicated, the dome gas chamber of the bottom circulating valve is charged to a pressure level at which the hydrostatic pressure in the well at the depth of

the bottom circulating valve is sufficient to hold the valve at its open position. When the bottom circulating valve is seated within its nipple 124 its valve assembly is held at the open position by the liquid in the well at the nipple thus permitting the required reverse circulation of fluid from the annular flow passage in the casing around the production tubing inwardly through the slots 1908 in the nipple into and through the open valve assembly of the bottom circulating valve. The fluid flows upwardly through the valve into the production tubing to lift the tool train upwardly in the tubing for its return to the surface during which the sliding sleeves are each returned upwardly to its open position and a gas lift valve is releasably locked in each of the sleeves.

After the bottom circulating valve with its latch unit is released from the flexible probe and locked in the nipple 124 the lowermost bottom circulating valve with its latch unit moves to its intermediate locked position on the flexible probe. The tool train, including the flexible probe and all of the gas lift valves, is pumped upwardly from the bottom circulating valve until the external bosses on the locking dogs of the detent unit are aligned with and engage the internal annular recess 1857 at the upper end of the downwardly positioned closed sliding sleeve in the lowermost of the sliding sleeve valves. The top piston unit along with the down-shift assembly which has its monitor feeler and down-shift keys in retracted position pass without interference through the lowermost sliding sleeve. With the locking dogs on the detent unit aligned with the recess 1857 in the sleeve valve mandrel the dogs expand outwardly releasably engaging the detent unit with the sleeve valve and thus holding the tool train against further upward movement. A pressure signal is transmitted to the surface through the fluid being pumped into the annular space for displacing the tool train upwardly thus indicating the presence of the tool train at the sliding sleeve. The pressure of the fluid being pumped into the annular space is increased by the added resistance of the locking of the detent unit in the sliding sleeve so that the lower piston unit compresses the tool train below the detent unit until the slack is absorbed between the several components of the tool train between the detent unit and the lower piston unit. As soon as the slack is removed from this portion of the tool train, further pumping of the lower piston units compresses the up-shift assembly 1000 to activate it by telescoping of its shifting unit mandrel 1059 upwardly over the neck portion 1046 of its top connector effecting relative downward movement of its slider through the sleeve shifting unit 1049 and monitor unit 1041 to release the up-shift keys 400a and the monitor feeler 1137 which is biased outwardly by its spring into contact with the inside wall of the production tubing. The slider is forced downwardly against the spring 1122 until the slider and trigger sear plates are interlocked to releasably hold its slider at its lower position thus fully activating the up-shift assembly. Further increase in the fluid pressure being applied across the lower piston unit causes the piston unit to lift the tool train with sufficient force to release the detent unit locking dogs from the sleeve valve recess 1857 allowing the tool train to assume upward travel. The tool train continues its upward movement until the up-shift keys 400a of the up-shift assembly which are sliding along the inside wall of the production tubing are aligned with and expand outwardly into the recesses 1876 and 1877 of the sleeve of the sleeve valve assembly. With the engagement of the up-shift keys in the recesses of the sleeve, the sleeve is lifted by the up-shift assembly as the tool train continues upward movement. The split ring 1853 is cammed radially outwardly farther into its recess 1854 from the lock ring recess 1852 on the collect fingers 1851 at the upper end of the sleeve releasing the sleeve for upward movement. The sleeve is then moved upwardly by the keys until the upper ends of its collet fingers engage the downwardly facing shoulder 1856 in the upper mandrel of the sliding sleeve assembly

while at the lower end of the sleeve the external annular recess 1860 around the sleeve is aligned with the lower mandrel recess 1862 and the split lock ring 1861 snaps radially inwardly into the recess 1860 to releasably lock the sliding sleeve at its upper position. The upward movement of the sliding sleeve uncovers the lower internal annular recess 1865 within the lower mandrel. When the sleeve is moved to its upper end position the outwardly biased feeler 1137 of the monitor unit 1041 on the up-shift assembly moves outwardly into the recess 1865 thereby disengaging the trigger sear plate from the slider sear plate releasing the slider from its lower end locked position to permit the compressed spring 1132 to expand returning the slider upwardly. The upward movement of the slider retracts the up-shift keys 400a inwardly into their windows 1057 while simultaneously retracting the monitor feeler 1137 into its window thus releasing the up-shift assembly from the sliding sleeve with the sliding sleeve at its upper end open position. The release of the upshift assembly from the sliding sleeve frees the tool train for continued upward movement.

The tool train resumes its upward travel until the locking dogs on the latch unit on the lowermost gas lift valve are aligned with the internal annular recesses 1827 and 1830 in the upper mandrel of the just opened sliding sleeve valve assembly at which time the latch unit dogs expand radially outwardly into the sleeve valve locking recess allowing the latch unit sleeve and the mandrel to be moved in opposite directions by the springs pressing upon its cleat ring to lock the dogs outwardly by moving the fingers 1403 between the dogs and the latch unit mandrel while fully releasing the latch unit from the flexible probe. The gas lift valve is supported from its latch unit with its upper and lower seal assemblies 1536 and 1536a being seated with the cylindrical seat surfaces 1833b and 1833c, respectively, above and below the slots 1834 of the sliding sleeve so that fluid flow into the sliding sleeve is restricted to a path through the slots 1835 and 1834 into the slots 1580 of the gas lift valve.

The release and locking of the lowermost gas lift valve and its latch unit in the lowermost sliding sleeve also releases the next gas lift valve and its latch unit on the flexible probe to its intermediate locked position. The tool train proceeds upwardly in the same manner as just described to releasably lock the next gas lift valve in its latch unit in the next sliding sleeve.

Each of the gas lift valves is so released sequentially to permit its latch unit to shift to its intermediate locked position on the probe as the gas lift valve immediately therebelow is fully released from the probe and locked by its latch unit in its sliding sleeve valve. All of gas lift valves with their respective latch units are sequentially freed from the probe and each releasably locked in its sliding sleeve valve with the uppermost gas lift valve and latch unit supported at the head of the flexible probe being the last to be freed from the probe. Each sleeve valve is opened as described before the release and locking of each of the gas lift valves.

After the last gas lift valve and its latch unit is released from the probe, the tool train including the bore probe is pumped back into the lubricator section 114a between the end cap 120 and the valve 115. The tool train is then withdrawn from the lubricator by removing the end cap 120.

With the gas lift and bottom circulating valves all installed in the production tubing as above described the gas lift system is operated in accordance with standard procedures. Lift gas is injected into the well casing through the conduit 112 with the lift gas flowing downwardly around the production tubing in the annular space 111. The liquid level within the annular space is displaced downwardly by the lift gas until a "working level" is reached at which level the liquid remains during a sub-

stantial portion of the period during which the well is produced by the gas lift system.

Generally, upon initiation of gas lift procedure, most, if not all, of the valves below the liquid level are held open by hydrostatic pressure. The liquid in the annulus is therefore displaced by gas lift through all of the gas lift valves into the production tubing through which it flows to the surface. As the liquid level is lowered, those valves which are sufficiently above the normal operating level that the liquid does not provide adequate hydrostatic pressure to hold them at the open position will thus close with the final result being that all the gas lift valves above the level of the liquid in the annulus will close with the valve functioning to admit lift gas being the one above and nearest the operating level of the liquid in the annulus. Since the particular valves disclosed herein are of the tubing responsive type, the lift gas is admitted from the annulus through the particular valve functioning only in response to a predetermined liquid pressure within the production tubing at which the valve has been adjusted to open by the pressure to which its dome chamber has been charged. Thus, the functioning valve remains closed until the liquid level in the production tubing has been raised to a predetermined level above the valve. The gas lift valve is opened by the pressure of the liquid in the production tubing acting over an effective annular area of the gas lift valve assembly defined between the mean effective diameter of the inner bellows 1559 and the effective diameter of the outer valve seat while the casing annulus or input gas pressure acts on the balance of the effective annular area of the gas lift valve assembly defined between the mean effective diameter of the valve seat and the mean effective diameter of the outer bellows 1563a. The relationship between the above two portions of the effective annular area determines the range between the opening and the closing pressure, known as the "spread" of the gas lift valve. When the liquid has been displaced to the extent that the hydrostatic pressure at the gas lift valve provided by the column of liquid in the production tubing is reduced to a predetermined level, the dome gas pressure within the chamber 1574 moves the valve assembly downwardly to its closed position shutting off the supply of lift gas into the production tubing through the gas lift valve from the annulus.

The gas lift valves are removed from the production tubing by the same tool train employed to install them. The tool train is assembled using the components previously described and illustrated in FIGURE 1, the flexible probe, however, being modified by substitution of the bottom probe link 1239, FIGURE 18B, for the bottom probe link 1235 employed in running the valves into the well. The tool train with its modified empty flexible probe is inserted into the lubricator section 114a after removal of the cap 120 and closure of the valves 122 and 115 to isolate the lubricator. The bottom end of the probe in the first portion of the tool train inserted into the lubricator. The well system is adjusted to establish a liquid circulation pattern, as previously described, for pumping the tool train downwardly in the production tubing with the displacing liquid passing into the production tubing behind the tool train and the displaced liquid flowing outwardly through the bottom circulating valve into the annular space 111 and returning through the annular space to the surface and outwardly through the return conduit 112. The increased hydrostatic head of the displacing liquid in the system effects the opening of the bottom circulating valve. With the valves 113, 115, and 122 open, liquid is pumped into the conduit 121 displacing the tool string from the lubricator through the conduit 114 into the production tubing string.

The tool train is pumped downwardly with its flexible probe. The released latch unit and its gas lift valve may lift valve and its latch unit until the head assembly 1210 of the probe is seated on the upper end section of the sleeve 1380 of the latch unit on the uppermost gas lift

valve. A lower end spherical surface portion of the retainer 1218 engages the spherical surface portion 1383 at the upper end of the latch unit sleeve. Downward force applied from the tool train through the flexible probe head to the latch unit sleeve moves the sleeve downwardly relative to its mandrel and its locking dogs which are held against downward movement by the engagement of the lower end surfaces of the bosses on the locking dogs with the shoulders 1829 and 1832 at the lower ends of the locking recesses in the sliding sleeve valve upper mandrel. The downward movement of the latch unit sleeve relative to its dogs and mandrel moves the lock member 1396 engaged with the lower end portion of the finger section 1386 of the latch unit sleeve downwardly withdrawing the lock fingers 1403 from between the mandrel and the latch unit locking dogs. As soon as the fingers 1403 are withdrawn from between the mandrel and the dogs, the locking recess shoulders 1829 and 1832 cam the dogs inwardly releasing the latch unit from the sliding sleeve valve.

After its release, the gas lift valve with its latch unit is not attached either to the production tubing or the flexible probe. The released latch unit and its gas lift valve may remain on the probe if the frictional resistances between the wall of the production tubing and the packing assemblies on the gas lift valve along with the locking dogs on the latch unit are sufficient to prevent the valve and latch unit from falling ahead of the tool train is pumped downwardly. Probably, however, the released gas lift valve and its latch unit will fall downwardly in the production tubing at close to the fluid column speed until the assembly comes to rest on the top of the latch unit of the next gas lift valve below in the production tubing, which, at this stage in the procedure, remains locked in its sliding sleeve valve.

The sliding sleeve valve from which the uppermost gas lift valve and its latch unit is released is in its open upper end position and the downward movement of the released gas lift valve and latch unit does not affect the open position of the sleeve in the sliding sleeve valve since the locking dogs on the latch unit of the released gas lift valve do not fit any of the recesses in the sliding sleeve 1833. Thus, the tool train, upon releasing the uppermost gas lift valve and its latch unit, resumes downward travel with the lower piston units and the upshift assembly of the tool train passing through the open sliding sleeve valve until the detent unit dogs are aligned with and expand into the recess 1865 at the lower end of the open sleeve 1833 releasably locking the detent unit until the down-shift assembly 300 is activated, as previously described, and sufficient force is applied to the detent unit to release it from the locking recess of the sliding sleeve valve. The detent unit releases permitting the tool train to resume downward movement until the down-shift keys of the down-shift assembly engage the down-shift shoulder 1873 of the sleeve 1833 so that the down-shift assembly moves the sleeve downwardly to its closed position at which time the feeler 354 on the monitor unit of the down-shift assembly releases the down-shift assembly to permit continued downward movement of the tool train.

The tool train again moves downwardly until its flexible probe is inserted through the released uppermost gas lift valve and its latch unit which if it has fallen downwardly is resting on the next gas lift valve and latch unit. The flexible probe is inserted through both the released uppermost gas lift valve and latch unit and the next gas lift valve and latch unit which is still locked in its sliding sleeve valve. The tool train with its flexible probe moves downwardly until the head assembly 1210 of the flexible probe is again engaged with the top of the sleeve of the uppermost latch unit forcing the uppermost latch unit and its gas lift valve downwardly against the next latch unit so that the lower end of the bottom retainer 1609 on the uppermost gas lift valve bears against the upper end of the next latch unit forcing its sleeve downwardly and thereby releasing it from its sliding sleeve valve nipple, as

previously described. When this second lift valve with its latch unit is released, the two gas lift valves with their latch units drop downwardly to be followed by the tool train which shifts the sliding sleeve valve to its closed position and then continues its downward movement in the production tubing string. Each gas lift valve and its latch unit is sequentially released from its sliding sleeve valve and each sleeve valve is closed until the entire group of gas lift and bottom circulating valves with their latch units are released and rest in end-to-end array within the production tubing at its lower end on the pin collar 126.

The tool train continues downwardly until it moves into engagement with the stack of released gas lift valves and latch units inserting the flexible probe through all of the gas lift valves and latch units so that they are arranged on the probe in the same order as when initially installed in the tubing string by the probe. The tool train is pumped downwardly with the flexible probe inserted through all of the gas lift and bottom circulating valves and latch units with the entire stack of valves and latch units being compressed longitudinally by the tool string. The sleeve of each of the latch units is telescoped downwardly over its mandrel and locking dogs to fully lock its locking dogs at their inward positions and to insert the bottom pulling link 1239 of the flexible probe into the bottom release assembly 1729 on the lower end of the bottom circulating valve. The locking dogs 1246 of the pulling probe ratchet or snap downwardly through the internal annular locking flanges in the mandrel of the bottom release assembly with the teeth 1247 on the locking dogs of the pulling probe bottom pulling link being received in a group of the annular recesses 1730 within the mandrel when the link reaches its lower extent of travel which occurs when the stack of valves and latch units are fully compressed together. The gas lift and bottom circulating valves with their latch units are thus compressed and locked in end-to-end array on the flexible probe which penetrates the entire string of valves.

The fluid circulation is reversed in the system to pump the tool train with the valves and latch units back to the surface. Upward movement of the tool train lifts the flexible probe along with the entire string of gas lift and bottom circulating valves with their latch units. As the tool train moves upwardly each of the sliding sleeve valves is returned to its open position by the up-shift assembly in the same manner as previously described. The tool train with the valves is pumped back into the lubricator section 114a from which it is withdrawn by removal of the end cap 120 after closure of the valve 115. The pulling probe 1239 is released from the bottom circulating valve by insertion of a suitable tool, such as a small wedge through the hole 1241 at the lower end of the probe between the free lower ends of its dogs 1246 to pivot the dogs about their pin 1243 moving the upper ends of the dogs laterally inwardly disengaging them from the locking recesses of the bottom release assembly whereby the flexible probe may be withdrawn from or the bottom circulating and gas lift valves. During the retrieval of the gas lift and bottom circulating valves their latch units are not locked on the probe but rather they are all held on the probe by the pulling link as discussed above. Thus, with the release of the bottom link all of the valves and latch units freely slide off the probe.

Each of the down-shift and up-shift assemblies is provided with means for releasing their shifting keys from the sleeve of a sliding sleeve valve in the event a malfunction of either the sliding sleeve valve with which a down-shift or up-shift assembly is engaged or if the operating mechanism of either of the assemblies prevents the assembly from being disengaged from the sleeve by its monitor unit and subsequent expansion of its main slider spring.

If the down-shift assembly fails to function normally to disengage from a sleeve of a sliding sleeve valve, a suitable fishing tool is inserted into the production tubing

such as on a wireline and connected with the upper end connector 205 of the uppermost piston unit on the lodged tool string. Pulling dogs on the fishing tool are received in the socket recess 208 at the upper end of the top piston unit. An upward force is applied to the fishing tool pulling the down-shift assembly top connector 303 upwardly to shear the shear pins 393 in the down-shift unit 302 between its outer body mandrel or sleeve 392 and its member 388. The release of the member 388 permits an upward force applied through the monitor unit to lift the member 388 which lifts the key retractors causing the down-shift keys to be retracted inwardly thus releasing the down-shift assembly from the sleeve of the sliding sleeve valve. The upward movement of the key retractors moves the slider 308 upwardly engaging the trigger arm 350 pivoting the trigger clockwise to retract the feeler 354 into its window 316.

Similarly, a stuck up-shift assembly 1000 is disengaged from a sleeve which it is endeavoring to move to an upward open position with increased upward thrust applied to the tool train by a fishing tool. The increased upward thrust is applied to the upper socket connector 1042 of the up-shift assembly to shear the pin 1047 permitting relative longitudinal movement between the sleeve 1046 and the reduced neck section or stem 1045 of the top connector. The released top connector stem moves upwardly until its lower end flange 1055 engages the internal flange 1065 of the split sleeve 1064 which has a lower end flange engaged with the up-shift key retractors. The upward movement of the top connector through the sleeve 1046 lifts the key retractor effecting retraction of the keys 400a thereby disengaging them from the sleeve of the sliding sleeve valve to permit the tool train to resume upward movement within the production tubing. The upward movement of the key retractors lifts their lower ends from the head 1034 of the push rod 1083 which engages the upper end of the slider of the up-shift assembly. Thus, the upward movement of the key retractors may permit the spring 1122 to expand to move the slider upwardly with the key retractors. If, however, the malfunctioning of the up-shift assembly prevents the spring 1122 returning the slider upwardly to retract the monitor feeler 1137 inwardly, the up-shift assembly is movable through the production tubing and its various sliding sleeve valves to return to the surface with the tool train. While the feeler 1137 remains resiliently biased outwardly it is not rigidly held at such outward position and thus is cammed inwardly against the force of its springs by tubing and sliding sleeve valve surfaces encountered by the feeler as the tool train pulls it back to the surface.

While the method and apparatus described herein are discussed in terms of installing a gas lift valve in each of the sliding sleeve valves provided in the production tubing of the system, it is to be understood that if it is not desired to install such a valve in a particular sliding sleeve a dummy valve may be placed on the flexible probe with a latch unit for installation in the sliding sleeve. While a dummy valve is not illustrated herein, such a valve may be readily fabricated. For example, a central tubular solid walled mandrel, not shown, may be substituted for the valve section 1521 of the gas lift valve 1500. It will be obvious, of course, that such a mandrel will require opposite end sections adapted to be pivotally interconnected by the universal joints shown to the upper and the lower annular packer sections so that packing is provided above and below the side ports in the sliding sleeve in which the dummy is installed to prevent fluid communication through the sliding sleeve valve into the production tubing. Such a dummy valve with its latch unit is handled in precisely the same manner as the gas lift valves and their latch units in the system.

It will now be seen that the new and improved system for producing fluids from a well has been described and illustrated.

It will be further seen that a new and improved gas

lift system for production of well fluids has been described and illustrated.

It will be further seen that new and improved apparatus for installation and removal of fluid flow control valves in a gas lift system has been described and illustrated.

It will be seen that the method and apparatus includes the use of a train of well tools for installing and removing gas lift valves which is moved through a flow conductor between a surface location and the operating positions of the valves within the flow conductor of a well by pumping the tool train between such locations.

It will be seen that the gas lift system includes production tubing having a sliding sleeve valve at each depth within the well at which a gas lift valve is installed.

It will be seen that a method and apparatus for closing and opening sliding sleeve valves in a string of well production tubing during installation and removal of gas lift valves within the sliding sleeve valves has been described and illustrated.

It will be seen that the method of installing gas lift valves includes moving each of the sliding sleeve valves downwardly to a closed position during the pumping of the installation tool train through the production tubing to its bottom end.

It will be seen that the tool train includes apparatus having means for closing open sliding sleeve valves in the production tubing as the tool train is pumped through the tubing to its lower end.

It will be seen that the tool train includes means for engaging sliding sleeve valves in a production tubing and moving the valves upwardly to an open position as the tool train moves upwardly in the tubing.

It will be seen that the tool train includes apparatus for releasing a gas lift valve and its locking assembly from the tool train and releasably locking them in a sliding sleeve valve in the production tubing through which the tool train is moved.

It will be seen that the tool train for installing and removing valves in the system of the invention includes an articulated flexible probe for supporting the valves while installing, removing, and transporting them through production tubing.

It will be seen that the tool train includes pumpable piston or locomotive propulsion units adapted to be displaced through a flow conductor responsive to a pressure differential applied across each unit and to bypass the displacing fluid responsive to a pressure differential applied across each unit in excess of a predetermined value.

It will be seen that the tool train includes a detent unit adapted to releasably lock the tool train in selected locking nipples within a flow conductor when the force applied to move the tool train is below a predetermined value and to release the tool train for movement through the flow conductor and when such force exceeds a predetermined value.

It will be seen that the gas lift system includes a plurality of gas lift valves releasably locked at selected depth locations in a string of production tubing in a well and a circulating valve releasably locked within the production tubing below the gas lift valve to permit circulation of fluid in either direction between the production tubing and an annular flow channel within the well bore around the production tubing for circulating well tools into and out of the production tubing between its bottom and surface ends.

It will be seen that the tool train includes "down-shift" and "up-shift" assemblies for opening and closing sliding sleeve valves, such units being activated for engagement and shifting of sliding sleeve valves by a compressive force applied between the detent unit and the piston unit or units of the tool train.

It will also be seen that the tool train includes apparatus for moving a sliding sleeve downwardly in a flow conductor in a well bore, such apparatus being

adapted to move downwardly past a sliding sleeve which has previously been closed.

It will be seen that a plurality of gas lift valves are supported in end-to-end array on a tool string which is first pumped to a lower end position in a flow conductor of a well and then pumped back to the surface as each valve is sequentially released from the tool train and releasably locked at a selected location in the flow conductor, the lowermost of the valve being first released during the return of the tool train to the surface.

It will be seen that the gas lift valves are removed from the flow conductor by sequentially releasing each valve beginning at the uppermost valve, displacing the released valves downwardly to the lower end of the conductor, and withdrawing the valves simultaneously in end-to-end array from the lower end of the flow conductor during a single continuous upward return passage of the tool train to which the valves are secured.

It will also be seen that the valves are removed by moving a flexible probe supported from a tool train downwardly in the flow conductor, sequentially introducing the probe into and releasing each of the valves from its locking nipple beginning with the uppermost valve until the probe has been inserted through and released all of the valves which are displaced downwardly to the lower end of the production tubing where they are assembled in end-to-end array with the probe inserted through all of the valves and the lower end of the probe releasably locked with the lowermost valve after which the valves are lifted with the tool train back to the surface through the flow conductor.

It will be further seen that the gas lift valves and bottom circulating valve of the system of the invention are releasably supported during both installation and removal on an articulated tool train displaceable by fluid pressure through a flow conductor having curved longitudinal portions.

The foregoing description of the invention is explanatory only, and changes in the details of the construction illustrated may be made by those skilled in the art, within the scope of the appended claims, without departing from the spirit of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. Apparatus for installing and removing well tool means in a flow conductor including sliding sleeve valve means having sleeve means movable between open and closed positions and means for releasably locking well tool means within said sleeve valve means, comprising: first seal means slidable in said flow conductor; first sleeve shifting means connected with said first seal means for moving said sleeve means in a first direction; detent means connected with said first sleeve shifting means for releasably holding said apparatus against movement within said flow conductor; second sleeve shifting means connected with said detent means for moving said sleeve means in a second direction; second seal means slidable in said flow conductor connected with said second sleeve shifting means; and well tool support means connected with said second seal means for holding a well tool means during installation and removal of said tool means in said flow conductor.

2. The apparatus of claim 1 wherein said seal means, said sleeve shifting means, and said detent means are interconnected by universal joint means providing an articulated assembly adapted to traverse curve sections of said flow conductor.

3. Apparatus in accordance with claim 1 wherein one of said seal means is adapted to apply a greater thrust to said apparatus than the other of said seal means responsive to fluid pressure differentials of equal value imposed across each of said seal means.

4. Apparatus in accordance with claim 3 wherein said detent means is adapted to release from locking engagement within said flow conductor responsive to a force

less than the lower thrust applicable to said apparatus by either of said seal means.

5. Apparatus as defined in claim 4 wherein each of said seal means is adapted to bypass fluid therethrough when the pressure differential applied across said seal means exceeds a predetermined value.

6. Apparatus for installing and removing well tools in a flow conductor including spaced sliding sleeve valves each having a sleeve movable longitudinally between open and closed positions comprising: first propulsion means for applying a thrust to said apparatus in said flow conductor; first sleeve shifting means connected with said first propulsion means for moving each of said sleeves in a first direction; detent means connected with said first sleeve shifting means for releasably holding said apparatus at selected locations in said flow conductor against movement in said flow conductor; second sleeve shifting means connected with said detent means for moving each of said sleeves in a second direction; second propulsion means connected with said detent means for applying a thrust to said apparatus in said flow conductor; and means connected with said second propulsion means for releasably supporting well tools while installing and removing said well tools in said flow conductor.

7. A tool train for installing and removing gas lift valves and a bottom circulating valve in a flow conductor including longitudinally spaced sliding sleeve valves and a ported landing nipple for a bottom circulating valve, comprising: a first piston propulsion unit adapted to apply a thrust to said tool train in said flow conductor responsive to a fluid pressure differential imposed across said unit; a first sleeve valve operator assembly connected with said first piston unit for moving each of said sliding sleeve valves in a first direction; a detent unit connected with said first sleeve valve operator assembly for releasably holding said tool train against movement in said flow conductor at selected locations along said conductor; a second sleeve valve operator assembly connected with said detent unit for moving each of said sleeve valves in a second direction opposite to said first direction; a second piston propulsion unit connected with said second sleeve valve operator assembly for applying a thrust to said tool train in said flow conductor responsive to fluid pressure imposed across said unit; and a support assembly connected with said second piston unit for releasably supporting said gas lift valves and said bottom circulating valve during installation and removal of said valves.

8. A tool train as defined in claim 7 wherein each of said sleeve shifting operator assemblies includes means for engaging a slidable sleeve in each of said sleeve valves as said tool train is moved in said flow conductor for shifting said sleeve from a first position to a second position and means for disengaging said operator assembly from said sleeve when said sleeve is shifted to said second position.

9. A tool train as defined in claim 7 wherein said support assembly comprises flexible means adapted to be inserted through said gas lift and bottom circulating valves and having a free end portion provided with means for releasably locking said assembly with the lowermost valve supported thereon for holding said valves on said unit.

10. A tool train as defined in claim 7 wherein each of said sleeve valve operator assemblies comprises a sleeve shifting unit having laterally expandable sleeve shifting keys adapted to be biased radially outwardly for engaging and shifting a sliding sleeve and adapted to be retracted inwardly for disengagement from a sliding sleeve and a monitor unit operably connected with said shifting unit for detecting said second position of said sleeve and effecting retraction of said shifting keys to release said shifting unit from said sleeve.

11. In combination with the tool train of claim 7 a plurality of gas lift valve and a bottom circulating valve

assemblies each including a latch unit having means for releasable engagement with said support assembly and means for releasable locking within said flow conductor.

12. A tool train as defined in claim 9 wherein said free end portion of said support assembly includes a well tool retrieving assembly having outwardly biased locking dogs for releasably engaging the lowermost valve assembly in said flow conductor to support all of said valve assemblies on said support assembly for removal of said valve assemblies from said flow conductor.

13. The combination defined in claim 11 wherein said bottom circulating valve assembly includes a bottom release unit adapted for releasable connection with said support assembly.

14. The apparatus of claim 13 wherein said bottom release unit includes means actuatable by engagement between said bottom circulating assembly and a bottom stop in said flow conductor to release said unit from said support assembly.

15. A tool train for installing and removing valves of a well system in a well bore having a flow conductor including a plurality of spaced sliding sleeve valves comprising: a first piston propulsion unit adapted to apply a thrust to said tool train in said flow conductor responsive to a fluid pressure differential imposed across said unit, said unit including an annular seal assembly adapted to slide within said flow conductor while effecting a sealing relationship with the inner wall of said conductor around said unit; a first sliding sleeve valve operator assembly pivotally connected with said first piston unit for releasably engaging a sliding sleeve within a sliding sleeve valve for moving said sleeve in a first direction, said sleeve shifting assembly having at least one sleeve engaging key adapted to be biased radially outwardly for engaging each sleeve to be shifted by said assembly and adapted to be retracted to and locked at an inward position for releasing said assembly to pass through said sliding sleeve, key releasing and locking means for releasing said key to be biased radially outwardly and for retracting and locking said key at an inward position, operator means for actuating said key releasing and locking means for moving said means between releasing and locking positions, and sleeve position detector means operably interconnected with said operator means for detecting movement of said sleeve to a predetermined position and releasing said operator means responsive thereto for retracting said key from said sliding sleeve; a detent unit pivotally secured at one end to said first sliding sleeve valve operator assembly for releasably holding said tool train against movement through said flow conductor at preselected locations along said conductor when the thrust applied to said train is below a predetermined value and for releasing said train for movement in said flow conductor from each of said locations when said thrust exceeds a predetermined value, said detent unit having radially expandable dogs provided with bosses adapted to be received within internal recesses provided at said locations along said flow conductor, said dogs being adapted to be locked outwardly when said bosses are received within said recesses at each of said locations and being further adapted to be released for radial inward movement when said thrust exceeds said predetermined value; a second sliding sleeve valve operator assembly pivotally connected with the other end of said detent unit for releasably engaging a sliding sleeve within a sliding sleeve valve for moving said sleeve in a second direction, said second sliding sleeve valve operator assembly having at least one sleeve shifting key adapted to be biased radially outwardly for engaging said sleeve to be shifted by said assembly in said second direction and adapted to be shifted by said assembly in said second direction and adapted to be retracted to and locked at an inward position for releasing said assembly to pass through said sliding sleeve, key releasing and locking means for releasing said key to be biased radially outwardly and for

retracting and locking said key at an inward position, operator means for actuating said key releasing and locking means for moving said means between releasing and locking positions, and means operably interconnected with said operator means for detecting movement of said sleeve to a predetermined position and releasing said operator means responsive thereto for retracting said key from said sliding sleeve for releasing said assembly to pass through said sliding sleeve; a second piston propulsion unit pivotally connected with said second sliding sleeve valve operator assembly for applying a thrust to said tool train in said flow conductor responsive to a pressure differential imposed across said unit, said unit including an annular seal assembly adapted to slidably engage the inner wall of said flow conductor in sealing relationship around said piston unit; and an articulated support assembly connected with said second piston unit for releasably supporting a plurality of valves in end-to-end array during installation and removal of said valves in said flow conductor, said support means including a plurality of link members pivotally interconnected with each other, selected links of said support assembly having means for receiving a releasable lock associated with each of said valves supported on said support means permitting releasable locking of each of said valves with one of said selected links of said support assembly.

16. A tool train as defined in claim 15 wherein one of said piston units is adapted to apply a greater thrust than the other of said piston units and said detent unit is adapted to release said tool train from locking engagement in said flow conductor at each said preselected location responsive to a thrust less than the thrust applicable to said tool train by the piston unit having the lesser thrust generating capacity.

17. A tool train as defined in claim 15 wherein each of said piston units includes: a body having a central bore therethrough and an external annular recess defined between external annular upwardly and downwardly facing seal surfaces; an annular seal in said recess, said seal comprising an annular seal in said recess, said seal comprising an annular resilient body disposed in said recess and having a plurality of longitudinally extending circumferentially aligned rigid segments secured to one another for pivotal movement relative to one another to permit radial contraction and expansion of said seal, said segments having boss means extending outwardly of said recess to engage internal surfaces of said flow conductor to seal between said body and said internal surfaces, said resilient body having an annular seal portion at opposite ends engageable with said seal surfaces defining opposite ends of said annular recess on said body; and a longitudinally movable valve positioned within said central flow passage through said body, said valve being resiliently biased toward a neutral position in said flow passage and adapted to be longitudinally displaced along said flow passage toward either end of said body responsive to a pressure differential imposed across said valve to a first closed position and farther to a second open position to bypass fluid through said passage responsive to a pressure differential in excess of a predetermined value, whereby each of said piston units is adapted to apply a predetermined maximum thrust to said tool train responsive to a pressure differential imposed across said piston unit and to bypass fluid through said central flow passage when said pressure differential imposed across said unit exceeds a predetermined value.

18. A piston propulsion unit for generating a predetermined maximum thrust within a flow conductor responsive to a pressure differential applied across said unit, said piston unit including: a body having a central bore therethrough and an external annular recess defined between external annular facing seal surfaces; an annular seal in said recess, said seal comprising an annular resilient body disposed in said recess and having a plurality of longitudinally extending circumferentially aligned rigid

segments secured to one another for pivotal movement relative to one another to permit radial contraction and expansion of said seal, said segments having boss means extending outwardly of said recess to engage internal surfaces of said flow conductor to seal between said body and said internal surfaces, said resilient body having an annular seal portion at opposite ends engageable with said seal surfaces defining opposite ends of said annular recess on said body; and a longitudinally movable valve positioned within said central flow passage through said body, said valve being resiliently biased toward a neutral position in said flow passage and adapted to be longitudinally displaced along said flow passage responsive to a pressure differential imposed across said valve toward one end of said body to a first closed position and farther to a second open position responsive to a pressure differential in excess of a predetermined value and toward the other end of said body to a first closed position and farther to a second open position responsive to a pressure differential in excess of a predetermined value, whereby each of said piston units is adapted to apply a predetermined maximum thrust to said tool train responsive to a pressure differential imposed across said piston unit to a predetermined maximum value and is further adapted to bypass fluid through said central flow passage of said unit when said pressure differential imposed across said unit exceeds said predetermined value.

19. In combination with the tool train of claim 15 a plurality of valves supported on said articulated support assembly, each of said valves including a latch unit having means for releasably connecting said unit on one of said selected links of said support assembly and means for releasably locking said unit at selected internal recesses within said flow conductor, each said latch unit being operable between a first position at which said unit is locked on a support assembly link and said locking means are held at a retracted position, a second position at which said latch unit remains locked on said link of said support assembly and said locking means on said unit is released and biased radially outwardly against the inner wall of said flow conductor, and a third position at which said latch unit is released from said link of said support assembly and said locking means on said latch unit is expanded radially outwardly into said recesses of said flow conductor releasably locking said latch unit within said flow conductor independently of said articulated support assembly.

20. A latch unit for releasable locking engagement on a running tool and for releasable locking engagement within a flow conductor including: body means having a longitudinal central flow passage therethrough; locking dog means pivotally supported on said body means and biased radially outwardly from said body means; sleeve means telescopically engageable over one end portion of said body means and over one end portion of said locking dog means for holding locking dog means retracted inwardly, said sleeve means including a finger section extending along said body means beyond the other end of said locking dog means; a lock member supported from said finger means adapted to coast with said body means and said locking dog means for holding said locking dog means at a radially expanded position; resilient means operably connected between said sleeve means and said body means biasing said sleeve means and said body means in opposite directions toward locking relationship between said lock member on said finger portion and said locking dog means; locking means connected with said resilient means between said sleeve means and said body means biased radially outwardly and adapted to be releasably locked at an inward position for locking said latch unit on said running tool; and lock pin means for releasably locking said locking means at an inward position.

21. A position propulsion unit as defined in claim 18

wherein said body has internal annular valve seat surfaces around said central bore spaced longitudinally apart along said bore, said annular seat surfaces having a diameter less than the diameter of said bore, said valve comprises a valve core member longitudinally moving in said central flow passage between said closed, open, and neutral positions, an external annular seal supported on said valve core member adapted to seat within each of said seat surfaces around said bore of effecting a closed position of said valve responsive to pressure differential in either direction across said valve, and spring means operably engaged with said valve for biasing said valve toward a neutral position and for resisting movement of said valve to either of its open positions.

22. A piston propulsion unit as defined in claim 21 wherein said valve core member is provided with a fluid flow passage having flow restriction means therein for permitting fluid bypass through said valve core.

23. A latch unit for releasable connection on a running tool and within landing nipple means having internal annular recess means comprising: a body mandrel having a longitudinal central bore extending therethrough; an outer cage member telescopically supported over said body mandrel having a sleeve portion extendable over a first end portion of said body mandrel and a finger portion extending along a substantial portion of the length of said body mandrel; radially expandable and retractable locking dogs pivotally supported on said body mandrel having external boss means receivable in said recess means of said landing nipple means for releasably holding said latch unit within said landing nipple means when said locking dogs are radially expanded; a portion of said sleeve portion of said cage member being adapted to extend over one end portion of said locking dogs at a first position of said cage member on said body mandrel for holding said locking dogs at their inward position at one relative position of said cage member on said body mandrel and for releasing said locking dogs for radial expansion at another relative position of said cage member on said body mandrel; a lock member supported along a portion of the free end of said finger portion of said cage member and slidable with said cage member along said body mandrel, said locking member being engageable with the other ends of said locking dogs when said dogs are retracted inwardly for limiting the movement of said cage member on said body mandrel to a second intermediate position for releasing said locking dogs while holding said latch unit locked on said running tool; said locking member being adapted to be inserted along a portion thereof between said body mandrel and said locking dogs allowing said cage member to move to a third position relative on said body mandrel for locking said locking dogs at a maximum radially expanded position and releasing said latch unit from said running tool; a split ring member positioned within said sleeve portion of said cage member at said first end of said body mandrel; spring means supported between said split ring member and said body mandrel for biasing said cage member and said body mandrel in opposite directions; latch means operably supported by said ring member and adapted to pivot relative to said ring member between radially inward and outward positions for releasably locking said latch unit on said running tool, said latch means being biased radially outwardly about its pivotal axis by the biasing force of said spring means between said split ring and said body mandrel; and locking pin means releasably held by said body mandrel and engageable with a free end portion of said latch means for holding said latch means radially inward at a position for locking said latch unit on said running tool at said first and second positions of said cage member on said body mandrel and for releasing said latch means for radial expansion to release said latch unit from said running tool at said third position of said cage member on said body mandrel.

24. A method of installing well tool means in a flow conductor of a well including sliding sleeve valve means

having a sliding sleeve movable between an open position and a closed position, comprising: releasably supporting said well tool means from a fluid pressure displaceable tool train including sleeve shifting means for moving each of said sliding sleeves between said open and closed positions; pumping said tool train including said well tool means through said flow conductor from a first end thereof to said sliding sleeve valve means in said flow conductor; releasably interconnecting said sleeve shifting means of said tool train with said sliding sleeve of said sliding sleeve valve and moving said sliding sleeve longitudinally downwardly from an open position to a closed position and releasing said sleeve shifting means from said sliding sleeve when said sleeve is at said closed position; pumping said tool train with said well tool means from said sliding sleeve valve means to stop means in said flow conductor; pumping said tool train with said well tool means in said flow conductor from said stop means to said sliding sleeve valve means; releasably engaging said sliding sleeve with said sleeve shifting means of said tool train, moving said sliding sleeve from its closed position to an open position; releasing said well tool means from said tool train and releasably locking said tool means within said sliding sleeve valve means; pumping said tool train through said flow conductor back to said first end thereof and removing said tool train from said flow conductor.

25. A method of installing well tools in a flow conductor of a well including a plurality of sliding sleeve valves each having a sliding sleeve movable between an open position and a closed position, comprising: releasably supporting said well tools in end-to-end array on an articulated probe assembly secured in a fluid pressure displaceable tool train including piston propulsion units, a sliding sleeve down-shift assembly, a detent unit, and a sliding sleeve up-shift assembly; inserting said tool train with said well tools supported on said flexible probe assembly probe assembly end first into one end of said flow conductor; pumping displacing fluid into said flow conductor displacing said tool train with said well tools through said flow conductor to a first of said sliding sleeve valves until said detent unit releasably engages recess means in said sliding sleeve valve holding said tool train against further movement in said flow conductor and generating a pressure pulse in said displacing fluid; detecting said pressure pulse in said displacing fluid at said first end of said flow conductor; increasing the pressure in said displacing fluid for activating said down-shift assembly and releasing said detent unit from said sliding sleeve valve to permit said tool train to resume travel in said flow conductor; releasably engaging said down-shift assembly with said sliding sleeve of said sleeve valve, shifting said sliding sleeve downwardly to a closed position, and releasing said down-shift assembly from said sliding sleeve; sequentially repeating each of the aforementioned steps of displacing said tool train to each of the succeeding sliding sleeve valves, activating said down-shift assembly, releasably engaging said sliding sleeve of each of said valves, shifting said sliding sleeve to closed position, and releasing said down-shift assembly from said sliding sleeve to permit said tool train to resume travel in said flow conductor until all of said sliding sleeve valves in said flow conductor have been moved to closed positions; pumping said tool train with said valves from the last of said sliding sleeve valves to stop means in said flow conductor whereby a pressure signal is generated in said displacing fluid; detecting said pressure pulse at said first end of said flow conductor; reversing the direction of fluid flow in said flow conductor to displace said tool train from said stop means toward said first end of said flow conductor; pumping said tool train upwardly in said flow conductor to the last of said sliding sleeve valves; releasably engaging said detent unit of said tool train with recesses provided in said sliding sleeve valve and activating said up-shift assembly of said train, a pressure pulse being generated in said fluid and transmitted to said first

end of said flow conductor upon the releasable engagement of said detent unit with said sliding sleeve valve; increasing the pressure of said displacing fluid responsive to said pressure pulse detected at said first end of said flow conductor to release said detent unit from said sliding sleeve valve to permit said tool train to resume travel in said flow conductor; releasably engaging said up-shift assembly with said sliding sleeve of said last sliding sleeve valve, shifting said sliding sleeve to its open position, and releasing said up-shift assembly from said sliding sleeve permitting said tool train to resume travel in said flow conductor; releasably engaging the last of said well tools on said probe assembly with the last of said sliding sleeve valves while disengaging said well tool from said probe assembly; pumping said said tool train toward said first end of said flow conductor repeating the afore-mentioned steps to sequentially move each of the succeeding remaining sliding sleeve valves from its closed position to its open position, releasing each of the succeeding remaining well tools from said probe assembly and releasably locking each of said well tools in a sliding sleeve valve, until all of said well tools on said probe assembly are each releasably locked in a sliding sleeve valve; displacing said tool train with said probe assembly back to said first end of said flow conductor; and removing said tool train from said flow conductor.

26. A method of removing well tool means from a flow conductor including sliding sleeve valve means each having a sliding sleeve movable between an open position and a closed position, said well tool means being releasably supported in said sliding sleeve means with said sliding sleeve means and its open position, comprising: introducing into a first end of said flow conductor a fluid pressure displaceable tool train including sliding sleeve shifting means and means for supporting said well tool means; pumping displacing fluid into said first end of said flow conductor behind said tool train; displacing said tool train through said flow conductor to said sliding sleeve valve means; engaging said well tool means in said sliding sleeve means with said supporting means; releasing said well tool means from said sliding sleeve means; engaging said sliding sleeve means with said sleeve shifting means and moving said sliding sleeve means from an open position to a closed position; disengaging said sleeve shifting means from said sliding sleeve means; displacing said tool train and said well tool means through said flow conductor beyond said sliding sleeve means to stop means therein; engaging said tool train with said well tool means; reversing the direction of flow of displacing fluid in said flow conductor; displacing said tool train with said well tool secured thereon back to said sliding sleeve means; releasably engaging said sliding sleeve means with said sleeve shifting means of said tool train; moving said sliding sleeve means back to said open position; releasing said sliding sleeve means from said sleeve shifting means of said tool train; displacing said tool train with said well tool means secured thereon back to said first end of said flow conductor; and removing said tool train with said well tool means from said flow conductor.

27. A method of removing well tools from sliding sleeve valves in a flow conductor, said sliding sleeve valves each having a sliding sleeve at its open position, comprising: introducing into a first end of said flow conductor a tool train including piston propulsion means, a first sliding sleeve shifting assembly for moving each of said sliding sleeves from an open to a closed position, a detent unit, a second sliding sleeve shifting assembly for moving each of said sliding sleeves from a closed to an open position, and an articulated probe assembly having free-end means for releasably engaging well tools thereon; pumping fluid into said first end of said flow conductor behind said tool train; displacing said tool train through said flow conductor to a first of said sliding sleeve valves; inserting said articulated probe assembly through a well tool in said first sliding sleeve valve to release said well tool

from said sleeve valve and displace said tool toward a second end of said flow conductor; releasably engaging said detent unit with said first sliding sleeve valve thereby holding tool train against movement in said flow conductor and generating a pressure pulse in said displacing fluid; detecting said pressure pulse at said first end of said flow conductor; increasing the pressure in said displacing fluid to release said detent unit from said first sliding sleeve valve and compress said first sleeve shifting assembly to activate said assembly whereby said tool train resumes travel in said flow conductor toward said second end; releasably engaging said first sliding sleeve shifting assembly with said sliding sleeve of said first sliding sleeve valve; shifting said first sliding sleeve to its closed position and releasing said first sleeve shifting assembly from said sliding sleeve to permit said tool train to resume travel in said flow conductor toward said second end; repeating the aforementioned steps of releasing each subsequent well tool from its sliding sleeve valve and moving the sliding sleeve of each said sleeve valve to a closed position until all of said well tools have been displaced from their respective sliding sleeve valves toward said second end of said flow conductor and all of said sliding sleeves have been moved to closed positions; displacing said tool train from the last of said sliding sleeves toward said second end of said flow conductor; introducing said articulated probe assembly through said released displaced well tools until said probe assembly is inserted through all of said well tools and said well tools are assembled on said probe in end-to-end array and the last of said well tools released is held against movement toward said second end of said flow conductor by bottom stop means in said conductor; releasably engaging said pulling means on said free end of said articulated probe assembly with said last well tool, said tool being held against said stop means to hold all of said well tools in end-to-end array while said flexible articulated probe assembly is inserted through all of said well tools and releasably locked therewith whereby a pressure pulse is generated in said displacing fluid within said flow conductor; detecting said generated pulse at said first end of said flow conductor; reversing fluid flow in said flow conductor to displace said tool train with said well tools releasably locked on said probe assembly toward said first end of said flow conductor; releasably engaging said detent unit with the sliding sleeve valve nearest said second end of said flow conductor releasably holding said tool train against movement in said flow conductor while generating a pressure pulse in said displacing fluid; detecting said pulse in said fluid at the said first end of said flow conductor; increasing the pressure in said displacing fluid to release said detent unit from said sliding sleeve valve and activate said second sleeve shifting assembly; releasably engaging said second sleeve shifting assembly with said sleeve in said sleeve valve nearest said second end of said flow conductor and shifting said sleeve valve to an open position; releasing said second sleeve shifting assembly from said sliding sleeve to permit said tool train to resume travel in said flow conductor toward said first end sequentially repeating the steps of displacing said tool train into each of the succeeding sliding sleeve valves toward said first end of said flow conductor and moving each of the sliding sleeves in each of said valves to an open position until the last of said valves nearest said first end of said flow conductor has been opened; displacing said tool train with said well tools secured on said probe assembly back to said first end of said flow conductor; and withdrawing said tool train and said well tools from said flow conductor.

28. Apparatus for installing and removing well tool means in a flow conductor having sliding sleeve valve means with sleeve means movable between first and second positions comprising: elongate tool train assembly means; first sleeve valve shifting means forming part of said tool train assembly means engageable with said sleeve

means for moving said sleeve means in a first direction; detent means forming part of said tool train assembly means for releasably holding said tool train assembly means against movement within said flow conductor; second sleeve valve shifting means forming part of said tool train assembly means engageable with said sleeve means for moving said sleeve in a second direction; seal means forming part of said tool train assembly means adapted to be displaced within said flow conductor responsive to a pressure differential applied thereacross for moving said tool train assembly means in a first and a second direction in said flow conductor; and well tool support means connected with said tool train assembly means for holding said well tool means during installation and removal of said well tool means in said flow conductor.

29. A piston propulsion unit for generating a predetermined thrust to a tool train within a flow conductor responsive to a pressure differential applied across said unit comprising: a body having means for connecting it with said tool train and having a central bore providing a flow passage therethrough; external seal means on said body to effect a seal with said flow conductor around said body slidable within said flow conductor; and a longitudinally movable valve positioned within said central flow passage through said body, said valve being resiliently biased toward a neutral position in said flow passage and adapted to be longitudinally displaced along said flow passage in one direction responsive to a pressure differential in said one direction imposed across said valve toward one end of said body to a first closed position and farther to a second open position responsive to a pressure differential in said one direction in excess of a predetermined value, and adapted to be displaced longitudinally of said flow passage in an opposite direction toward the other end of said body to a first closed position and farther to a second open position responsive to a pressure differential in said opposite direction in excess of a predetermined value, whereby said piston unit is adapted to apply a predetermined thrust to said tool train responsive to a pressure differential imposed across said piston unit to a predetermined value and is further adapted to bypass fluid through said central flow passage of said unit when said pressure differential imposed across said unit exceeds said predetermined value.

30. A piston propulsion unit as defined in claim 29 wherein said body has internal annular valve seat surfaces around said central bore spaced longitudinally apart along said bore, said annular seat surfaces having a diameter less than the diameter of said bore, said valve comprises a valve core member longitudinally movable in said central bore between said closed, open, and neutral positions, an external annular seal supported on said valve core member adapted to seat within each of said seat surfaces around said bore for effecting a closed position of said valve responsive to pressure differentials in opposite longitudinal directions across said valve, and spring means operably engaged with said valve for biasing said valve toward a neutral position and for resisting movement of said valve to either of its open positions.

31. A piston propulsion unit as defined in claim 30 wherein said valve core member is provided with a fluid flow passage having flow restriction means therein for permitting fluid bypass through said valve core.

32. A tool train as defined in claim 15 wherein each of said piston units includes: a body having a central bore therethrough; external seal means on said body to effect a seal around said body within and slidable relative to said flow conductor; and a longitudinally movable valve positioned within said central flow passage through said body, said valve being resiliently biased toward a neutral position in said flow passage and adapted to be longitudinally displaced along said flow passage toward either end of said body responsive to a pressure differential imposed across said valve to a first closed position and farther to a second open position to bypass fluid through said pas-

sage responsive to a pressure differential in excess of a predetermined value, whereby each of said piston units is adapted to apply a predetermined thrust to said tool train responsive to a pressure differential imposed across said piston unit and to bypass fluid through said central flow passage when said pressure differential imposed across said unit exceeds a predetermined value.

33. A latch unit for releasable locking engagement on a running tool and for releasable locking engagement within a flow conductor including: body means having a central flow passage therethrough; radially movable first locking means on said body means for releasable holding engagement with said flow conductor for preventing movement of said unit in said flow conductor; means movably supported on said body means movable between a position engaging said locking means for holding said locking means radially inwardly in retracted nonlocking position on said body means and a position out of engagement with said locking means for releasing said locking means for radial expansion to locking position; second locking means operably connected with said body means for radial inward movement to a position for engaging said running tool; and means on said body engageable with said second locking means for holding said second locking means in a position for releasably locking said unit on said running tool and movable to a position freeing said second locking means for movement out of locking engagement with said running tool.

34. A latch unit for releasable locking engagement on a running tool and for releasable locking engagement within a flow conductor including: body means having a flow passage therethrough; external locking means on said body means for releasably locking said unit within said flow conductor; control means supported on said body means and movable relative thereto between positions engaging said external locking means for holding said external locking means radially inwardly on said body and out of engagement with said external locking means for releasing said external locking means for radial expansion on said body; means supported by said control means relative to said body and said external locking means; internal locking means operably connected with said body for releasably locking said unit on said running tool; and means carried by said body for holding said internal locking means at its inward locked position at one relative position of said body and said control means and movable to a position freeing said internal locking means for movement to unlocked position to disconnect said unit from said running tool.

35. A well system comprising: flow conductor means supported in a well bore defining a central flow passage and including spaced sliding sleeve valve means each having a sliding sleeve movable between first and second positions; means providing a flow passage in said well bore into said flow conductor below the lowermost of said sliding sleeve valve means independent of said central flow passage; and means for installing and removing well tool means in each of said sliding sleeve valve means including first sleeve shifting means for moving each of said sleeve valve means in a first direction, detent means for releasably holding said apparatus against movement in said flow conductor; second sleeve shifting means for moving each of said sleeve means in a second direction, seal means slidable in said flow conductor and adapted to move said apparatus in either direction within said flow conductor responsive to fluid pressure applied across said seal means, and well tool support means for holding well tool means during installation and removal of said tool means in said sleeve valve means of said flow conductor.

36. A well system including: a flow conductor supported within a well bore defining a central flow passage and an annular flow passage within said well bore, said flow conductor including sliding sleeve valve means having sleeve means movable between first and second positions spaced along the length of said flow conductor;

means for fluid communication with said central flow passage of said flow conductor; means for fluid communication with said annular flow passage; and means for installing well tool means in said sliding sleeve valve means comprising first seal means slidable in said flow conductor, first sleeve shifting means connected with said first seal means for moving said sleeve means in a first direction, detent means connected with said first sleeve shifting means for releasably holding said apparatus against movement within said flow conductor, second sleeve shifting means connected with said detent means for moving said sleeve means in a second direction, second seal means slidable in said flow conductor connected with said second sleeve shifting means, and well tool support means connected with said second seal means for holding a well tool means during installation and removal of said tool means in said flow conductor.

37. A well system comprising: a well having a well head; a flow conductor supported in said well connected with said well head, said flow conductor defining a central flow passage and an annular flow passage within said well and including a plurality of spaced sliding sleeve valves, each of said sliding sleeve valves having a sleeve member slidable therein between upper and lower positions and provided with an internal annular recess above said sleeve when said sleeve is in said lower position and below said sleeve when said sleeve is in said upper position; bottom stop means secured in said flow conductor below the lowermost of said sliding sleeve valves; fluid communication means through said well head into said flow conductor; said fluid communication means connected with said flow conductor having a lubricator section for the introduction and removal of a pumpable tool train; fluid conduit means in communication with said annular flow passage; and a tool train adapted to be displaced through said flow conductor between said well head and said bottom stop means for installing and removing well tools in said sliding sleeve valves comprising: a first piston propulsion unit adapted to apply a thrust to said tool train in said flow conductor responsive to a fluid pressure differential imposed across said unit, said unit including an annular seal assembly adapted to slide within said flow conductor while effecting a sealing relationship with the inner wall of said flow conductor around said unit, a first sliding sleeve valve operator assembly pivotally connected with said first piston unit for releasably engaging said sleeve member within said sliding sleeve valves for moving said sleeve member in a first direction, said operator assembly having at least one sleeve member engaging key adapted to be biased radially outwardly for engaging each sleeve member to be shifted by said assembly and adapted to be retracted to and locked at an inward position for releasing said assembly to pass through said sleeve member, key releasing and locking means for releasing said key to be biased radially outwardly and for retracting and locking said key at an inward position, operator means for actuating said key releasing and locking means for moving said means between releasing and locking positions, and sleeve member position detector means operably interconnected with said operator means for detecting movement of said sleeve member to a predetermined position and releasing said operator means responsive thereto for retracting said key from said sleeve member; a detent unit pivotally secured at one end to said first sliding sleeve valve operator assembly for releasably holding said tool train against movement through said flow conductor at said recesses at opposite ends of each of said sleeve members along said conductor when the thrust applied to said train is below a predetermined value and for releasing said train for movement in said flow conductor from each of said recesses when said thrust exceeds a predetermined value, said detent unit having radially expandable dogs provided with bosses adapted to be received within said internal recesses, said dogs being adapted to be locked outwardly when said bosses are received within said recesses and being further adapted to be released for radial inward movement when

said thrust exceeds said predetermined value, a second sliding sleeve valve operator assembly pivotally connected with the other end of said detent unit for releasably engaging a sliding sleeve within a sliding sleeve valve for moving said sleeve in a second direction, said second sliding sleeve valve operator assembly having at least one sleeve shifting key adapted to be biased radially outwardly for engaging said sleeve to be shifted by said assembly in said second direction and adapted to be shifted by said assembly in said second direction and adapted to be retracted to and locked at an inward position for releasing said assembly to pass through said sliding sleeve member, key releasing and locking means for releasing said key to be biased radially outwardly and for retracting and locking said key at an inward position, operator means for actuating said key releasing and locking means for moving said means between releasing and locking positions, and means operably interconnected with said operator means for detecting movement of said sleeve member to a predetermined position and releasing said operator means responsive thereto for retracting said key from said sleeve member for releasing said assembly to pass through said sleeve member; a second piston propulsion unit pivotally connected with said second sliding sleeve valve operator assembly for applying a thrust to said tool train in said flow conductor responsive to a pressure differential imposed across said unit, said unit including an annular seal assembly adapted to slidably engage the inner wall of said flow conductor in sealing relationship around said piston unit, and an articulated support assembly connected with said second piston unit for releasably supporting a plurality of valves in end-to-end array during installation and removal of said valves in said sliding sleeve valves of said flow conductor, said support means including a plurality of link members pivotally interconnected with each other, selected links of said support assembly having means for receiving a releasable lock associated with each of said valves supported on said support means permitting releasable locking of each of said valves with one of said selected links of said support assembly.

38. In combination with the well system of claim 35 a plurality of valves supported on said articulated support assembly, each of said valves including a latch unit having means for releasably connecting said unit on one of said selected links of said support assembly and means for releasably locking said unit at one of said recesses at opposite ends of said sliding sleeve members, each said latch unit being operable between a first position at which said unit is locked on a support assembly link and said locking means are held at a retractable position, a second position at which said latch unit remains locked on said link of said support assembly and said locking means on said unit is released and biased radially outwardly against the inner wall of said flow conductor, and a third position at which said latch unit is released from said link of said support assembly and said locking means on said latch unit is expanded radially outwardly into said recesses of said flow conductor releasably locking said latch unit within said flow conductor independently of said articulated support assembly.

39. A well tool comprising: first seal means slidable in a flow conductor; first sleeve shifting means connected with first seal means for moving a sliding sleeve in a first direction; means connected with said first sleeve shifting means for releasably holding said well tool against movement within said flow conductor; second sleeve shifting means connected with said last mentioned means for moving a sliding sleeve in a second direction; second seal means slidable in said flow conductor connected with said second sleeve shifting means; and support means connected with said second seal means for releasably holding well tool means installed in and removed from said flow conductor by said well tool.

40. A well tool assembly comprising: first shifting means for moving a sliding sleeve in a first direction;

means connected with said first shifting means for releasably holding said tool assembly against movement within a flow conductor; second shifting means connected with said first shifting means for moving a sliding sleeve in a second direction; slidable seal means connected with said first and second shifting means for propelling said well tool assembly along said flow conductor responsive to a pressure differential applied across said seal means; and support means connected with said seal means for releasably holding a well tool means during installation and removal of said well tool means by said well tool assembly in said flow conductor.

41. A method of installing well tool means in a flow conductor having sliding sleeve valve means each including a sliding sleeve movable between open and closed positions, said method comprising: displacing said tool train along said flow conductor through said sliding sleeve valve means sequentially moving each of said sliding sleeves through which said tool train passes from its open to its closed position; reversing the direction of movement of said tool train in said flow conductor displacing said tool train back through said sleeve valve means while sequentially moving each of said sliding sleeves back to its open position and releasing one of said well tool means from said tool train and releasably locking said well tool means in each of said sliding sleeve valves.

42. A method of removing well tool means from sliding sleeve valve means in a flow conductor, said sliding sleeve valve means each having a sliding sleeve movable between an open position and a closed position with a fluid displaceable tool train including means for supporting said well tool means thereon comprising: displacing said tool train from a first end of said flow conductor toward a second end thereof sequentially releasing each well tool means from its sliding sleeve and moving said sleeve to a closed position until all of said well tool means have been released from said sliding sleeve valve means and said sleeves have been moved to a closed position; assembling said well tool means in end-to-end array toward a second end of said flow conductor; coupling said well tool means to said support means of said tool train; and displacing said tool train with said well tool means secured thereto back toward said first end of said flow conductor through said sliding sleeve valve means sequentially moving each of said sliding sleeves to an open position.

43. A method of installing devices in a well having a tubing string, a plurality of locking nipples in said tubing string, each nipple having a selective seat for one of said devices, comprising: the steps of inserting a train of said devices in said tubing string, pumping a fluid into said tubing string above said train to move said train down said tubing string to a lower position below the locking nipples, reversing the flow of fluid in the tubing string to move said train up said tubing string and seat and latch each device in the selective locking nipple in which it will seat until all of said devices are seated in their locking nipples.

44. The method of removing a plurality of devices from a well having a tubing string, a plurality of locking nipples in said tubing string, each nipple having a selective seat for one of said devices, comprising: the steps of inserting propulsion means in the tubing string above the uppermost locking nipple, injecting fluid pressure in the tubing string above said propulsion means to progressively unseat each of said devices from the upper to the lower and move said devices to the lowest locking nipple, and reversing the fluid pressure in the tubing

string to the lower end of the tubing to inject fluid pressure below the lowest locking nipple, and moving the devices and propulsion means as a train by such fluid pressure from below upwardly out of said tubing string.

45. The method of installing a device in a well having a tubing string, a plurality of locking nipples in said tubing string, one of said nipples having a selective seat for receiving said device, said method comprising: the steps of inserting said device in said tubing string, pumping a fluid into the tubing string above said device to move said device down the tubing string to the lower end thereof, and reversing the movement of the fluid in the tubing string to below the device to move said device upwardly in said tubing string to the selective locking nipple for receiving said device, and latching and seating said device in said locking nipple.

46. The method of removing a device from a well having a tubing string, a plurality of locking nipples in said tubing string, one of said nipples having a selective seat receiving said device, said method comprising: inserting an operating tool assembly in said tubing string above said uppermost nipple; pumping fluid into said tubing string above said assembly to move said device out of said nipple and said assembly and said device down said tubing string to the lower end thereof, reversing the movement of fluid in the tubing string to the lower end of the tubing string below the device and said assembly, and then pumping said assembly and said device up said tubing string out of said well.

47. The method of installing and removing devices for a well having a tubing string, a plurality of locking nipples in said tubing string, each nipple having a selective seat for one of said devices, comprising: the steps of inserting a train of devices in said tubing string, pumping fluid in said tubing string above said train to move said train in said tubing string to the lower end thereof; reversing the flow of fluid in the tubing string to below the train of devices and pumping said fluid up said tubing string to move said train up said tubing string and seat each device in the locking nipple in which it will seat until all of said devices are seated in their respective locking nipples; thereafter exerting fluid pressure on the upper end of said tubing string above the uppermost device in said tubing string; pumping said devices progressively down the tubing to the lower end thereof to unseat the same and connect the devices in a train; and then reversing the flow of fluid in said tubing string to pump said devices upwardly out of the tubing string as a train.

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166—5, 153, 224, 214; 137—625.12, 155; 103—233

**UNITED STATES PATENT OFFICE**  
**CERTIFICATE OF CORRECTION**

Patent No. 3,419,074

December 31, 1968

Norman F. Brown

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 36, "a", first occurrence, should read -- at --. Column 3, line 31, "coupled" should read -- coupler --; line 43, "seciton" should read -- section --. Column 4, line 41, "of the sleeve shifting unit of the up-shift" should read -- illustrating the sleeve shifting unit in its --. Column 7, line 52, "prove" should read -- probe --. Column 32, line 61, after "connector" insert -- socket --. Column 60, line 42, "1873" should read -- 1874 --. Column 65, line 34, "clog" should read -- dog --; line 40, after "permit" insert -- fluid --. Column 73, line 72, "The released latch unit and its gas lift valve may" should read -- being inserted into and through the uppermost gas --. Column 82, line 75, "position" should read -- piston --. Column 83, line 9, "of" should read -- for --. Column 90, line 49, "retractable" should read -- retracted --.

Signed and sealed this 28th day of April 1970.

(SEAL)  
Attest:

EDWARD M. FLETCHER, JR.  
Attesting Officer

WILLIAM E. SCHUYLER, JR.  
Commissioner of Patents