Sept. 21, 1971 H. E. SCHWEGMAN 3,606,926

APPARATUS AND METHOD FOR INSTALLING AND REMOVING WELL TOOLS IN A TUBING STRING

Filed April 17, 1969 11 Sheets-Sheet 1

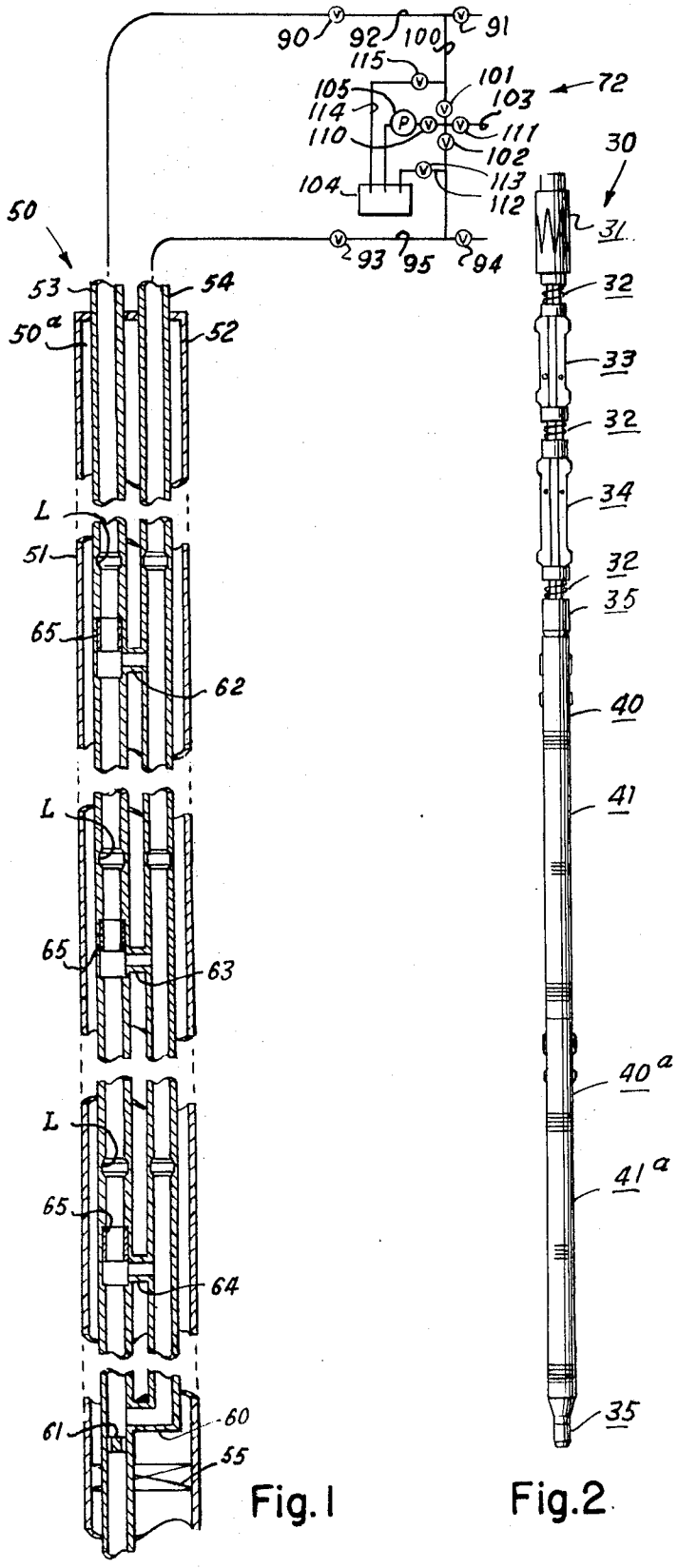


Fig. 1

Fig. 2

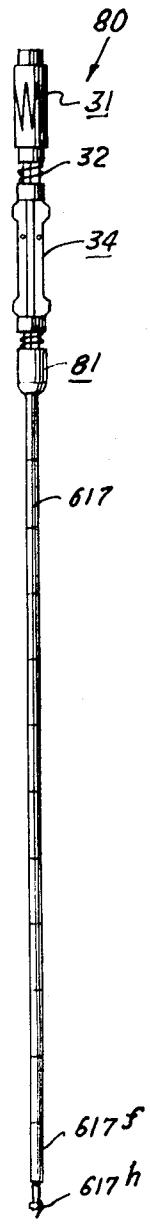


Fig. 13

INVENTOR.
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ATTORNEY

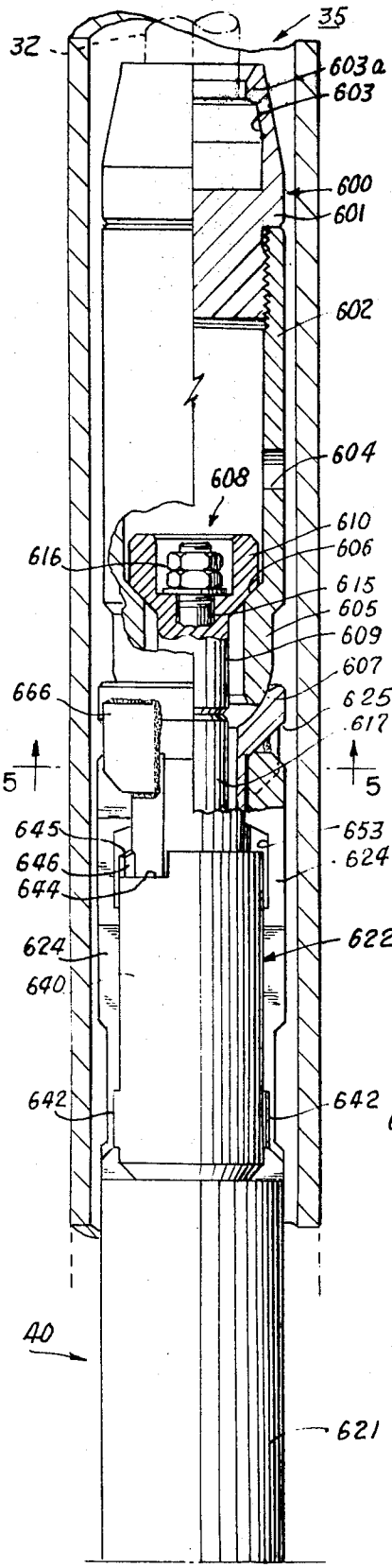


Fig. 3A

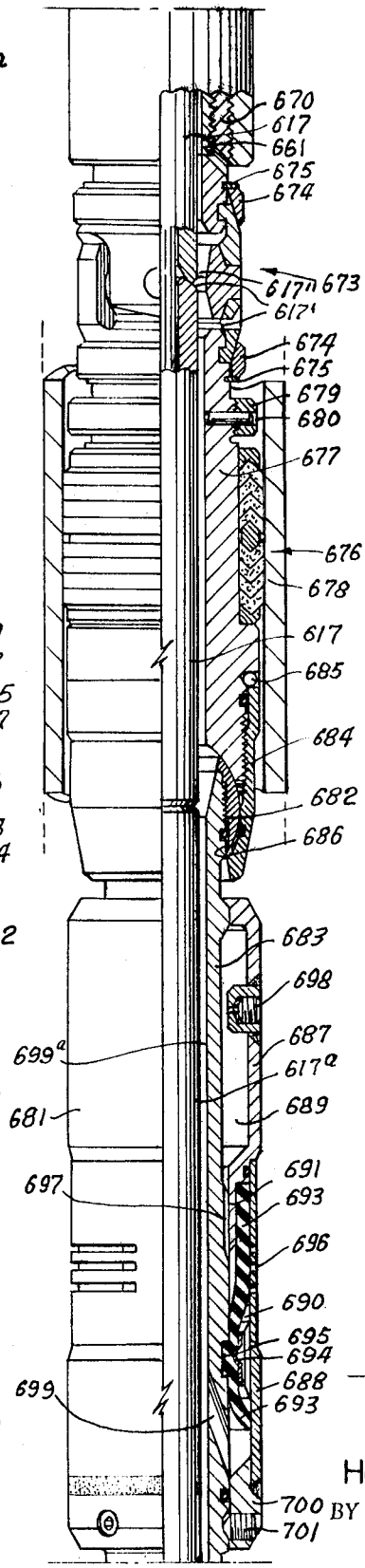


Fig. 3B

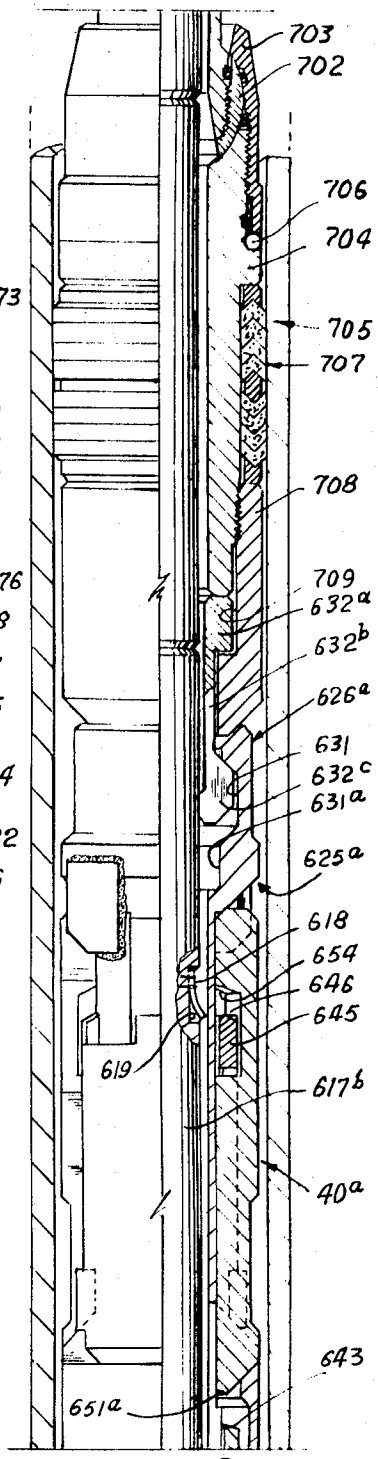


Fig. 3C

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Sept. 21, 1971 H. E. SCHWEGMAN 3,606,926

APPARATUS AND METHOD FOR INSTALLING AND REMOVING WELL TOOLS IN A TUBING STRING

Filed April 17, 1969 11 Sheets-Sheet 3

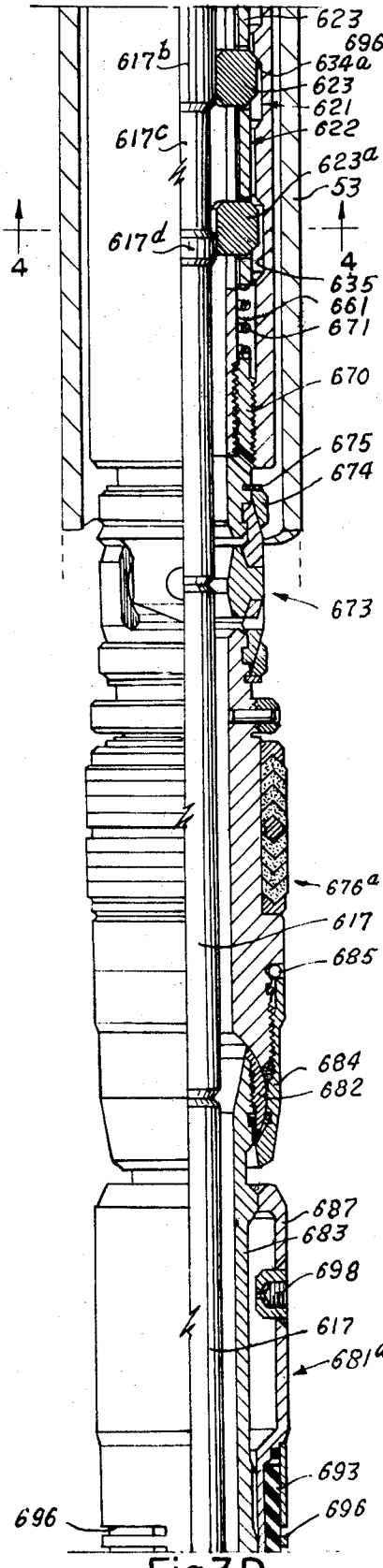


Fig.3D

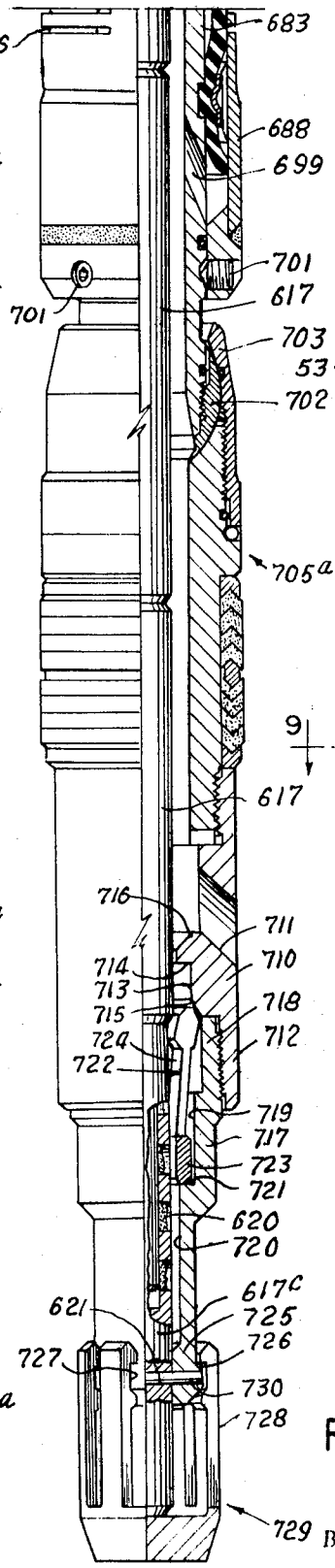


Fig.3E

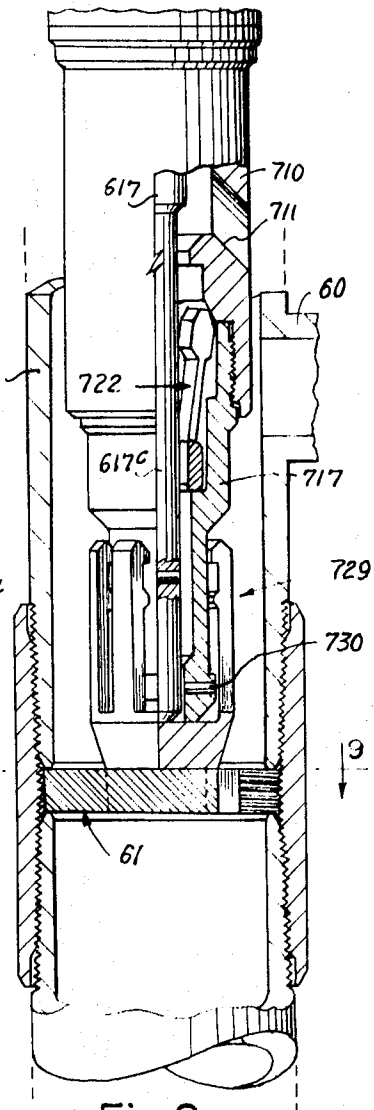


Fig.8

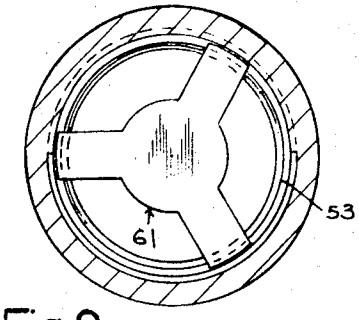


Fig.9

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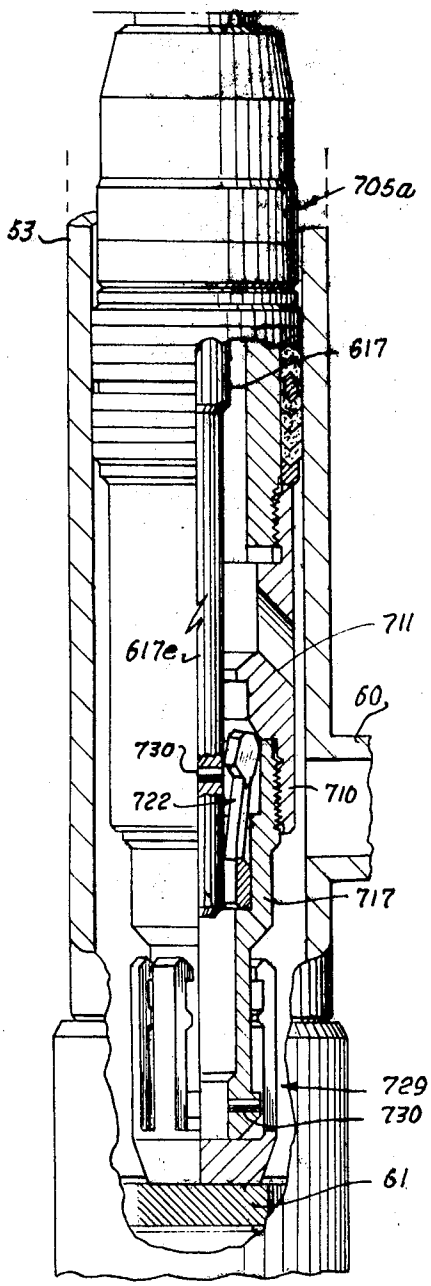


Fig.10D

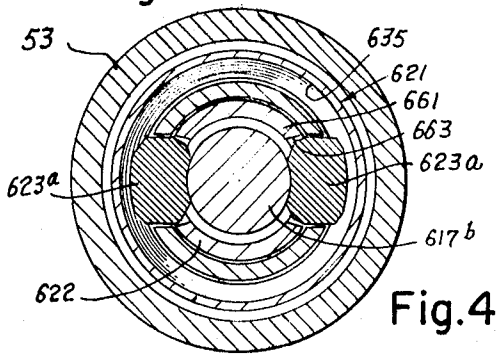


Fig.4

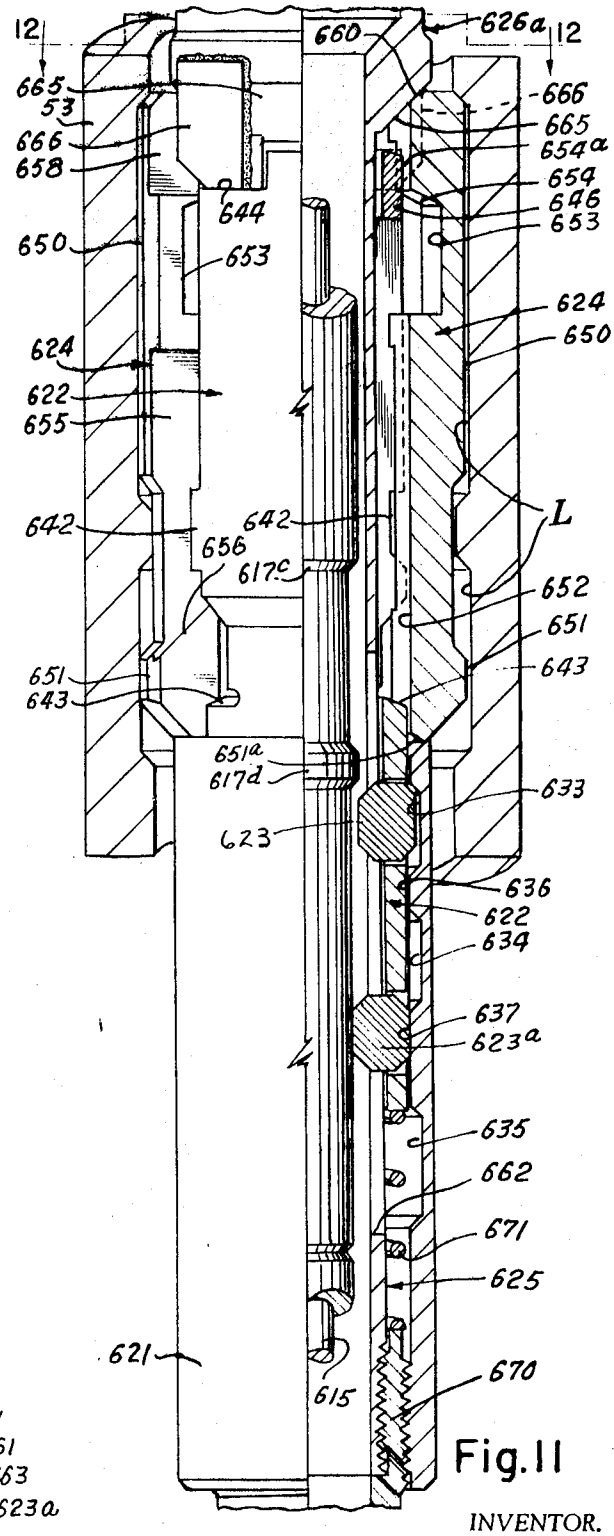


Fig.11

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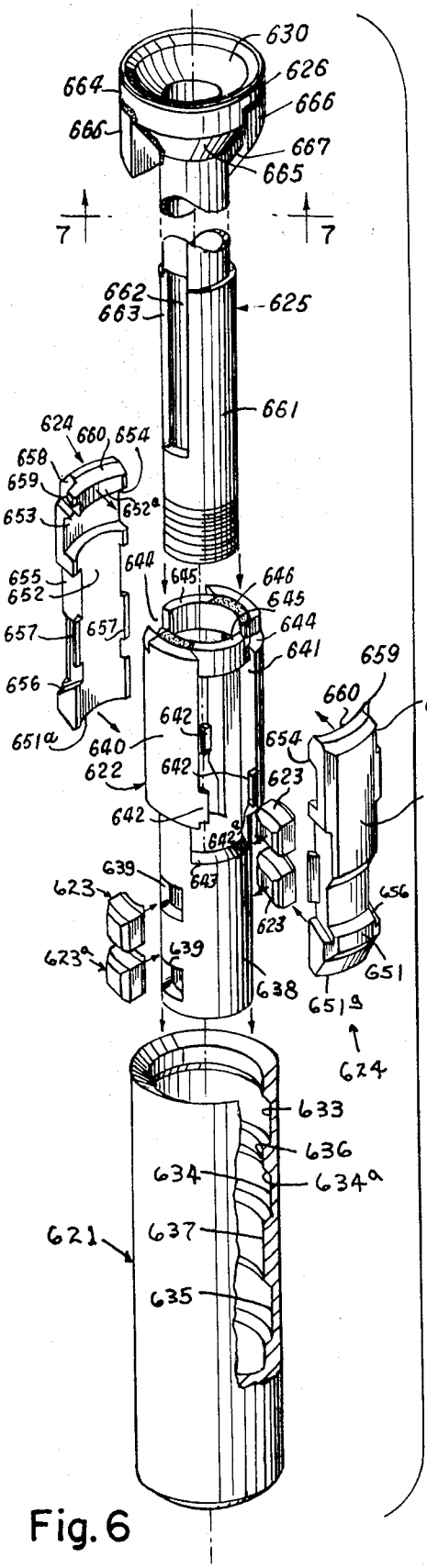


Fig. 6

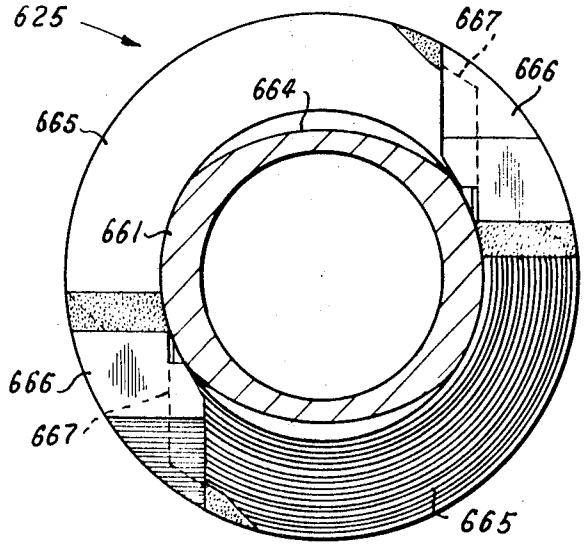


Fig. 7

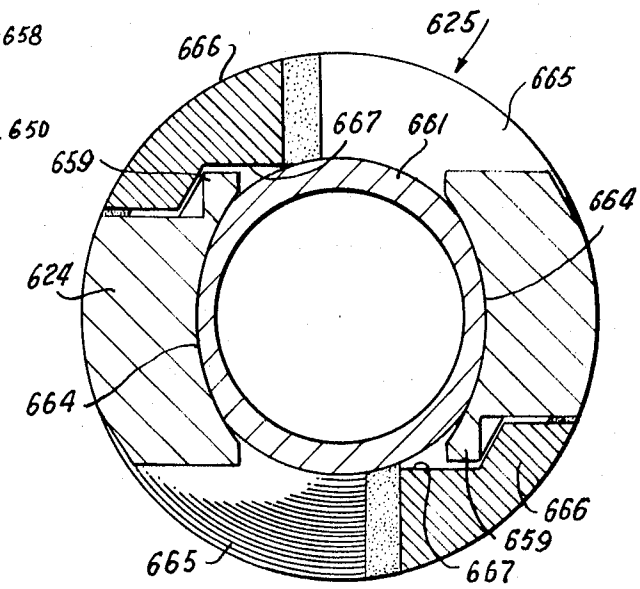


Fig. 5

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Sept. 21, 1971 H. E. SCHWEGMAN 3,606,926
APPARATUS AND METHOD FOR INSTALLING AND
REMOVING WELL TOOLS IN A TUBING STRING
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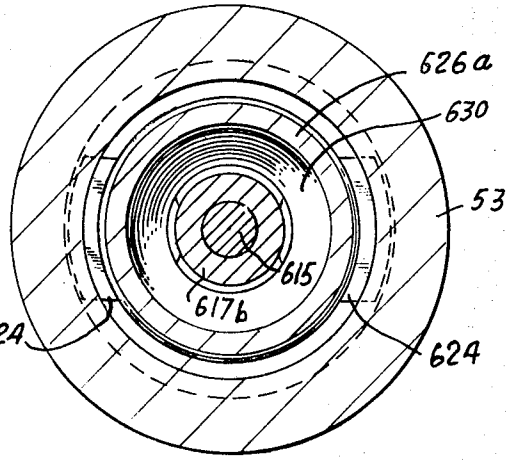


Fig.12

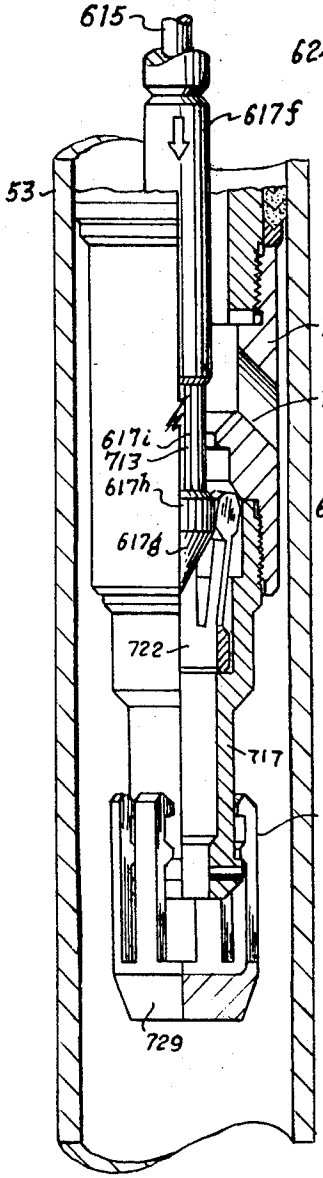


Fig.14

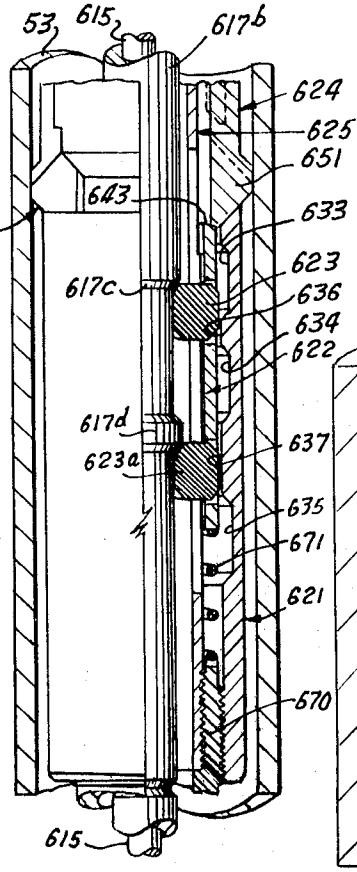


Fig.8A

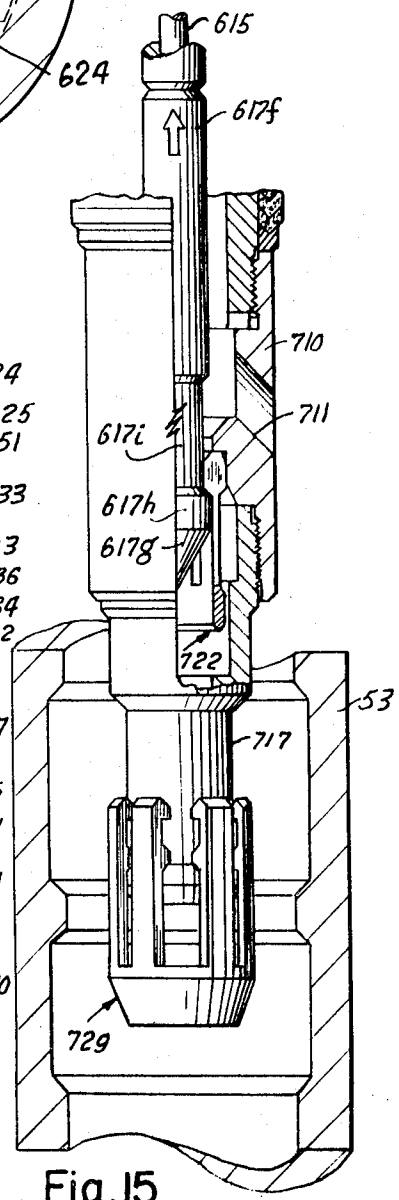


Fig.15

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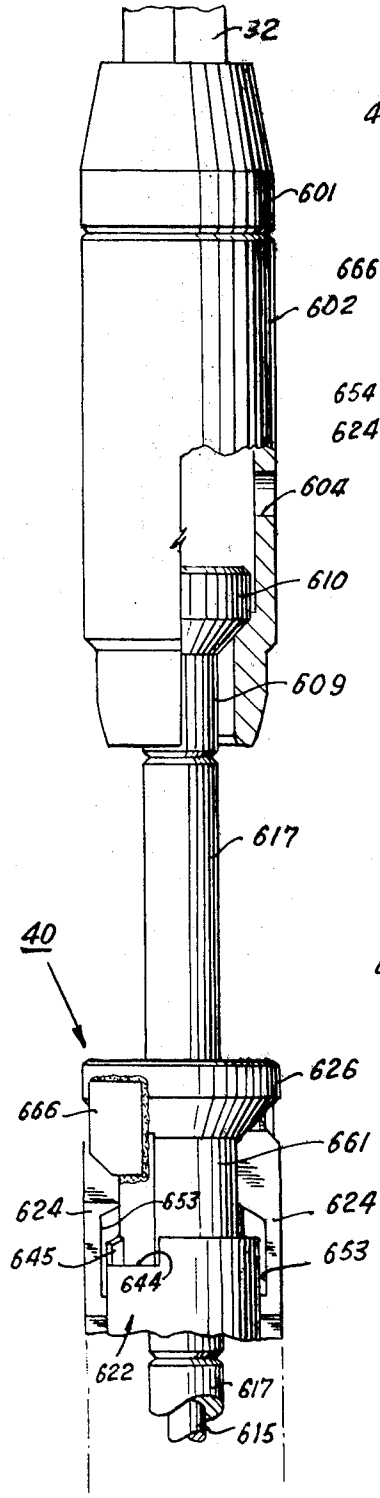


Fig. 10 A

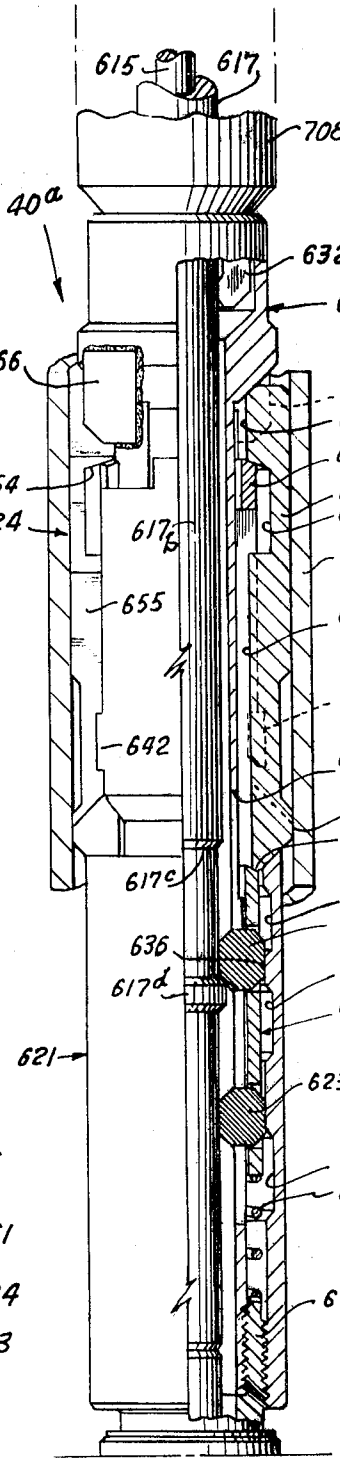


Fig. 10 B

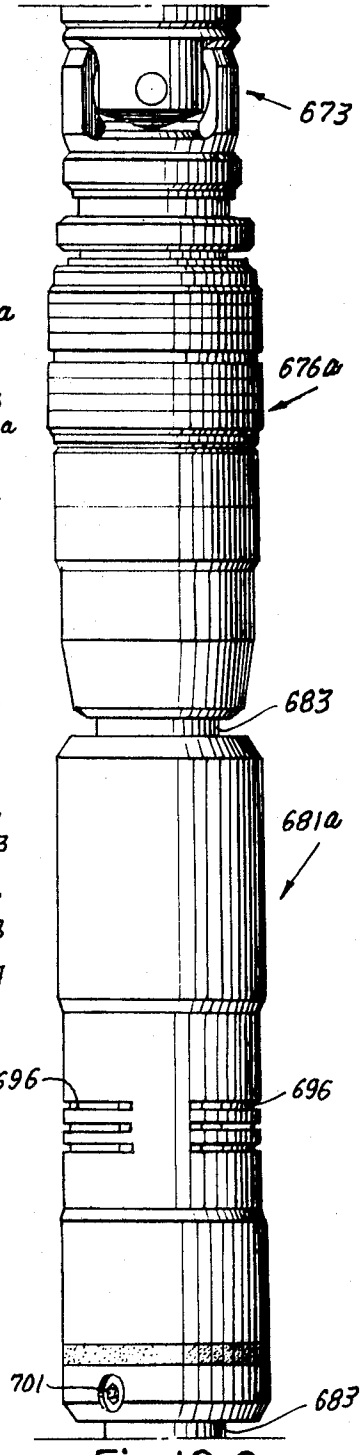


Fig. 10 C

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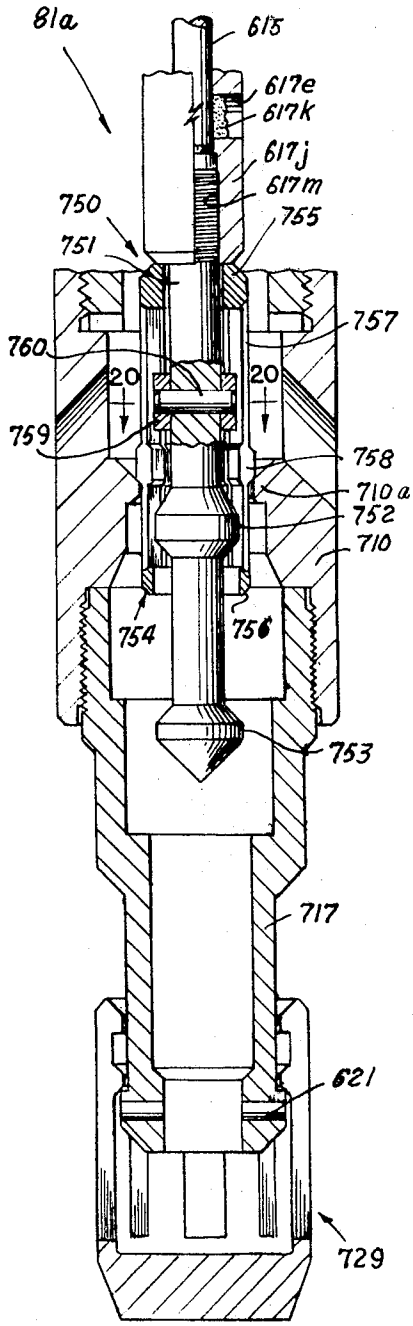


Fig.16

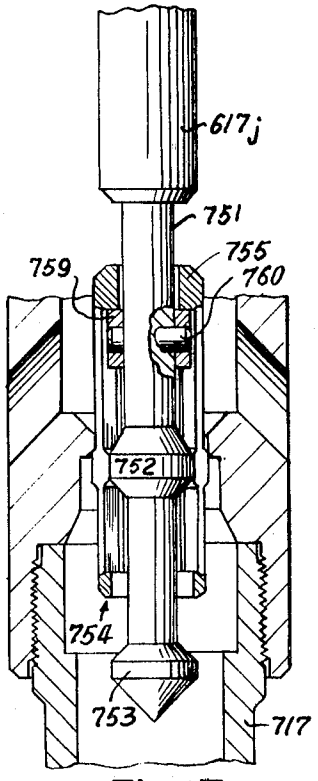


Fig.17

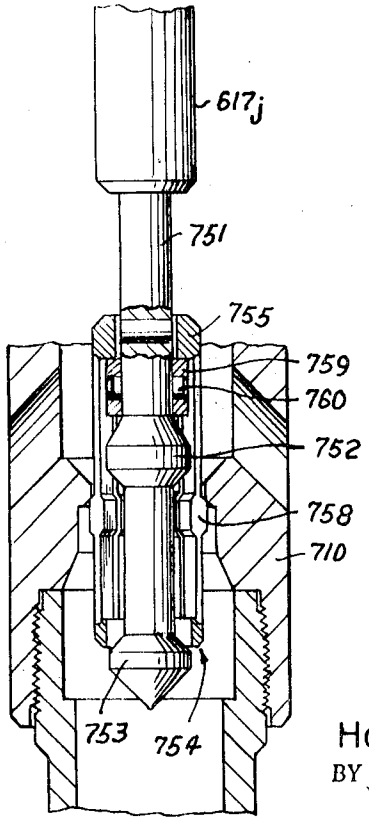


Fig.18

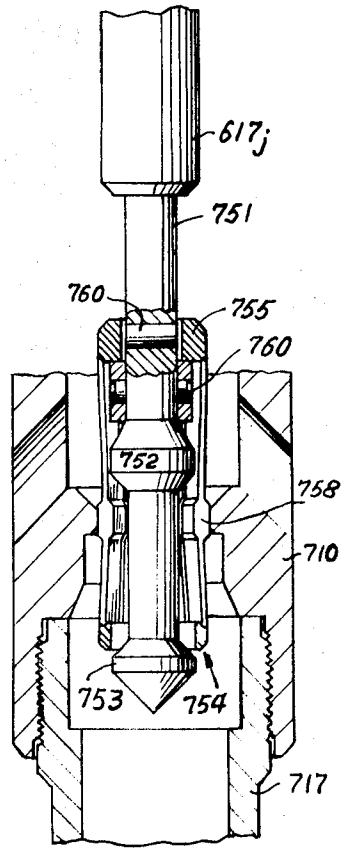


Fig.19

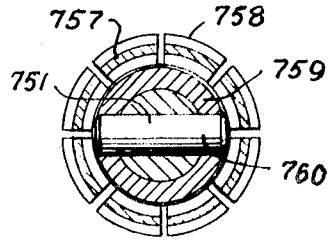


Fig.20

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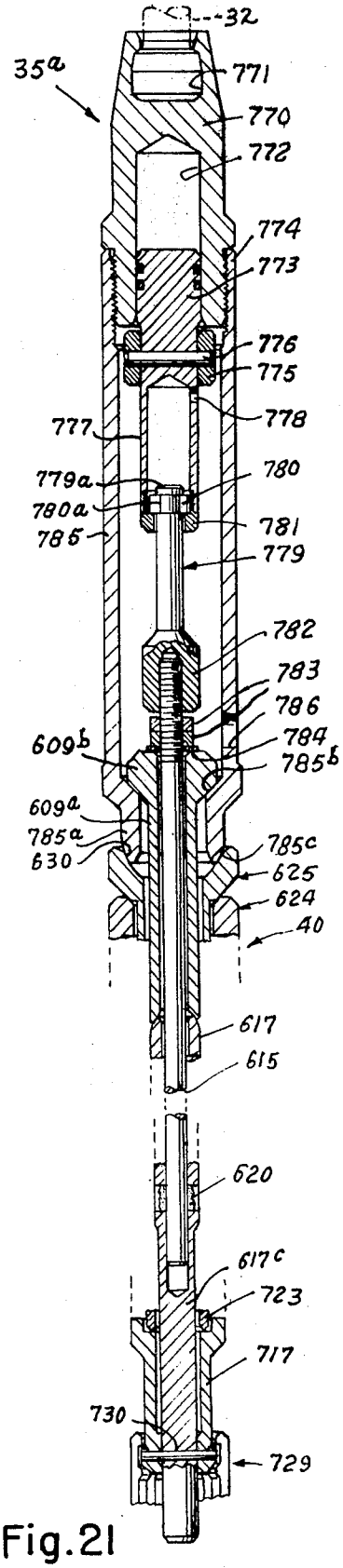


Fig.21

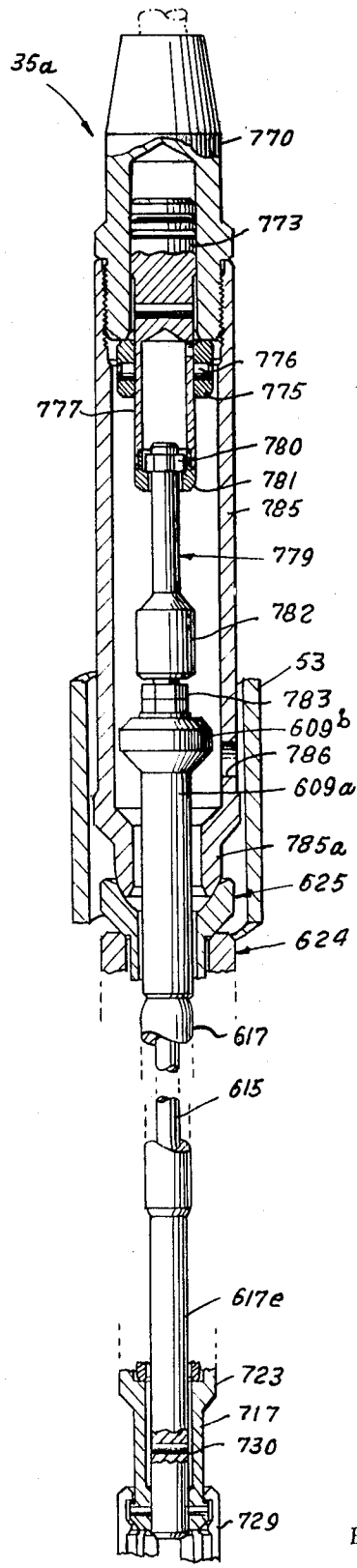


Fig.22

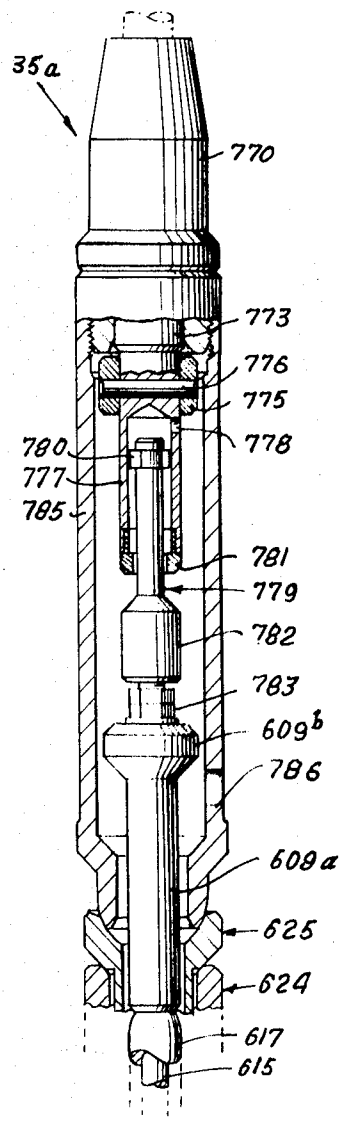


Fig.23

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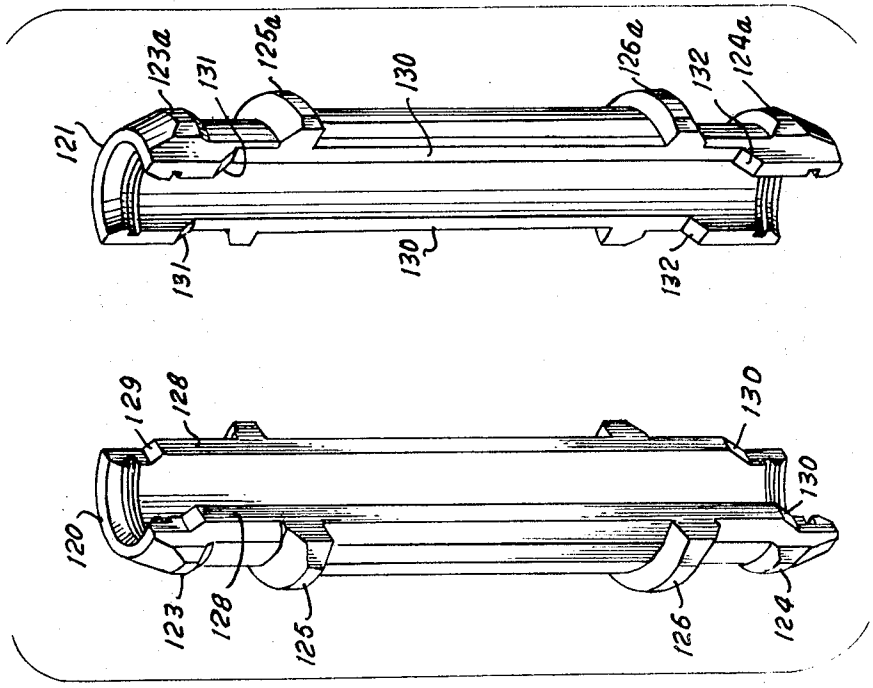


Fig.26

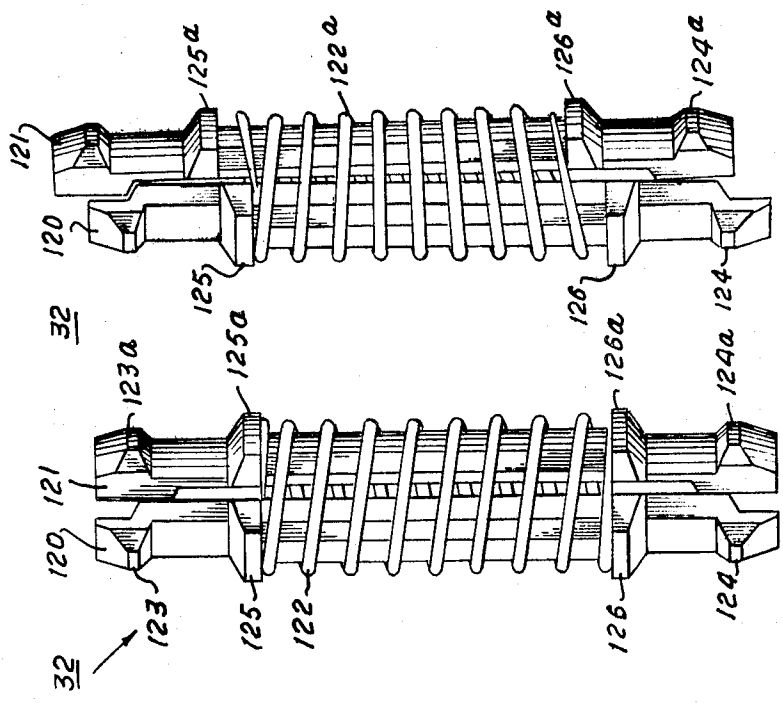


Fig.25

Fig.24

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Sept. 21, 1971 H. E. SCHWEGMAN 3,606,926

APPARATUS AND METHOD FOR INSTALLING AND REMOVING WELL TOOLS IN A TUBING STRING

Filed April 17, 1969 11 Sheets-Sheet 11

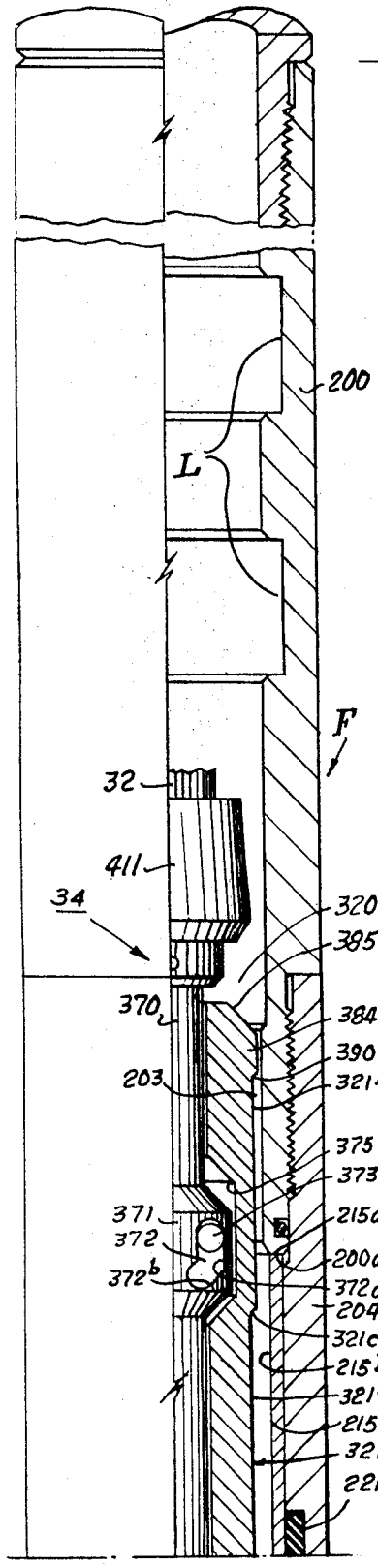


Fig. 27

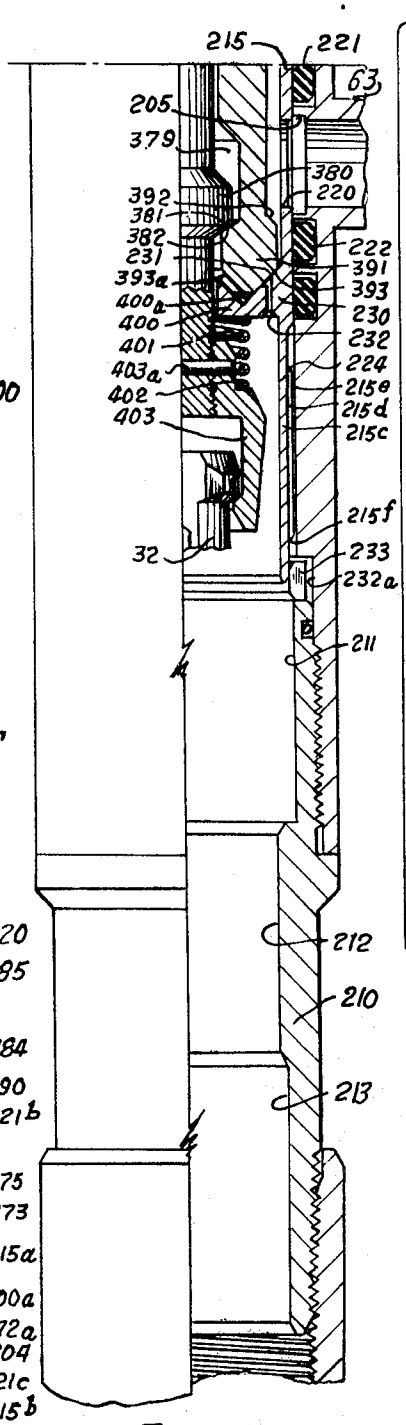


Fig. 27A

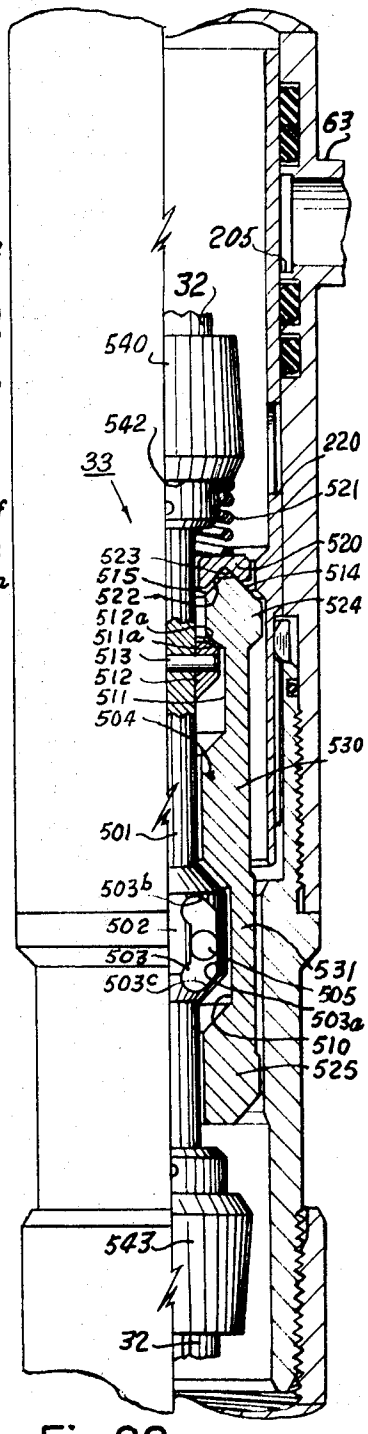


Fig. 28

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United States Patent Office 3,606,926 Patented Sept. 21, 1971

3,606,926

APPARATUS AND METHOD FOR INSTALLING AND REMOVING WELL TOOLS IN A TUBING STRING

Harry E. Schwegman, Plano, Tex., assignor to Otis Engineering Corporation, Dallas, Tex.

Filed Apr. 17, 1969, Ser. No. 816,942
Int. Cl. E21b 23/02
U.S. Cl. 166—315 54 Claims

ABSTRACT OF THE DISCLOSURE

A well tool system for installing and retrieving well tools, such as gas lift valves, in a tubing string. A tubular latch is provided for locking each well tool at a landing nipple in the tubing string. The latch has locking keys with operator members manipulated responsive to a supporting probe for locking and releasing each latch at a landing nipple. One or a plurality of the latches with connected well tools are supported on the probe in tandem. The probe and supported latches and well tools are connected in a tool train which may include wireline or pump-down handling tools with sleeve valve operators for opening and closing sliding sleeve valves at the landing nipples when installing and removing the latches and well tools. The tool train is run in a tubing string to a depth below the lowest landing nipple and is then returned to the surface sequentially releasing and locking the latches at the landing nipples spaced along the tubing string. The latches and tools are retrieved by running the tool train with a probe downwardly sequentially releasing the latches and engaging them on the probe in end-to-end array. When all of the latches and well tools are released and on the probe, the tool train is returned to the surface. During both installing and removing the latches and tools, the sleeve shifting units in the tool train open and close the sleeve valves as required.

This invention relates to well tools and more specifically to a well tool system for installing and removing tools in a well tubing.

It is a particularly important object of the invention to provide a new and improved tool system for installing and removing well tools in well tubing.

It is another object of the invention to provide a well tool system of the character described which is operable by pumping techniques.

It is another object of the invention to provide a system and method for the installation and removal of well tools in a well located remotely from a surface installation as in the case of an off-shore underwater well connected with an on-shore surface well control and servicing installation.

It is another object of the invention to provide a system which permits well tools to be pumped between a control station and locations within the tubing of a well.

It is another object of the invention to provide a system for installing well tools in a tubing string wherein each well tool, such as a gas lift valve, is sequentially released and locked in the tubing as a string of the tools including apparatus for manipulating the tools in the tubing is pumped through the tubing.

It is another object of the invention to provide a method and apparatus for the installation of well tools in a tubing wherein a string of well tools is pumped from the surface through the tubing to a depth below that at which one or more of the well tools is to be released and locked in the tubing and the tool or tools are released and locked in the tubing during the return trip of the string of tools toward the surface.

It is another object of the invention to provide a well tool system of the character described wherein a string of tools is pumped through tubing to a collar stop in the tubing below the locations at which the tools are to be released and locked in the tubing with the impact of striking the collar stop partially releasing or "arming" latches in the tool string for subsequent release from the string and locking in the tubing.

It is another object of the invention to provide a well tool system of the character described wherein the string of tools to be installed in the tubing string is pumped only to a depth below the lowest location at which one or more of the tools is to be released and locked in the tubing.

It is a further object of the invention to provide a well tool system of the character described wherein the well tools supported in the tool string are released and locked at desired locations in the tubing string by manipulation of fluid pressure in the tubing.

It is a further object of the invention to provide a well tool system of the character described wherein a string of well tools is pumped through the well tubing to a depth below the location at which the lowermost well tool is to be installed and the tool string is returned toward the surface sequentially releasing and locking each well tool in the string with the supporting and motive means for the string of well tools being returned to the surface and removed from the well system.

It is a further object of the invention to provide a well tool system of the character described wherein the well tools are sequentially released from locking recesses in the well tubing, pumped down the tubing to stop means therein, secured on retrieving means, and pumped as a tool string unit back to the surface.

It is another object of the invention to provide a well tool system which includes a latch for releasably locking a well tool at a locking recess in well tubing, a running probe for supporting and installing the latch in well tubing, and a pulling probe for releasing and removing the latch from the well tubing.

It is another object of the invention to provide a well tool string for pumping through well tubing including a power piston, sleeve valve operating means, and probe means for supporting one or more well tools for movement through the well tubing.

It is another object of the invention to provide a well tool system of the character described including releasable latch means adapted to be pumped with a well tool coupled thereto into well tubing, locked in the tubing, subsequently released from the tubing, and pumped back to the surface in the tubing.

It is a further object of the invention to provide a well tool system of the character described which includes a power piston for pumping a tool string through a well tubing, a sleeve valve shifter for moving sleeve valves in well tubing from an upper to a lower position, a sleeve valve shifter for moving the sleeve valves back upwardly from the lower position, a running probe for supporting one or more well tools to be released and locked in the well tubing, and one or more latches supportable on the probe to be released and locked in the well tubing for supporting a well tool connected with each of the latches.

It is a further object of the invention to provide a well tool system of the character described including a power piston, a sleeve valve shifter for returning sleeve valves in a well tubing from a lower to an upper position, and a pulling or retrieving probe for releasing, coupling with, and retrieving well tools from the well tubing.

It is a still further object of the invention to provide a tool string for pumping well tools into well tubing and releasing and locking the tools in the tubing including a running probe adapted to release the well tools supported

on the probe responsive to a mechanical impact force against a stop member in the well tubing.

It is another object of the invention to provide a well tool system of the character described including a running probe for supporting the well tools including means for hydraulically releasing the well tools supported on the probe at any desired depth in a well by manipulation of fluid pressures in the well tubing.

It is a further object of the invention to provide a well tool system of the character described including a pulling probe for releasing and removing the well tools from well tubing and including means for release of the probe from well tools which are stuck or jammed in the well tubing and thus cannot be removed by normal forces applicable through the probe.

It is a still further object of the invention to provide a latch for releasably supporting well tools in a well tubing, the latch being supportable on a probe structure during installation and retrieval and being pumpable through the well tubing from a surface installation.

It is a further object of the invention to provide a well tool system including tool strings for both installation of and removal of well tools such as strings being articulated to permit traverse of curved tubing sections.

It is a further object of the invention to provide a well tool latch for releasably locking a well tool in a tubing including expandable and contractable locking keys movable by operator lugs and sleeve means operable responsive to positioning of a running or pulling probe inserted through a longitudinal central passage through the latch.

It is another object of the invention to provide a well tool latch for releasably locking a well tool in a tubing, such latch having a full bore opening throughout its length.

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

FIG. 1 is a schematic view of a well system in which a well tool system embodying the invention is operable and showing particularly a fragmentary longitudinal broken section of a cased well having a well tubing system for manipulating the well tool system by pumpdown techniques;

FIG. 2 is a longitudinal view in elevation of a tool string embodying the invention for running-in or installing well tools by pumpdown procedures;

FIGS. 3A–3E constitute a longitudinal view, partially in section, of the tool string including the running probe, latches, and gas lift valves shown in FIG. 2 as the tool string is run into a well tubing;

FIG. 3A shows the head of the running probe and the upper end of the upper latch of the tool string;

FIG. 3B illustrates the lower end of the upper latch and the upper gas lift valve with its upper seal assembly;

FIG. 3C shows the lower seal assembly of the upper gas lift valve and the upper portion of the lower latch in the tool string;

FIG. 3D shows the lower portion of the lower latch together with the upper seal assembly and an upper portion of the lower gas lift valve;

FIG. 3E illustrates a lower portion of the lower gas lift valve with its lower seal assembly and the lower end of the running probe together with the bottom subassembly on the lower gas lift valve for coupling the tools and latches with the running and pulling probes;

FIG. 4 is a cross-sectional view taken along the line **4—4** of FIG. 3D;

FIG. 5 is an enlarged cross-sectional view of the upper latch mandrel head and locking keys taken along the line **5—5** of the FIG. 3A;

FIG. 6 is an exploded perspective view partially broken away of the major parts of the upper latch;

FIG. 7 is an enlarged cross-sectional view of the upper latch mandrel head taken along the line **7—7** of FIG. 6;

FIG. 8 is a fragmentary view in longitudinal section and elevation showing the lower end of the tool train and the running probe after the train has landed on a stop in the tubing to release the latches from the running probe;

FIG. 8A is a fragmentary longitudinal view, partly in section, showing the relative positions of the running probe, the locking keys and the operating lugs of the lower latch when armed or partially released after the running probe engages the stop as represented in FIG. 8;

FIG. 9 is a view in section of the bottom stop along the line **9—9** of FIG. 8;

FIGS. 10A through 10D comprise a longitudinal view, partly in section, of the tool string during a return trip in a tubing with the lower latch armed for release and locking at a landing nipple;

FIG. 10A shows the head of the running probe with the upper end of the upper latch;

FIG. 10B illustrates intermediate and lower sections of the lower latch with the locking keys expanded to the tubing wall as the latch moves upwardly toward a landing nipple in the tubing string;

FIG. 10C shows the lower gas lift valve and its upper seal assembly in elevation;

FIG. 10D shows the lower end of the lower seal assembly of the lower gas lift valve and the bottom subassembly of the tool string for coupling the string after the tool string and probe have landed at the bottom stop in the tubing and with the probe moved upwardly relative to the latches and gas lift valve;

FIG. 11 is an enlarged fragmentary view, partly in section, showing the relative positions of the running probe with the latch locking keys and operating lugs when the latch is locked at a landing nipple by its locking keys expanded into the locking recesses of the landing nipple;

FIG. 12 is a view in section along the line **12—12** of FIG. 11;

FIG. 13 is a reduced longitudinal view in elevation of a tool string including a pulling probe, a power piston unit, and a sliding sleeve downshift unit;

FIG. 14 is a fragmentary, longitudinal view partly in section of the lower end of the bottom subassembly of the lower gas lift valve and the lower end of the pulling probe as the pulling probe is initially inserted into the subassembly;

FIG. 15 is a view similar to FIG. 14 as the pulling probe is lifted engaging the subassembly for raising the lower gas lift valve and latch in the tubing;

FIG. 16 is a fragmentary longitudinal view partly in section, of the lower end of a modified form of pulling probe when inserting the probe into the bottom of a modified form of bottom subassembly adapted for use with the modified probe;

FIG. 17 is a fragmentary longitudinal view partly in section, similar to FIG. 16 showing the pulling probe engaged in the subassembly for lifting the assembly in the tubing;

FIG. 18 is a view similar to FIG. 17 showing the functioning of the releasable feature of the modified pulling probe when the subassembly and its related tools become jammed or lodged in the tubing string;

FIG. 19 is a view similar to FIG. 18 showing a subsequent stage in the functioning of the modified pulling probe as the probe releases from the subassembly;

FIG. 20 is a view in section along the line **20—20** of FIG. 16;

FIG. 21 is a fragmentary longitudinal view in section of the head and bottom ends of a further modified form of running probe adapted to be hydraulically actuated in the tubing string at any desired depth, showing the probe as run into the tubing;

FIG. 22 is a longitudinal view similar to FIG. 21 show-

ing the modified running probe after it has been hydraulically actuated to release the probe from the gas lift valves and latches supported on it;

FIG. 23 is a view similar to FIG. 22 showing only the upper end portion of the modified running probe after mechanically releasing the probe from the gas lift valves and latches at the bottom of a tubing;

FIG. 24 is a longitudinal view in elevation of a coupler used for connecting together the power piston and sleeve shifting tools in the tool string;

FIG. 25 is a view of the coupler shown in FIG. 24 with its parts shifted so that they are compressed together at one end for insertion into the coupling recess of a well tool;

FIG. 26 is an enlarged exploded perspective view of the two principal parts of the coupler;

FIGS. 27 and 27a taken together illustrated in section and elevation a sliding sleeve valve for use in the well system of FIG. 1, showing the valve at its upper open position, and a sleeve valve shifting tool disposed in the sleeve valve for moving the valve downwardly to a closed position;

FIG. 27 shows upper portions of the sleeve valve and the sleeve shifting tool;

FIG. 27A shows lower portions of the sleeve valve and sleeve shifting tool and a fragment of the coupling of FIGS. 24–26 connected into the lower end of the sleeve shifting tool; and

FIG. 28 is a view similar to FIGS. 27 and 27A showing a lower portion of the sliding sleeve valve at a closed position with a sleeve shifting tool for moving the sleeve valve upwardly to an open position.

Referring to FIGS. 1, 2, and 13, a preferred form of tool string **30** embodying the invention includes a pumpable power piston **31** for driving the tool string through a tubing during both well tool installation and retrieval. The piston is connected by a coupler **32** to a sleeve shifter **33** for moving sliding sleeve valves in a well tubing string from lower to upper positions. The sleeve shifter **33** is secured by another coupler **32** to a sleeve shifter **34** for moving the sliding sleeve valves from an upper to a lower position. A running probe **35** is connected by another coupler **32** to the sleeve shifter **34** for supporting well tools and latches during the installation procedure in the well tubing. An upper latch **40** and gas lift valve **41** and a lower latch **40***a* and lower gas lift valve **41***a* are releasably supported on the running probe for installation in a well tubing.

A well system **50** in which the tool string **30** is useful for the installation of well tools, FIG. 1, includes a well **50***a* having a casing **51** provided with a well head **52** through which a pair of strings of well tubing **53** and **54** are supported in sealed relationship for conducting well fluids from the well and directing well servicing fluids into and out of the well. The casing may extend through and be perforated at a producing earth formation, not shown. The tubing **53** extends through a suitable conventional packer **55** downwardly to the vicinity of the producing formation for flowing well fluids to the surface. A lateral conduit **60** connects the lower end of the tubing **54** with the tubing **53** for communicating the tubings when the tool string is to be pumped into or out of the well. A stop **61** is secured in the tubing **53** in the vicinity of the conduit **60** so that when the lower end of the tool string engages the stop the piston **31** is above the conduit **60**. The tubings **53** and **54** communicate at spaced intervals through crossover connections **62**, **63**, and **64**. The tubings are selectively communicated and isolated from each other by sliding sleeve valves **65** located in the tubing string **53** at the cross-over connections **62**, **63** and **64**.

A surface installation **72** is connected with the surface ends of the tubings **53** and **54** for controlling the production of well fluids from the well through either of the tubings and for selectively directing fluids, such as lift gas and tool string displacing fluids, into either of the tubings while receiving fluid returns through the other of the tubings. Thus, the surface installation provides both for the control of primary well production and for effecting various well servicing and secondary recovery techniques in the well through the tubing strings and the related cross-over connections and other apparatus. The tubing **53** may include a standing valve, not shown, located below the conduit **60** to allow well fluids to rise from a producing formation into the tubings **53** and **54** while preventing the backflow of fluids, either well fluids or well servicing fluids, into any of the well conduits below the standing valve.

A pulling tool string **80** embodying the invention is illustrated in FIG. 13 and includes a power piston **31**, a sleeve shifter **34** for moving the sliding sleeve valves and a pulling probe **81** for removal of well tools from a locked relationship in a tubing of a well system. The pulling probe comprises an elongated articulated tubular structure for releasing well tools in a tubing and withdrawing the tools from the tubing.

In operation the tool string **30** is inserted into the surface end of the tubing **53** at the surface installation **72** which is adjusted to pump displacing fluid, such as oil or water, through the tubing **53** of the well system **50** and return to the surface installation through the tubing **54**. The tool string is pumped downwardly in the tubing **53** with the sleeve shifter **34** sequentially engaging and moving each of the sliding sleeve valves **65** downwardly to their closed positions as the tool string is pumped to the lower end of the tubing against the stop **61** partially releasing the latches on the probe. When the tool string reaches the stop the direction of fluid flow in the well system is reversed from the surface installation **72** to pump the tool string **30** upwardly on a return trip in the tubing **53**. The piston **31** and the sleeve shifting tool **33** pass upwardly through the lowest sleeve valve **65**. The sleeve shifter **33** which engages and moves the sleeve valve upwardly to its open position. The upper latch **40** and gas lift valve **41** pass through the lower sleeve valve **65** and the lower latch **40***a* is then fully released from the probe and locked in the tubing at the locking recess L above the sleeve valve. Continued upward movement of the tool string withdraws the probe from the lower latch and gas lift valve and lifts the probe in the upper latch and gas lift valve shifting the upper latch keys to an intermediate armed condition. The upper latch is lifted by the probe into the next sleeve valve **65** which has been engaged by the sleeve shifter **34** and shifted open. The upper latch **40** and gas lift valve **41** are then released from the probe and locked at the sleeve valve. The tool string, after releasing all of the latch units and gas lift valves supported on its running probe, is pumped back to the surface installation **72** where it is removed from the system so that further well procedures such as gas lift production may be carried out in the well system.

When removal of the latches and gas lift valves from the well system **50** is desired, the tool string **80** with its pulling probe **81** is inserted into the tubing **53** at the surface installation and pumped through the tubing downwardly in the well. As the tool string arrives at the upper latch and gas lift valve the pulling probe is inserted downwardly through the latch and gas lift valve releasing the latch from its locking recess in the tubing. Continued pumping then forces the tool string with the upper latch and gas lift valve on the pulling probe downwardly in the tubing until the tool string reaches the next latch and gas lift valve where the procedure is repeated with the latch and gas lift valve becoming engaged on the probe and forced downwardly with the tool string. Each latch and gas lift valve assembly locked in the tubing is thus sequentially released and engaged on the pulling probe. After each latch and valve assembly is released and forced downwardly, the sleeve valve at which it had been locked is moved downwardly to a closed position by the downshifter **34**. The entire tool string including all of the re-

leased latches and gas lift valves on the probe are forced downwardly until the lower end of the probe engages the collar stop **61** to cause the latches to be fully locked on the pulling probe. Fluid flow direction is then reversed in the well system pumping the tool string with the pulling probe and latches and gas lift valves engaged thereon back to the surface installation where they are removed from the tubing string.

The surface installation **72** schematically illustrated in FIG. 1 is exemplary of only one arrangement of conduits, valves, pumps, and the like for controlling the production and servicing of a well system. The installation may in the case of an offshore well be situated at a shore location perhaps as far as several miles from the actual location of the well system **50**. The tubing **53** at the surface installation is connected through spaced valves **90** and **91** defining a lubricator tubing section **92** for the loading and unloading of the tool strings **30** and **80**. Similarly, the tubing **54** at the surface installation includes spaced valves **93** and **94** which define a lubricator tubing section **95** in the tubing **54** which similarly may be used for the insertion and removal of a tool string such as the tool strings **30** and **80**. The lubricator sections **92** and **95** communicate through a conduit **100** which connects into the lubricator sections near the valves **91** and **94**, respectively, so that displacing fluid may be pumped into the lubricators for displacing the tool strings from the lubricators through the tubing into the well system. The conduit **100** is connected through a pair of spaced valves **101** and **102**. A conduit **103** is connected into the conduit **100** between the valves **101** and **102**. The conduit **103** leads to a reservoir tank **104** through a pump **105** and includes a pair of spaced valves **110** and **111** located on opposite sides of the conduit **100**. A return line **112** including a valve **113** leads from the conduit **100** to the reservoir for returning fluids from the lubricator section **95** into the reservoir tank. The conduit **112** is connected into the conduit **100** between the valve **102** and the connection of the conduit **100** into the lubricator section **95**. Similarly, a return line **114** including a valve **115** is connected from the reservoir tank into the conduit **100** at a location between the valve **101** and the lubricator section **92**. The surface ends of the tubings **53** and **54** connected into the valves **91** and **94**, respectively, may lead to well fluid treatment facilities such as separators, storage tanks, and the like and, also, may be connected with other facilities such as means for pumping lift gas into the well system when the well is to be produced by such a secondary recovery method.

The well head **52** and the supporting and sealing connections at the well head for the tubings **53** and **54**, may be any suitable standard apparatus.

A preferred form of the sleeve valves **65** in the tubing **53** is illustrated in FIGS. 27 and 27A.

The sleeve valve includes an upper sub **200** which is internally threaded at its upper end for connection with a section of tubing string above it. The sub is provided with the internal spaced recess L for receiving locking keys on the latches **40** and **40***a* and with a reduced bore portion **203** which receives a seal on the gas lift valves and also functions in holding the lower end portions of the sleeve shifting keys of the sleeve shifter **34** pivoted outwardly while shifting the sleeve valve downwardly. The upper sub is threaded at its lower end into the upper end of a housing section **204** which is provided with a lateral port **205** for providing flow communication into the cross-over conduit **63** to the tubing string **54**. The lower end of the housing **204** is threaded on the upper end of a lower sub **210** which has an upper bore portion **211**, a reduced middle bore or cam portion **212**, an a lower bore portion **213** of a diameter intermediate that of the bore portions **211** and **212**. An upwardly facing shoulder surface **214** is provided in the bore of the lower sub between the upper bore portion **211** and intermediate bore portion **212**.

The sleeve valve **65** is slidably disposed in the housing section for movement between an upper open position, FIGS. 27 and 27A, and a lower closed position, FIG. 28. Upward movement of the sleeve is limited by engagement of its upper end surface **215***a* with the lower end surface **200***a* of the upper sub. The sleeve has an upper bore portion **215***b* which is larger in diameter than the cam bore portion **203** of the upper sub. A plurality of circumferentially spaced lateral ports **220** provided in the sleeve valve are alignable with the housing port **205** when the sleeve valve is at its upper position to provide flow communication between the interior of the valve and the cross-over conduit **60**. The sleeve outside diameter is slightly reduced along the ports **220** to provide an annulus around the sleeve for improved fluid distribution. Upper ring seal **221** and lower ring seals **222** are disposed within internal annular recesses provided in the housing **204** above and below the lateral port **205** for sealing between the sleeve valve and the housing. Intermediate its ends, at the lower end of the upper bore portion **215***b* the sleeve is provided with an internal annular flange **230** providing an upwardly facing shoulder **231** and a downwardly facing shoulder **232** which are engageable by sleeve shifting keys on the shifting tools **33** and **34** for moving the sleeve in the housing. The sleeve valve has a lower end portion **215***c* of reduced external diameter below the flange **230** which telescopes into the upper bore portion **211** of the lower sub **210** when the sleeve valve is moved downwardly to its lower or closed position. When the sleeve valve is moved downwardly to its closed position the ports **220** are below the seal rings **222** so that there is no fluid flow communication between the exterior of the housing and the interior of the sleeve **215** through the port **205**.

The lower end portion of the sleeve valve **215** has a plurality of longitudinally extending circumferentially spaced lands **215***d* which have upper shoulder surfaces **215***e* effectively defining an external annular recess **224** around the sleeve valve at the upper ends of the lands. The lands are provided at their lower ends with downwardly and inwardly slope surfaces **215***f*. An internal annular recess **232** is provided in the housing above the upper end of the lower sub **210**, and an inwardly sprung detent **233** in the form of a C ring is disposed in the recess **232** to restrain the sleeve **215** against sliding movement at both its upper open position and its lower closed position so that it is not accidentally moved. The downwardly facing shoulder surfaces **215***f* on the sleeve lands are engageable with the detent for restraining the sliding sleeve against downward movement, but when sufficient downward force is applied to the sleeve the detent is spread and expanded outwardly into the recess **232***a* releasing the sleeve to move downwardly until the detent contracts inwardly into the recess **224** at the upper end of the lands for releasably restraining the sleeve at its lower position. An upward force on the sleeve engages the shoulders **215***e* at the upper ends of the lands with the detent to cam it outwardly to release the sleeve for movement upwardly to its open position as shown in FIG. 27A.

The form of the tool string **30** shown in FIG. 2 includes the power piston **31** which is a pumpable seal unit movable along a flow conductor responsive to a fluid pressure differential applied across the unit. A suitable power piston which may be used for moving the tool string is illustrated and described in U.S. Pat. No. 3,318,605, issued to Norman F. Brown, May 9, 1967. The piston unit shown in the Brown patent is pumpable in either direction and thus may be connected into the tool string **30** by engaging the coupling **32** in the swivel cap **23** shown in FIG. 1 of the drawings of the Brown patent.

The coupler **32** is used to interconnect the several tools included in the tool string between the power piston **31** and the probe head **35** as indicated in FIG. 2 so that the tool string is a loosely coupled, fully articulated system which readily traverses curves in the tubings between the surface installation and the bottom ends of the tubings in the well. The coupler is illustrated in detail in FIGS. 24–26 showing its parts and their relative operational rela-

tionships. The coupler comprises a male member **120** and a female member **121** supported together by a coil spring **122**. The male member is basically a half tubular structure having end locking flanges **123** and **124** and spring retainer flanges **125** and **126** spaced from each other and spaced inwardly from the end flanges. A male flange section **128** is defined along each longitudinal edge of the coupler member **120** between the end cam surfaces **129** and **130**. The female coupler member **121** is a half tubular member similar to the male member **120** and is provided with correspondingly positioned end locking flanges **123***a* and **124***a* and spring flanges **125***a* and **126***a*. The longitudinal edges of each female member is provided with a female recess **130** defined between sloping end cam surfaces **131** and **132** which are closer together than the cam surfaces **129** and **130** on the male flanges of the male member so that the recess **130** is shorter than the male flange portions **128**. The male and female coupler members are held together by the spring **122** which encircles the members and is confined between the flanges **125** and **125***a* at one end of the members and the flanges **126** and **126***a* at the other end of the members. In the absence of forced conditions moving one of the members relative to the other, such as by opposite forces acting on the members or one of the members being held while the other is subjected to a longitudinal force, the members are held in alignment by the spring as shown in FIG. 24. When aligned the members are parallel to each other because the male flange portions **128** on the male member extend beyond the ends of the female recesses **130** in the female member so that the vertical longitudinal edges of the female member endwardly of the recesses **130** lie against or engage the longitudinal edge surfaces of the male flange portions **128** thereby supporting the members parallel to each other. A normal running condition of the coupler is as shown in FIG. 24 at which positions of the members the flanged opposite end portions of the coupler are received in well tool locking recesses coupling the well tools together. For example, the flanged end portions of one end of the coupler are received in the coupling recess **603** of the running probe head, FIG. 3A, while the other flanged end portions of the coupler are received in a similar coupling recess at the lower end of the sleeve shifting tool **34**.

The end portions at either end of the coupler may be compressed together by longitudinal movement or displacement of one of the coupler members. As for example in FIG. 25, the male and female coupler members are shifted in opposite directions until the cam surfaces **129** on the male flange portions **128** of the male coupler are below the cam surfaces **131** at the upper end of the female recess **130** so that the upper end portion of the male flange portions are received within the upper end portions of the female recesses. At these relative positions of the male and female members the upper end portions of the couplers are compressed together as shown in FIG. 25 thereby reducing the effective diameter of the flanged end portions of the coupler members at the flanges **123** and **123***a* so that the compressed end of the coupler is insertable into the coupling recess of one of the well tools. After insertion of the compressed end of the coupler the members are released to relax allowing the members to return to the relative positions of FIG. 24 so that the flanged end of the coupling which had been compressed is connected into the coupling recess of the well tool. The other end of the coupler is similarly connected into an end locking recess in another well tool. A more detailed description of the coupler **32** is found in U.S. Pat. No. 3,428,346 issued Feb. 18, 1969 to John V. Fredd.

The sleeve shifting tool **34** of FIGS. 27 and 27A is symmetrical in form, only half of the tool being shown in the drawings. The tool has a mandrel **370** having an enlarged section **371** provided with a pair of laterally spaced transversely extending slots **372** each of which has an upper portion **372***a* extending longitudinally substantially parallel with the longitudinal axis of the mandrel and a lower downwardly and inwardly extending portion **372***b*. Each of the slots **372** receives a transversely extending pin **373** pivotally supporting one of the sleeve shifting keys **321** in longitudinally slidable and pivotal relationship on the body. The opposite end portions of the pivot pins **373** are each secured in a circumferentially arcuate key **321**. The keys **321** fit in opposed pivotally supported relationship along opposite sides of the mandrel **370** for both pivotal and laterally expandable and retractable movement on the body. Each key has an upper internal recess **375** conforming generally to the shape of the section **371** on the body and sufficiently longer to provide for the necessary longitudinal movement of the key on the mandrel which is required when each of the keys move downwardly and inwardly on the mandrel. The keys are loosely fitted to permit pivotal and longitudinal movement, Each key has a lower internal recess **379** for receiving a lower external annular enlargement or cam member **380** on the mandrel. The lower end of the recess **379** in each key is defined by an upwardly facing cam surface **381** which is engageable with the downwardly facing cam surface **382** on the lower enlarged section **380** of the mandrel so that downward force is transmitted directly from the mandrel to the lower end portion of each of the keys. Like the upper recess **375** of each of the keys, the lower recess **379** is substantially longer than the section **380** to provide for the desired pivotal and longitudinal movement of each of the keys along the mandrel. Each of the keys has an upper external boss **384** providing an upwardly facing cam surface **385** and a downwardly facing cam surface **390**, and a lower external boss **391** provided with an upper cam surface **392** and a lower cam surface **393**. The cam surface **393** is engageable with the shoulder surface **231** of the sliding sleeve **215** for moving the sleeve downwardly. Additionally, the outer surface of each of the keys is relieved along a lower portion **321***a* to facilitate wobbling or pivoting the keys past obstructions in the tubing string and in the flow control device. Each key is somewhat thicker along an upper portion **321***b* above an external shoulder **321***c* to provide sufficient thickness for structural rigidity of the key along the internal recess **375**.

The lower end of each key is V-shaped in section as defined by an upwardly and inwardly sloping inner surface **393***a* and the upwardly and outwardly sloping cam surface **393**.

A ring **400** is disposed on the mandrel **370** below the keys and is supported on a spring **401** which biases the ring upwardly against the lower ends of the keys. The upper face of the ring **400** is in the form of a V-shaped groove **400***a* which is substantially complementary to the shape of the lower ends of the keys, so that the upward force exerted by the ring on the lower ends of the keys tends to cam the lower ends of the keys inwardly toward the tool body. The slopes of the key end surfaces **393** and the corresponding outer surface portion of the groove **400***a* in the ring **400** is greater than the slopes of the engaging cam surface **382** and the upwardly facing inner key cam surfaces **381** so that the net effect of the upward force of the ring on the lower ends of the keys is to cam the lower end portions of the keys inwardly.

The lower end of the spring **401** is supported by an upwardly facing shoulder surface **402** on a lower connector socket **403** threaded on the lower end of the tool body **370** and locked in place by a pin **403***a*. The socket **403** functions to receive a coupler **32** for connecting the lower end of the sleeve shifting tool to the running probe **35**. An upper connector socket **411** is threaded on the upper end of the mandrel **370** for connecting a coupler **32** to the upper end of the tool in the pump-down tool string.

When the tool **34** is moving freely through a full diameter portion of the tubing string, the spring **401** holds the ring **400** fully in contact with or seated against the lower

ends of the sleeve shifting keys so that the keys are restrained at a substantially neutral position generally parallel with the longitudinal axis of the tool body. At such position the internal cam surface **381** at the lower end of the lower recess **379** in each key is biased against the downwardly facing cam surface **382** on the lower enlargement **380** of the tool mandrel **370** and the lower end surfaces **393** and **393***a* are seated in the key groove **400***a*. The pivot pin **373** of each key is located in its slot **372** substantially as shown in FIG. 27, though the keys are parallel with the body as distinguished from pivoted outwardly along their lower ends as in FIG. 27.

The tool **34** is moved downwardly in the tool string with its sleeve shifting keys **321** held at their neutral position by the ring **400**, until the lower ends of the keys enter the restricted bore portion **203** at the lower end of the sub **200** of the first or uppermost sleeve valve **65**. Above this restricted bore portion the internal diameter of the sub, with the exception of those portions along the locking recesses **201** and **202**, is the same as the full diameter of the tubing string above the flow control device so that the sleeve shifting keys remain at their neutral position until their lower ends enter the restricted bore portion **203**. The restricted bore portion cams the lower ends of the keys slightly inwardly pivoting the keys on the pins **373** so that the lower end portions of the keys pass through the restricted bore portion into the upper bore portion **215***b* of the sleeve valve **215**. As soon as the lower key bosses **391** pass below the restricted bore portion **203**, the upward force of the ring **400** against the keys returns the keys to their neutral positions until the upper external bosses **384** on the keys arrive at the restricted bore portion **203**. When the upper bosses **384** enter the restricted bore portion, the upper end portions of the keys are cammed inwardly, pivoting the keys on the pins **373** and moving the lower end portions of the keys outwardly. The substantial length of the keys below the support pins compared with the length of the keys above the pins provides for a relatively small amount of inward movement of the upper end portions of the keys to effect a substantial outward movement of the lower end portions of the keys as the keys pivot. The keys and components of the sleeve valve are so relatively proportioned that the upper key bosses **384** enter the restricted bore portion **203** when the lower cam surfaces **293** on the keys are slightly above the cam surface **231** of the sliding sleeve at the upper end of the internal annular flange **215**. The tool continues downward movement until the key surfaces **393** engage the sleeve shoulder surface **231**. Since the restricted bore portion **203** of the sub **200** holds the upper end portions of the keys inwardly, the lower end portions of the keys are held outwardly and cannot move inwardly, so that further downward movement of the tool also moves the sleeve **215** downwardly. The downward force applied at the upper end of the mandrel **370** from the piston unit **31** is transmitted directly from the lower cam surface **382** of the enlarged portion **380** of the mandrel through the lower end portion of the keys to the sliding sleeve at its shoulder surface **231**, so that the pins **373** function for pivotal support of the keys but do not transmit force between the keys and the tool mandrel.

As the sleeve valve **215** is forced downwardly in the housing **204**, the downwardly facing shoulder surfaces **215***f* on the lands **215***d* engage the detent **233** expanding or spreading the ring outwardly releasing the sleeve for downward movement. The sleeve shifting tool continues to force the sliding sleeve valve downwardly so long as the upper bosses **384** of the keys are engaged with the restricted camming bore portion **203** of the upper sub. At substantially the same time as the upper key bosses pass downwardly from the camming bore, the detent **233** enters the upper recess **224** on the lower end portion of the sleeve valve to hold the sleeve at its lower closed position. If the sleeve is forced downwardly slightly beyond the position of alignment of the detent ring with the recess **224** the lower end of the sleeve will engage the upwardly facing stop shoulder surface **214** in the bore of the lower sub **210** to prevent any further downward movement of the sleeve.

As soon as the upper bosses **384** of the keys exit from the restricted camming bore portion **203**, the lower end portions of the keys are free to pivot inwardly. The upward force of the spring **401** acting on the ring **400**, coupled with the camming action of the shoulder surface **231** in the sliding sleeve against the lower outer end surfaces **343** of the keys, cams the lower ends of the keys inwardly as soon as the keys are free to swing or pivot, and the keys are disengaged from the surface **231** of the sliding sleeve, releasing the shifting tool to move downwardly in the tubing string.

The lower outer bosses **391** on the keys move through the internal boss or flange **230** of the sliding sleeve leaving the sleeve at its lower position as the shifting tool moves downwardly. When the upper bosses **384** of the keys arrive at the boss **230**, the lower bosses **391** are substantially below the restricted bore portion **212** of the lower sub so that the keys are free to pivot on the pins **373** and the upper end portions of the keys are cammed inwardly until the upper bosses **384** pass downwardly through the sleeve bore **230**. The keys continue to wobble, swing, or pivot sufficiently as the tool moves downwardly to fully clear the flow control device, after which the keys are returned by the spring biased ring **400** to their neutral position, in which they remain as the tool moves downwardly in the tubing string until the next sleeve valve is reached.

The tool **34** is returnable to the surface through each of the sleeve valves without shifting the sleeves from their lower closed positions. As the tool passes upwardly through the sleeve valves the keys **321** wobble or pivot on the pins **373** sufficiently for the keys to pass through the various restrictions in the sleeve valve. If the keys **321** encounter an obstruction in the tubing string or in any of the sleeve valves past which the keys cannot move by normal pivotal action on the pins **373**, the keys are forced downwardly and inwardly by the obstruction as the pins **373** move into the lower end portions **372***b* of the pivot pin slots. The inward position of the keys provides additional lateral clearance around the tool for movement past the obstruction, as already discussed.

FIG. 28 illustrates the sleeve shifting tool **33** for moving the sliding sleeve **215** upwardly from its lower closed to its upper open position, thereby returning the sleeve valve to the position of FIGS. 27 and 27A. The up-shifting tool has a mandrel **501** provided with a central annular enlargement **502** which has a pair of laterally spaced transverse slots **503** formed therein. Each slot has a central longitudinal portion **503***a* extending substantially parallel with the longitudinal axis of the mandrel, an upwardly and inwardly inclined upper portion **503***b*, and a downwardly and inwardly inclined lower portion **503***c*. A pair of oppositely positioned longitudinally extending sleeve shifting keys **504** are each loosely swingably or pivotally supported on the mandrel by a pivot pin **505** which passes through one of the slots **503** and is secured at its opposite ends in the arcuate key.

Each of the keys **504** has a lower internal arcuate recess **510** which receives a portion of the mandrel enlargement **502** and is somewhat longer than the enlargement to permit longitudinal movement along the mandrel. Each of the keys also has an upper internal arcuate recess **511** which receives a cam ring **512** secured by a shear pin **513** on the mandrel for transmitting force from the mandrel to the keys. The ring **512** has a downwardly and outwardly sloping shoulder upper surface **512***a* which is engageable with the downwardly facing sloping shoulder surface **511***a* of each key at the upper end of the upper key recess **511**. The upper end of each of the keys has boss **524** formed with an outwardly facing upwardly and inwardly sloping upper cam surface **514** and an inner downwardly and in-

wardly sloping end surface **515** providing a substantially V-shape to the upper end of the key.

A ring **520** is movably disposed on the mandrel above the upper end of the keys and biased downwardly by a spring **521** confined between the ring and an upper socket connector **540** for biasing the keys to a neutral position in the same manner as the ring **400** in the downshifting tool **34**. The ring **520** has a lower V-shaped face defined by an inner downwardly and inwardly sloping surface **522** and an outer downwardly and outwardly sloping surface **523**. The lower face of the ring is engageable with the V-shaped upper ends of the sleeve shifting keys for releasably holding the keys at a neutral position. Each of the keys also has at its lower end a lower external boss **525**. The outer surface of each of the keys is relieved along an upper portion **530** between the bosses to provide sufficient clearance for pivoting past the various restrictions encountered in the tubing string and flow control devices. Each of the keys is somewhat thickened along a lower portion **531** to provide sufficient material strength along the lower internal recess **510**.

The upper socket connector **540** is threaded on the upper end portion of the mandrel **501** for receiving a coupling **32** to connect the upper end of the up-shifting tool to the down-shifting tool **33**. The socket connector **540** has a downwardly facing shoulder surface **542** engaged by the upper end of the spring **521** so that the spring for biasing the ring **520** downwardly is confined between the shoulder and the upper face of the ring **520**. Similarly, a lower socket connector **543** is threaded on the lower end portion of the tool mandrel for receiving a coupler **32** for connecting the lower end of the up-shifting tool into the running probe.

As the tool **33** is moved downwardly through the tubing string, the sleeve shifting keys **504** are held by the ring **520** in a neutral position in which they are substantially parallel with the tool mandrel, so long as the tool is in normal diameter portions of the tubing string. When the tool reaches the uppermost sleeve valve and the keys enter the restricted cam bore portion **203** of the sleeve, the lower end portions of the keys are pivoted inwardly sufficiently to pass downwardly through such restricted bore into the larger bore of the housing **204** below the upper sub. When the upper bosses **524** of the keys enter the restricted cam bore portion **203** they are cammed inwardly, pivoting the lower end portions of the keys outwardly until the upper end portions of the keys pass below the restricted bore portion. If the sleeve valve **215** is at its lower position, the expanded lower end portions of the keys move freely downwardly in the housing **204** and sleeve without engaging the shoulder **231** of the sleeve. Irrespective of the sleeve valve position, the tool moves downwardly through the sleeve valve with the shifting keys wobbling, swinging, or pivoting sufficiently to clear the various restrictions within the flow control device, including the inner flange or boss **230** of the sleeve and the restricted bore portion **212** of the lower sub **210**. If the keys encounter an obstruction beyond which they cannot pass by the normal pivotal or wobbling effect, the keys are forced upwardly on the tool mandrel with the pivot pins **505** moving upwardly in the slots **503** to enter the inwardly sloping slot upper portions **503***b* and the keys are retracted inwardly toward each other to provide additional clearance for the keys to pass beyond the obstruction.

Thus, the up-shifting tool passes through all the sleeve valve on its downward run without affecting the valve position. During upward travel the tool moves the valve upwardly to a closed position. As the tool enters a flow control device from below, the upper end portions of the keys enter the restricted bore cam portion **212** of the lower sub **210** camming the upper ends of the keys slightly inwardly until they have moved above the restricted bore portion and enter the lower end of the bore of the sliding sleeve **215**. When the lower bosses **525** of the keys enter the restricted bore portion **212**, the lower ends of the keys are cammed inwardly to swing or pivot the keys on the pins **505**, swinging the upper end portions of the keys laterally outwardly so that the outer upper end surfaces **514** of the upper bosses engage the lower shoulder surface **232** of the sliding sleeve. The outward movement of the upper ends of the keys cams the ring **520** upwardly against the force of the spring **521**. FIG. 28 illustrates the up-shift tool at about the position at which it initially engages the shoulder **232** of the sleeve valve for moving the valve upwardly. The force applied to the mandrel of the tool for moving the tool upwardly is transmitted from the mandrel through the shear pin **513** to the ring **512**. The upper face **512***a* of the ring engages the inner downwardly facing surface **511***a* of each key, thereby applying upward force to the upper end portions of each of the keys which is then transmitted from the surface **514** of each of the keys to the internal shoulder surface **232** of the sliding sleeve. Thus, the upward force necessary to move the sleeve is not applied to the pivot pins **505**.

As the sleeve valve moves upwardly the detent **233** is cammed outwardly into the recess **232** by the upper end surfaces **215***e* on the sleeve, releasing the sleeve for upward movement. The tool moves the valve upwardly until the bosses **525** at the lower ends of the key emerge upwardly from the restricted bore cam portion **212**, at which time the valve is at its upper closed position and the detent **233** is contracted inwardly around the sleeve below the lower cam surfaces **215***f* on the lower end portion of the lands **45***d* on the sleeve valve.

Since the lower bosses **525** on the keys have moved above the restricted bore portion **212** the lower ends of the keys are free to expand slightly, allowing the keys to pivot so the upper end portioins of the keys swing inwardly due to the combined action of the spring biased ring **520** and the shoulder surface **532** acting on the key surfaces **514**. The keys are thus cammed inwardly back to their neutral positions. The sleeve is thus released at its upper closed position, with the tool continuing upwardly and the sleeve valve shifting keys wobbling or pivoting to clear the remaining restricted bore portions of the flow control device.

If, when the keys engage the sleeve valve, the valve is stuck and cannot be moved upwardly by the normal force employed with the operating tool string, the shear pin **513** holding the ring **512** on the tool mandrel is sheared. allowing the ring to move downwardly on the mandrel and thereby freeing the sleeve shifting keys for downward movement to the extent permitted by the engagement of the pivot pins **505** in the slots **503**. As the keys are forced downwardly, the pins **505** enter the downwardly and inwardly sloping lower end portions **503***c* of the slots, so that the keys are retracted inwardly to provide additional clearance for the keys to move upwardly through the sleeve valve, leaving it at the position at which it is stuck.

The running probe **35**, which supports a string of well tools such as the latches and gas lift valves illustrated in FIG. 2 during installation of the latches and valves in a tubing, is shown in detail in FIGS. 3A–3E. The probe is shown within the latches and gas lift valves supported on the probe. The probe is an articulated assembly which readily bends to traverse curved portions of a flow conduit, such portions leading to underwater wells equipped for pumpdown procedures may have curved lengths designed on radii of approximately 5 feet or greater. Referring to FIG. 3A the probe has a head **600** which includes an upper end cap **601** threaded into a housing **602**. The cap has a coupling socket or upwardly opening recess **603** for connection of the coupling **32** to provide a pivotal support for the head from the coupling. The housing **602** has a port **604** to permit free flow of liquid or gases into and out of the housing to prevent any piston effect within the housing which may interfere with proper operation of the probe. The lower end portion **605** of the probe head housing is reduced in diameter providing an internal shoulder **606** and a downwardly converging external arcuate

surface **607**. An articulated rod assembly **608** is loosely supported from the probe head on the shoulder surface **606**. The rod assembly has a tubular head **609**, having an enlarged flange portion **610** which is supported on the shoulder surface **606** in the housing **602**. An internal, flexible elongated rod **615** extends throughout the length of the probe holding the rod assembly together while giving it sufficient flexibility to negotiate curve conduit portions in a pumpdown well system. The rod is a relatively slender continuous member threaded along its upper end portion into nuts **616** which support the rod from the rod head **610** as seen in FIG. 3A. A plurality of tubular sections or probe sleeves **617** are supported in end-to-end array along the entire length of the rod **615**. The sleeves are generally of substantially the same length with the exception of those such as **617***a*, FIG. 3B, and **617***b*, FIG. 3C, which extend through the rigid sections of somewhat longer well tools. The lengths of the probe rod sleeves are gauged to align the joints between them at the joints between adjacent well tools in the string or swivel joints between sections of the tools. For example, in FIG. 3B it will be noted that the upper two sleeves **617** meet within the swivel connection between the lower end of the latch **40** and the upper end of the gas lift valve **41**. A typical joint or engagement between abutting ends of the sleeves **617** is shown in the broken-away view of the probe in the upper portion of FIG. 3B. The lower end of the uppermost sleeve **617** is provided with an upwardly and inwardly convergent arcuate internal annular surface **617''** which is complementary to and engages an upwardly and inwardly convergent external end surface **617'** on the adjacent or next downward sleeve **617** of the probe. Each joint between abutting sleeves of the probe on the rod **615** are formed in the same manner as the one shown in FIG. 3B which permits the sleeves to conform generally to the rod **615** for supporting the various tools on the probe as it traverses a curved section of a conduit. The probe sleeve **617***a*, FIGS. 3B–3C, is substantially longer than the sleeve **617** as it extends through the valve section of the gas lift valve assembly **41**. The probe sleeve **617***b*, FIG. 3C, is disposed during the running-in procedure through the lower latch **40***a* and is provided with a detent spring **618** which is welded along an upper end portion in a recess **619** formed longitudinally along the probe. The spring functions to limit upward movement of the latch on the probe after the latch has been released to its armed condition. As shown in FIG. 3D the probe sleeve **617***b* is reduced in diameter along a lower end portion providing a shoulder **617***c* and having a boss **617***d* spaced from the shoulder **617***c*. The shoulder **617***c* and the boss **617***d* serve release and locking functions during the installation of the latch in a tubing.

As shown in FIG. 3E the lower end portion of the probe rod **615** extends into a bottom probe sleeve **617***e* and is welded to the sleeve through a plurality of lateral hole **620**. The sleeve **617***e* is solid along its lower end portion below its connection with the rod **615** and is provided with a lateral hole **621** for a shear pin for connection of the probe in the lower end of the string of latches and gas lift valves during the running-in procedure, as discussed in more detail below.

The upper and lower latches **40** and **40***a* are identical in structure and function in all respects except for the features of the heads of the mandrels of the latches. The upper latch **40** is designed at its head to engage the head of the running probe while the head of the lower latch **40***a* is designed to be releasably supported from the lower end of the well tool immediately above it on the running probe. The principal characteristics of the latches will be described in terms of and by reference to FIGS. 3C, 3D, and 4–7. The main parts of both latches are best visualized and understood by reference to FIG. 6. The latches **40** and **40***a* each include a tubular body or sleeve-like housing **621** an internal operator sleeve **622**, operator lugs **623** and **623***a*, and locating and locking keys **624**. The upper latch **40** has an internal mandrel **625** supporting the operator sleeve, lugs, keys, and housing while these parts of the lower latch **40***a* are mounted on a mandrel **625***a* which is identical to the mandrel **625** in all respects except at its head end. The mandrel **625** has a flared head **626**, provided with an internal arcuate surface **630** engaged by the arcuate surface **607** on the head of the running probe, FIG. 3A when installing a string of tools in a tubing with the probe. The mandrel **625***a* of the lower latch, FIG. 3C has a head **626***a* having an internal upwardly opening coupling recess **631** which receives a collet **632** used to secure the lower latch to the lower end of the upper gas lift valve. The head of the mandrel **625***a* also has a counterbore portion **631***a* which receives the detent spring **618** for holding the lower latch against moving upwardly at an intermediate stage in the installation of the latches in a tubing as discussed below. In all other respects, the mandrels of the upper and lower latches are identical in structure and function. In a tool string using more than two latch-gas lift valve combinations the top latch has the mandrel **625** while all of the other latches below include the mandrel **625***a* since they are each connected to a well tool immediately above as distinguished from the top latch which engages the running probe head.

The latch housing **621** has an upper operating lug recess **633**, an intermediate lug recess **634**, and a lower lug recess **635** spaced along the body and separated by an upper internal locking surface **636** and a lower locking surface **637**.

The operator sleeve **622** has a lower tubular portion **638** of uniform diameter provided with a pair of upper oppositely positioned rectangular windows **639** for the upper lugs **623** and a pair of opposite lower windows **639***a* for the lower lugs **623***a*. The illustrated positions of the windows and lugs disposed therein have been revolved 90° in FIGS. 3D, 8A, 10B and 11 for purposes of clarity in illustration and description. The windows **639** and **639***a* may be located either as illustrated in FIG. 6 or revolved 90° as in the other figures. It is preferred that the FIG. 6 positioning be employed to maximize the structural strength of the operator sleeve **622**. The upper portion **640** of the operator sleeve is enlarged in diameter and bifurcated to provide elongate oppositely positioned windows **641** circumferentially spaced 180° from each other and 90° from the lug windows. Each of the windows **641** receives one of the locking keys **624** which are expandable and contractable during the locking and release of the latch in the tubing. The windows **641** extend into the lower reduced diameter portion **638** of the sleeve as best seen in FIG. 6. The sleeve is provided with two pairs of retracting and retainer flanges **642** disposed near the lower ends of and on opposite sides of each of the windows **641** for retaining the key **624** when at its expanded position relative to the sleeve and window. Each flange **642** has a tapered lower end face **642***a* for retracting and locking the lugs **624**. Each of the retainer flanges **642** for each window extends longitudinally of the sleeve and projects circumferentially into the window from the vertical face of the sleeve defining the longitudinal or vertical sides of the window. The flanges **642** for each of the windows provides balanced retaining means for the locking key in the window. The lower end of each of the windows **641** is defined by an upwardly and inwardly sloping cam surface **643** which is adapted to engage a similarly inclined lower end edge surface on the key in the window during the expansion of the key to a locking position.

At the upper end of the operator sleeve **622** a pair of diagonally oppositely disposed triangular shaped slots or recesses **644** are provided adjacent the upper ends of the windows **641**. One recess **644** is disposed along one side of one window **641** while the other recess **644** is spaced 180° from the first recess and adjacent the upper end

of the other side of the opposite window **641**. Each of the recesses **644** receives a portion of a locking key retainer formed on the heads of the mandrels **625** and **625***a*. The upper end edge surface portions **645** of the operator sleeve each extend circumferentially the width of the window **641** on that side of the sleeve and slope upwardly and inwardly for performing a locking key expansion function. In actual construction practice the operator sleeve **622** is machined so that from the lower end surfaces **643** defining the lower ends of the windows **641** the sleeve is forked or bifurcated to define the two oppositely disposed windows **641** and upper and inwardly opening recess in which a ring **646** is welded providing the upper boundary surfaces of the window **641** by the lower edge surfaces of the ring. The sleeve and ring are then milled to define the two recesses **644**. The inner diameter of the ring **646** is the same as the diameter of the remaining portion of the sleeve. Also, the ring is machined to provide the width of the windows **641** tapered end surfaces **645**. It will be evident that other approaches to the construction of the operator sleeve may be employed to form the novel shape of the upper end of the sleeve, the windows, and retainer flanges and related features shown in FIG. 6.

The locking keys **624** are identical and each provided with spaced outer bosses **650** and **651** which are contoured to conform to the shape of the particular tubing locking recess at which it is desired the latch be released and locked. The shape of the locking bosses on the keys may be varied for several latches to be run in a particular tubing so that the keys of each latch will fit only a particular specified locking recess while passing all other recesses along the tubing. In this way it is known exactly which locking recess the latch will release from the running probe and lock in. Each locking key has an arcuate inner surface **652** corresponding to the outer surface configuration of the portion of the mandrels **625** and **625***a* within the keys as best seen in FIG. 5. Each key has an internal arcuate lateral recess **653** the upper end of which is defined by a sloping cam surface **654** which is engageable by the cam surface **645** on ring **646** of the operator sleeve **622** for expanding the key during the locking of the latch in a tubing. The portion **652***a* of the inner key surface **652** above the recess **653** is engaged by the ring portion **646** across the window **641** when the key is fully expanded for holding the key at its expanded position. Each key is provided along opposite edges or sides with an outwardly opening longitudinal recess **655** which receives the retainer flanges **642** when the key is in the window **641**. The lower end of each side recess **655** is defined by a cam surface **656** which is engaged by the face **642***a* of the adjacent retainer flange **642** during the retraction of the locking keys and while holding the keys retracted. The positioning of the cam surfaces **656** at opposite sides of each of the keys near the lower end thereof provides balanced forces applied by the flanges **642** to the lower end of the key for smoothly and evenly retracting the keys responsive to downward movement of the operator sleeve **622**. Each of the keys has oppositely disposed side retainer flanges **657** which are engaged by the inner surfaces of the retainer flanges **642** of the operator sleeve to aid in holding the keys when they are in their fully expanded positions. The inner surfaces of the flanges **642** engage the outer surfaces of the key flanges **657**. The key flanges project from the side surfaces **655** of the keys as seen in FIG. 6. Each of the locking keys has an upwardly and outwardly opening upper side recess **658** along one side of the upper end portion of the key with a retainer ear **659** projecting from the side of the key near its inner surface **652** for holding the upper end of each key in alignment during its expansion and contraction and while at any given position relative to the mandrel and operator sleeve. Each of the keys has an upper inwardly facing sloping end surface **660**.

Both the mandrels **625** and **625***a* have a tubular body portion **661** provided with oppositely disposed longitudinal windows **662** through which the inward portions of the operator lugs **623** and **623***a* project to engage the articulated rod sleeves of the running and pulling probes. As best seen in FIG. 4, the longitudinal side edges **663** of the windows **662** are inwardly convergent so that the operator lugs may not move into the mandrel when the pulling or running probe is not disposed through the mandrel. The window side edges **663** engage the side edges of the operator lugs loosely to limit the inward movement of the lugs while allowing them to expand outwardly for movement of the operator sleeve **622** during the various steps of locking and releasing the latch. The operator lugs must be free to move radially inwardly and outwardly from an inward position at which they are aligned with the locking surfaces **636** and **637** within the body **621** and expanding positions at which their outer portions are received in the recesses **633**, **634**, and **635** of the housing **621**. The inward portions of the lugs must project through the windows **662** sufficiently to engage the running and pulling probes disposed through the latch during installation and retrieval of the latch.

The upper portion of the mandrels **625** and **625***a* aligned within the locking keys are undercut to provide arcuate longitudinal surfaces **664** along opposite sides of the mandrel spaced circumferentially 90° from the windows **662** and corresponding in shape to the inner surfaces **652** and **652***a* of the locking keys so that the locking keys may be slightly thicker and also may fully retract within the operator sleeve windows to the positions illustrated in FIGS. 5 and 3C.

The mandrel surfaces **664** are cylindrical but on a larger radius than the other cylindrical surfaces of the mandrel. The head **664** of the mandrel **625** is provided with the internal annular arcuate surface **630** at its upper end and with a downwardly and inwardly convergent surface **665** which is engaged by the upper end surfaces **660** of the locking keys. A pair of oppositely disposed retainer projections **666** spaced circumferentially 180° apart extend downwardly from the head **664** a short distance along the tubular portion of the mandrel, each provided with an upwardly and outwardly sloping recess **667** provided in the side face of the projection aligned to receive the locking ear **659** of the locking key **624** disposed along the mandrel surface **664** adjacent to the projection. It will be noted that each of the locking keys is provided with only one locking ear **659** so that each of the projections **666** has a recess **667** only in that side of the projection facing the adjacent locking key. The ear **659** is received in the recess **667** to hold the upper end of the locking key at any position of expansion or contraction of the key and guide the key during expansion and contraction. The lower latch mandrel **625***a* is identical other than having the coupling recess **631** instead of the arcuate end surface **630**.

When the latches are assembled, the operator sleeve **622** is telescoped into the housing **621** with the lower reduced diameter portion **638** of the sleeve disposed within the body, the relative longitudinal positions of the housing and sleeve depending upon the state of contraction or expansion of the locking keys. The mandrel, **625** in the case of the upper latch, **625***a* in the lower latch, is telescopically disposed within the operator sleeve with its retainer **666** aligned with the recesses **644** of the operator sleeve so that when the operator sleeve is forced upwardly on the mandrel the retainers enter the recesses **644** of the sleeve. The lugs **623** and **623***a* are disposed through the mandrel windows **663** and the operator sleeve windows **639** and **639***a* with the outside portions of the lugs extending outwardly of the sleeve to cooperate with the recesses and locking surfaces within the housing **621** while the inner portions of the operating lugs project inwardly of the mandrel windows **663** to function with the running or pulling probe. The locking keys **624** are each positioned within an operator sleeve window **641**. The ears

659 of each of the keys engage the adjacent guide slot 667 on the head of the mandrel while the retainer flanges 657 of the keys are within or beneath the flanges 642 of the operator sleeve. The cam surfaces 656 of the locking keys are inward of the operating sleeve retainer flanges 642 at the retracted positions of the keys. The flanges 642 engage the cam surfaces 656 holding the lower ends of the keys inwardly. The portion of the ring 646 extending across each window 641 is received within the recess 653 of the locking keys in the window at the retracted position of the key while the ring portion is inserted behind the inner surface 652*a* of the locking key below the end surface 660 at the expanded position of the locking keys as discussed hereinafter. The exact position of the parts forming the latches depends upon the degree of contraction or expansion of the locking keys which will be explained in more detail in connection with the operation of the latches and probes during installation and retrieval. As best seen in FIG. 3D when each of the latches is assembled for operation the mandrel 625 of the upper latch and 625*a* of the lower latch, is threaded along its lower end portion into a bottom sub 670 which is threaded into the lower end of the latch housing 621. A coil spring 671 is confined within the housing between the lower end of the operator sleeve 621 and the upper end of the bottom sub 670 biasing the operator sleeve upwardly relative to the housing and mandrel.

The lower end of the bottom sub 670 of the upper latch 40 is connected by a swivel joint 673 to the upper end of the upper gas lift valve assembly 41. The swivel joint is constructed as shown in detail in FIG. 3 of U.S. Pat. 3,403,694 issued to Norman F. Brown, Oct. 1, 1968. The swivel joint is secured to the flanged lower end portion of the bottom 670 by a retainer ring 674 secured in position by a lock ring 675.

The upper flanged end portion of the upper seal assembly 676 of the upper gas lift valve is similarly secured to the swivel joint 673 by a retainer ring 674 held in place by a lock ring 675. The seal assembly is substantially conventional in structure comprising a mandrel 677 on which a seal 678 is held by a retainer ring 679 threaded on the mandrel and held by a pin or locking ball 680. The lower end of the seal assembly is pivotally connected to the upper end of a gas lift valve 681. A bearing sleeve 682 having an annular spherical outer surface is threaded on the upper end portion of the mandrel 683 of the gas lift valve. The bearing sleeve is confined against the arcuate lower end of the seal assembly mandrel by an annular retainer 684 threaded on the lower end of the seal mandrel and locked by a pin or ball 685. The retainer 684 has an internal annular spherical surface 686 which engages the spherical surface of the bearing ring 682 to provide pivotal support for the gas lift valve from the seal assembly.

The gas lift valve 681 includes the mandrel 683, and an upper housing section 687 and a lower housing section 688 supported in concentric spaced relationship around the mandrel defining a dome gas chamber 689 and a lift gas annular flow passage 690. The upper housing section is reduced in diameter along a lower portion 691 extending into an upper end portion of the lower housing section 688 and confining therebetween an upper end portion of an annular flexible valve member 693. A lower intermediate portion of the valve member 693 is confined by an annular retainer ring 694 around the mandrel so that a central portion of the valve member may flex between the mandrel and the lower housing portion from an expanded position, FIG. 3B, closing ports 696 through the housing to a contracted position at which the valve member is contracted inwardly around the mandrel spaced from the ports 696 to allow lift gas to enter the housing 688 through the ports. A lower free end portion 693*a* of the valve member below the retainer ring 694 serves as a check valve to prevent backflow of fluid from within the gas lift valve upwardly between the mandrel and housing toward the ports 696. A flow passage 697 along the mandrel within the lower end portion of the upper housing section conducts dome gas from the chamber 689 downwardly behind the confined intermediate portion of the valve member for biasing the valve member outwardly over the housing ports 696. Gas is introduced into the dome chamber through a fitting 698 in the housing section 687 at the surface at a pressure which will permit the valve member 693 to open under desired well conditions for admitting lift gas into the valve. Ports 699 in the mandrel admit gas to the central flow passage 699*a* through the mandrel from the annular flow passage 690 so that lift gas around the valve may pass inwardly through the housing ports 696, downwardly along the valve member within the housing 688 past the check valve 693*a*, and inwardly through the ports 699 into the gas lift valve central passage 699*a*. The housing 688 is welded to a mounting ring 700 secured on the mandrel by set screws 701.

The lower end portion of the mandrel of the gas lift valve unit is threaded into a bearing ring 702 having an outer spherical surface which engages an internal spherical surface of a cap retainer 703 threaded on the upper end of a mandrel 704 of a lower seal assembly 705 for sealing within tubing below the gas lift valve unit. The reainer 703 is locked by a ball or pin 706 on the seal assembly mandrel. An annular seal 707 is held on the mandrel 704 by a retainer 708 which extends below the lower end of the mandrel 704 defining an internal recess 709 which receives the upper ring portion 632*a* of the collet 632. The collet has a plurality of downward extending circumferentially spaced fingers 632*b* having enlarged head portions 632*c* received within the coupling recess 631 in the head of the mandrel 625*a* of the lower latch 40*a*. The inner bosses along the collet heads engage the outer surface of the running probe as shown in FIG. 3C holding the collet heads expanded in the recess 631 thereby coupling the lower end of the upper gas lift valve with the upper end of the lower latch. As described in connection with the operation of the tool string, the lower latch is releasable from the upper gas lift valve when the running probe is withdrawn from within the collet 632 to allow the collet fingers to be cammed inwardly and the collet withdrawn upwardly from the upper end of the latch mandrel. As explained in more detail in connection with the operation of the apparatus, the several latches and associated well tools, such as the gas lift valves, remain coupled together as illustrated in FIGS. 3A–3E as they are run into a tubing on the running probe and are separated from each other sequentially as each latch-tool assembly is released and locked at the spaced locking recesses in the tubing.

The lower end of the lower latch 40*a* is connected with the upper end of the upper seal assembly 676*a* on the lower gas lift valve assembly 41*a* by another swivel joint 673. The seal assembly 676*a* and the lower gas lift valve 681*a* are identical in construction and function to the seal assembly 676 and the gas lift valve 681, both already described in detail. A lower seal assembly 705*a* identical to the seal assembly 705 is pivotally secured on the lower end of the lower gas lift valve 681*a* for sealing within the tubing below the gas lift valve. A coupling 710 is threaded on the lower end of the mandrel of the lower seal assembly 705*a*. The coupling has one or more ports 711 to admit fluid as the tool string is pumped through the tubing for flow through the tools in the string and exit thereform through the port 604 in the head of the running probe, FIG. 3A, thereby providing a fluid bypass through the tool string to minimize any piston effect which may be encountered in pumping the latches and gas lift valves through the tubing. The coupling 710 has an internally threaded lower end portion 712 that is counterbored at 713 providing an abrupt downwardly facing shoulder 714. The coupling also has

an upwardly and inwardly convergent internal annular cam surface **715** below the counterbore **713**. The coupling is further provided with downwardly and inwardly convergent internal annular guide surface **716** for guiding the pulling probe into position when retrieving the latches and well tools from a tool string.

A bottom sub **717** is threaded along an upper end portion **718** into the lower end portion **712** of the coupling **710**. The bottom sub has a stepped bore comprising an upper portion **718**, an intermediate portion **719**, and a lower portion **720**. An abrupt upwardly facing shoulder **721** is provided between the intermediate and lower bore portions. A pulling collet **722** having a lower solid ring **723** and upwardly extending circumferentially spaced collet fingers **724** is loosely confined between the coupling **710** and the bottom sub **717** for use with the pulling probe. Downward movement of the collet is limited by the shoulder **721** of the bottom sub while upward movement is limited by the downwardly facing shoulder **714** in the coupling **710**. The particular functioning of the collet will be described in detail in connection with the procedure of retrieving the latches and well tools from the tubing with the pulling probe **81**.

The bottom sub **717** has an enlarged lower flanged portion **725** having an external boss **726** received within recesses **727** of upwardly extending collet fingers **728** on a protective collet **729**. The collet **729** serves a guiding and probe end protecting function, particularly during the installation of the latches and well tools with the running probe. The lower end portion **725** of the bottom sub is connected by a shear pin **730** to the running probe spaced from its lower end as shown in FIG. 3E. The shear pin extends through the lateral hole **621** of the lower end section of the running probe holding the entire string of tools including the latches and gas lift valves in a somewhat compressed condition on the probe through sufficiently loose to provide enough flexibility for the tool string to traverse curves in the tubing as it is pumped both downwardly and upwardly in the tubing string. It must be noted that the tool string must pass through the tubing all the way from the surface installation **72** to the bottom of the tubing at the stop collar **61**. The head **625** of the mandrel of the upper latch **40** engages the lower end of the running probe head **602** when the tool string is held on the probe by the shear pin. During retrieval, of course, the latches and gas lift valves must be regrouped on the pulling probe and returned through the tubing to the surface installation.

The pulling probe **81** includes a smooth rod sleeve in place of the probe sleeve **617***b* with its detent spring **618** to permit easy insertion downwardly through the latches to be retrieved by the probe. Also, a lower end rod sleeve section **617***f*, FIGS. 14 and 15, is substituted for the running probe lower end sleeve section **617***e*. Otherwise, the pulling probe has the same features as the running probe. The pulling probe section **617***f* has a pointed, conical lower end surface **617***g* formed on a lower enlarged end portion **617***h*. The probe end section also has a collet locking recess **617***i* adjacent to its enlarged end portion so that the pulling probe may be engaged with the collet **722** during the tool retrieval procedure. The pointed end surface on the probe facilitates insertion through the latches and the gas lift valves during the removal procedure.

FIGS. 16–20 illustrate another form for the lower end of the pulling probe which is releasable in the event that the tools being retrieved are stuck in the tubing and cannot be freed by the force and techniques applicable with the pulling probe. Referring to FIG. 16, the modified form of pulling probe **81***a* has a bottom sleeve section **617***j* which is secured to the lower end portion of the flexible probe rod **615** by welds **617***k* within holes **617***l* of the sleeve. The sleeve section **617***j* has a downwardly opening internally threaded bore **617***m* into which is threaded a pulling probe assembly **750** including pulling probe foot **751** threaded into the bore **617***m* of the probe sleeve **617***j*. The probe foot **751** has spaced intermediate and lower end enlargements **752** and **753** respectively. A pulling collet **754** is loosely disposed on the probe foot for longitudinal movement between release and pulling positions as represented and further explained in relation to FIGS. 17–19. The collet has a continuous upper ring **755** and a continuous lower ring **756** interconnected by a plurality of circumferentially spaced, longitudinal flexible collet fingers **757** each of which has an intermediate internal and external boss portion or enlargement **758** which is alignable with the probe foot enlargement **752** when lifting the string of tools on the probe. The collet is supported at its lifting position by a ring **759** secured by a shear pin **760** on the probe foot above its enlargement **752**. The ring supports the pulling collet when removing well tools with the probe while being adapted to be released by the shear pin **760** to allow the collet to move to a probe releasing position. The bottom sub-arrangement including the coupling **710**, the bottom sub **717**, and the protective collet **729** connected on the lower end of the lowermost gas lift valve is identical to the structure shown and described in connection with FIG. 3E and used with the pulling probe **81**. The lower pulling end section of both the probes **81** and **81***a* are interchangeable and useful with the same well tools for removing the tools from the tubing.

Another form of running probe **35***a* is illustrated in FIGS. 21–23. This form of probe is used for releasing and locking well tools on the probe, such as the gas lift valves, in tubing at a depth generally substantially less than that at which the collar stop **61** is located in the tubing. More specifically, the hydraulically actuated probe **35***a* is operable to release and set the latches **40** and **40***a* by fluid pressure steps at any desired depth rather than by pumping the tool string to the collar stop at the lower end of the tubing where it is mechanically released by impact with the collar stop. The modified running probe has a head **770** provided with an upwardly opening coupling recess **771** for connection of one end of a coupling **32** securing the probe into a tool train including the piston and sleeve shifting tools. The head **770** has a downwardly opening cylinder **772** in which a piston **773** is slidably disposed. Piston rings **774**, which may be O-rings, are supported on the piston for sealing around the piston with the cylinder walls. A retainer ring **775** is secured by a shear pin **776** on the piston below the lower end of the head **770** to prevent movement of the piston farther into the cylinder **772** until predetermined pressure conditions are reached at which the shear pin **776** is severed to release the retainer ring to permit the piston to move farther into the cylinder. The piston has an integral downwardly opening supporting sleeve **777** which is internally threaded along its lower end portion and has a side bleed port **778** which prevents pressure build up within the cylindrical portion which might cause a piston effect to impair the operation of the probe.

A rod head support **779** is slidably suspended from the sleeve **777** by a U-shaped retainer or nut **780** secured on the upper end of the rod support and confined within the sleeve, by an annular closure member **781** and threaded into the lower end of the cylindrical portion **777**. As shown in FIG. 21 the retainer **780** fits in an annular recess **780***a* below an end flange **779***a* on the rod head. The rod may move between its lower end position as represented in FIG. 1 to an upper end position shown in FIG. 23. The rod head and support **779** has an enlarged lower end portion **782** threaded on the upper end of the probe rod **615**. The probe rod is supported on the upper end of a probe rod sleeve **609***a* by a pair of nuts **783** and a washer **784**. A probe head housing **785** threaded on the lower end portion of the head member **770** has a reduced lower end portion **785***a* provided with an internal shoulder surface **785***b* which supports

the enlarged head end 609*a* of the probe sleeve 609*a*. The housing 785 has a bleed port 786 to equalize the pressure on opposite sides of the housing wall. When a string of tools is run into a tubing on the probe 35*a*, the mandrel head 626 of the uppermost latch engages the arcuate lower end surface 785*c* of the housing 785. The lower end portion of the hydraulic probe 35*a* is identical to the probe 35 as described in connection with FIG. 3E. The probe 35*a* is operable hydraulically at any desired depth within a tubing or mechanically by impact at the lower end of the tubing on the collar stop 61.

The installation of the gas lift valves and latches of the tool string 30 shall be described in terms of the well system 50 including the steps involved in using both the running probe 35 and the running probe 35*a*. Similarly, the retrieval of the gas lift valves and latches from the well system shall be described in terms of the pulling tool string 80 using the probe 81 and the probe 81*a*.

The installation procedure shall be described first in terms of the use of the running probe 35 with well tools including the latches 40 and 40*a* with the gas lift valves 41 and 41*a* secured on the probe in the relationship illustrated in FIGS. 3A–3E. In assembling the tools on the probe, the upper latch 40 with the coupled gas lift valve assembly 41 is positioned with the flared head 626 of the latch mandrel 625 held against the probe head 602 so that the mandrel head surface 630 contacts the probe head surface 607. The spherical engaging surfaces permitting some flexing or pivoting relative to the longitudinal axis of the probe and tool string when curved sections of a well tubing are traversed by the tool string. The lower latch 40*a* and its gas lift valve 41*a* are coupled with the lower end of the lower seal assembly 705 on the upper gas lift valve assembly prior to installation on the probe. As evident in FIG. 3C, the collet 632 is engageable in and disengageable from the coupling recess 631 of the head end of the latch mandrel 625*a* of the lower latch only when the full diameter of the running probe is not in the collet. The running probe in the collet holds the collet heads 632*c* at their normal position and precludes their contraction so that so long as the probe is disposed through the collet and the lower latch and upper gas lift valve are coupled together by the collet the latch and gas lift valve may not be uncoupled. Interference with the detent spring 618 prevents sliding the latches and gas lift valves upwardly on the probe when assembling them on the probe preparatory to installation. One method of installation which prevents interference from the detent spring is to slide the assembled gas lift valves and latches on the probe at its upper end with the probe disassembled from its head 600 and the head section 609 of the probe rod disconnected from the rod. After the latches and gas lift valves have been telescoped over the rod, the upper end portion of the rod is inserted into the lower open end of the housing 602 with the rod head section 609 being dropped into place in the housing over the rod portion extending into the housing and the nut 616 secured within the head section 609 on the upper end of the rod. The head member 601 is then threaded into the housing 602. Alternatively, a thin walled long sleeve adapted to fit around the probe rod within the latches and gas lift valves may be placed on the probe to hold the detent spring 618 depresed while the latches and coupled gas lift valves are fed over the rod upwardly toward its head. The sleeve is then withdrawn over the lower end of the rod from within the latches and gas lift valves assembled on the rod thereby releasing the detent spring 618. After the upper and lower latches in their coupled relationship are assembled on the running probe they are moved to the position illustrated in FIGS. 3A–3E and somewhat compressed, if necessary, to align the bottom sub 717 on the lower seal assembly of the lower gas lift valve with the lower end sleeve section 617*e* of the running probe for insertion of the shear pin 730. The shear pin 730 is inserted to lock the latches and gas lift valves on the running probe with the protective collet 729 removed since the spacing between the collet fingers is preferably less than the diameter of the shear pin. After inserting the shear pin into position, the protective collet 729 is installed as illustrated in FIG. 3E by spreading its collet fingers on the lower end of the tool string. It will be noted that the lower end of the bottom sub 717 is spaced above the lower end of the running probe and the lower end of the protective collet.

When assembling the latches 40 and 40*a* on the running probe, the latch locking keys 624 must be adjusted to their fully retracted positions as represented in FIG. 3C by the manipulation of the operator sleeve 622 and the operator lugs 623. The keys are moved to and held at their retracted positions by the operator sleeve which is compressed against the spring 671 so that the tapered lower end faces of the flanges 642 engage the cam surfaces 656 on the locking keys camming each key inwardly to the retracted positions represented in FIGS. 3C and 5 at which the inner faces 652 of the keys rest along the surfaces 664 of the latch mandrel, thereby limiting or determining the maximum contraction of the keys. As each key is moved inwardly by the retainer flanges 642, the retainer ear 659 on the key is guided downwardly and inwardly along the recess 667 in the mandrel head into which the ear projects guiding the upper end of each key inwardly to the fully retracted position.

The movement of the operator sleeve to the position at which the keys are fully retracted is preferably accomplished by insertion of the running probe downwardly through the latch to engage the operating lugs 623 and 623*a* for shifting the operating sleeve as desired. Without the probe or a similar tool extending through the bore of the latch engaging the operating lugs, the normal position of the sleeve is as shown in FIG. 11 with the keys fully expanded. Prior to preparing the latch for running into a well tubing, the latch generally has its component parts positioned as shown in FIG. 11. The running probe is then introduced into the upper end of the latch and forced through the latch toward the operating lugs engaging the lugs to move the operating sleeve downwardly against the spring 671. The lower operating lugs 623*a* are aligned with the locking surface 637 in the sleeve 621 and the upper operating lugs 623 are aligned with the upper locking recess 633 of the sleeve. As the probe is forced through the latch bore, the boss 617*d* on the probe readily passes the upper operating lugs 623 which are cammed radially outwardly into the locking recess 633. The boss 617*d* on the running probe passes the upper operating lugs 623 moving through the latch bore until the boss engages the lower latch lugs 623*a* which are held against outward expansion by the housing locking surface 637 so that the probe boss cannot pass through or between the lugs and thus forces the lugs toward the spring thereby moving the operator sleeve 622 against the spring until the lower lugs are aligned with the lower locking recess 635 at which time the upper lugs 623 are aligned with the intermediate locking recess 634. The probe boss 617*d* cams the lower lugs outwardly into the lower locking recess 635 so that the probe boss passes below the lower lugs while simultaneously the probe shoulder 617*c* passes the upper lugs 623 so that the full diameter of the running probe is disposed between the upper locking lugs preventing their inward movement out of the locking recess 634. The longitudinal movement of the operator sleeve 622 as the operator lugs move to the locking recesses 634 and 635 fully retracts the latch keys 624 so that they are held inwardly as shown in FIG. 3C by the retainer flanges 642.

After the full diameter portion of the probe passes between the upper locking lugs 623 and the lower locking lugs 623*a* are between the probe boss 617*d* and the shoulder 617*c*, the force of the spring 671 biases the operator sleeve 622 upwardly so that the upper locking lugs 623 are forced against the shoulder surface 634*a* defining

the upper end of the locking recess **634**. Since the full diameter portion of the probe is within the upper locking lugs and the outer portions of the locking lugs are disposed in the locking recess **634**, the upper locking lugs cannot be cammed inwardly and are wedged against the recess shoulder surface **634***a* holding the operator sleeve **622** against further upward movement thereby holding the latch keys fully retracted.

The full diameter portion of the running probe extends through the upper and lower latches to a location at least below the upper operator lugs of the lower latch so that the keys on both latches on the probe cannot expand so long as the probe position is unaltered while pumping the probe with its tool string supported thereon into the well.

After the latches and gas lift valves are thus locked on the running probe and held on the probe by the shear pin **730** the running probe is connected by a coupler **32** to the sleeve shifting tool **34** which is coupled to the sleeve shifting tool **33** by another coupler **32**. A still further coupler **32** is connected between the upper end of the sleeve shifter **33** and the power piston **31**.

For pumping the tool string **30** into the well tubing **53** for installation of the gas lift valves and latches along the well tubing at the sleeve valves **65**, the surface installation **72** is adjusted for fluid input through the well tubing **53** and fluid return through the tubing **54**. Such fluid flow direction through the well system is obtained by closure of valves **102** and **103** and opening valves **101** and **110** so that fluid may be forced by the pump **105** from the reservoir **104** into the conduit **100** from which it flows into the lubricator section **92**, through the valve **90**, and into the tubing **53**. The valve **115** in the conduit **114** is closed. The valve **113** and the valve **93** are open and the valve **94** closed so that fluid returns from the tubing **54** and the conduit **100** into the reservoir **104**. The tool string **30** is inserted into the lubricator section **92** between the valves **90** and **91**. In inserting the tool string **30** into the lubricator section, the running probe along with the gas lift valve and latches is introduced first with the power piston of course being the last portion of the tool string to pass into the lubricator section. Fluid is pumped under pressure from the reservoir into the downstream end of the lubricator section adjacent to the valve **91** after adjustment of the system as explained. The fluid imposes a pressure differential across the power piston **31** displacing the piston propelling the tool string into the tubing **53**. The tool string is pumped downwardly through the well tubing with the gas lift valves and latches on the running probe passing downwardly through the uppermost sleeve valve **65** until the shifting tool **34** moves into and engages the sleeve valve. The tool **34** shifts the sleeve valve downwardly to its closed position, releases from the sleeve valve, and permits the tools to continue downwardly in the tubing. The tool string is pumped downwardly in the tubing to the collar stop **61** closing each of the sleeve valves in the tubing as it passes therethrough.

At the end of the downward movement of the tool string the lower end of the protective collet **729** at the bottom of the tool string strikes the collar stop **61** stopping the collet and the running probe which abuts the top face of the bottom plate of the collet. The momentum of the tools on the running probe causes them to tend to continue downward movement on the probe. If the tool string is moving at sufficient speed, the shear pin **730** is severed, and if not, the increase in pressure in the tubing above the tool string upon impact of the string against the bottom stop provides a pressure signal at the surface responsive to which the fluid pressure may be increased sufficiently to force the tool string downwardly against the shear pin **730** for severing the pin.

When the shear pin **730** is severed, the latches and gas lift valves move downwardly until the lower end of the bottom sub **717** engages the top surface of the bottom plate of the collet **729** as shown in FIG. 8. The downward movement of the latches and gas lift valves on the running probe actuates or arms the lower latch **40***a* causing its locking keys to expand against the inner wall of the tubing. A comparison of FIGS. 3D and 3E show that the downward movement of the latches and gas lift valves after shearing the pins **730** against the bottom plate of the collet **729** positions the upper operator lugs **623** a short distance below the running probe shoulder **617***c* and the lower operator lugs **623***a* pass below the probe boss **617***d*. The lower operator lugs freely pass around and below the probe boss since they may readily move outwardly in the lower locking recess **635**. As soon as the upper operator lugs, which have been wedged between the probe and the locking recess shoulder **634***a* holding the operator sleeve against upward movement, pass below the probe shoulder **617***c*, the force of the spring **671** on the lower end of the operator sleeve biasing the sleeve upwardly causes the shoulder surface **634***a* in the sleeve **621** to cam the upper operator lugs inwardly along the reduced diameter portion of the probe between its shoulder **617***c* and the boss **617***d*. As soon as the upper operator lugs are cammed inwardly along the reduced diameter probe portion, the upper lugs are released by the shoulder surface **634***a* so that they pass upwardly in the sleeve **621** along the locking surface **636** as shown in FIG. 10B. The upward movement of the operator sleeve and the lugs moves the retainer flanges **642** of the operator sleeve upwardly away from the sloping cam surfaces **656** of the latch keys **624** releasing the keys for expansion toward the tubing wall. The upward movement of the sleeve **622** also forces the keys **624** upwardly and outwardly to their expanded positions against the inner wall of the tubing to the position represented in FIGS. 8A and 10B. As evident in FIG. 3C, the spaicng of the surfaces **643** at the lower ends of the sleeve windows and the surfaces **646** at the upper end of the sleeve ring **645** from the lower ends of the keys and the key recess surfaces **654**, respectively, results in a lag between the release of the keys by upward movement of the retainer flanges **642** and the actual engagement of the keys by the sleeve for the expansion of the keys. As the retainer flanges move upwardly releasing the keys the sleeve surfaces **643** engage the lower end surfaces **651***a* on the keys and the upper end surfaces **645** on the sleeve insert ring engage the key recess surfaces **654** so that the keys are forced upwardly along the mandrel **625** with the upper end of the sloping inner surfaces **660** of the keys moving upwardly along the tapered conical surface **665** on the mandrel head forcing the keys radially outwardly. As the keys move upwardly and outwardly, the ear **659** of each key moves upwardly and outwardly along the retainer recess **667** of its guide flange **666** on the mandrel head. The keys move outwardly until the outer boss surfaces **650** and **651**, respectively, engage the inner wall surface of the tubing which prevents further expansion of the keys. FIG. 8A substantially represents the relative position of the probe, operator lugs, and locking keys immediately after the operator lugs have moved below the probe shoulder **617***c* and probe boss **617***d* and the spring **671** has expanded sufficiently to force the operator sleeve **622** along with the operator lugs upwardly along the probe for expanding the locking keys to the tubing wall. When the locking keys engage the tubing wall, they, in effect, are loosely lodged with the upper ends of the keys engaging the mandrel surfaces **665** and the lower ends of the keys along with the key recess surfaces **654** being engaged by the operator sleeve surfaces **643** and the insert ring surfaces **645**, respectively. The operator sleeve is thereby limited against further upward movement by the keys with the operator lugs being aligned with the locking surfaces **636** and **637** of the sleeve **621** so that the lugs cannot move outwardly. The upper operator lugs **623** are trapped or confined longitudinally between the probe shoulder **617***c* and the probe boss **617***d* while the lower operator lugs **623***a* are held inwardly along the reduced diameter probe section below the probe boss **617***d*.

At the time the latches and gas lift valves initially move downwardly on the probe responsive to the impact against the stop **61**, as represented by FIG. 8, the lower latch moves downwardly sufficiently on the probe that the detent spring **618**, FIG. 3C, moves outwardly into the counterbore **631***a* in the head of the mandrel of the lower latch to limit upward movement of the latches and gas lift valves on the probe during the return trip of the tool string up the tubing for releasing each latch and gas lift valve from the probe and locking them in the tubing. The detent spring serves a precautionary or safety function to prevent malfunctioning of the locking keys **624** of the latches. If the pressure differential across the latches and valves were high enough when pumping the tool string upwardly from the bottom stop, the latches and gas lift valves may tend to move upwardly at a faster rate than the power piston lifting the running probe so that the operator lugs of the lower latch are urged against the probe shoulder surfaces with sufficient force that the spring **671** cannot lift the sleeve and lugs a sufficient distance to expand the locking keys **624**. The detent spring **618** holds the latches and gas lift valves downwardly on the probe sufficiently that the operator lugs and sleeve can move up far enough to expand the keys without encountering the probe shoulders. If the pressure conditions in the tubing result in applying greater upward force to the power piston **31** than to the gas lift valves and latches on the running probe, the piston will lift the probe at a sufficient rate so that the latches and valves are lifted in the tubing by the probe. This latter step of returning the tool string **30** up the tubing after engaging the bottom stop **61** and before the lowest lower latch and gas lift valve have been released and locked in the tubing is represented in FIGS. 10A through 10D. The keys **624***a* are expanded against the tubing wall and dragged along the wall as shown in FIG. 10B. The upwardly moving probe is tending to lift the latches and gas lift valves so that the boss **617***d* on the probe engages the upper operator lugs **623** which cannot expand farther outwardly due to their engagement with the locking surface **636** within the latch sleeve **621**. The confinement of the locking keys **624** by the tubing wall prevents further expansion of the keys which in turn prevents further upward movement of the operator sleeve **622** so that the probe boss cannot lift the upper operator lugs above the locking surface **636** thus resulting in the lifting of the entire lower latch by the engagement of the probe boss with the upper operator lugs. This holds the entire string of latches and gas lift valves on the running probe while the tool string is pumped back upwardly toward the lower sliding sleeve valve **65** and it locking recess L.

When the upwardly moving tool string **30** enters the lowest locking sleeve **65** the piston **31** passes upwardly through the sleeve with the upshifting tool **33** engaging the downwardly positioned closed sleeve and moving it upwardly to its upper open position preparatory to setting the lower latch and gas lift valve at the cross-over connection **64** through the sleeve. After the upshifting tool **33** has opened the lower sleeve **65**, the shifting keys of the tool release from the sleeve valve and the tool train **30** continues upward movement with the upper latch **40** and its gas lift valve assembly **41** passing through the sleeve valve. At this stage of the releasing procedure the upper latch and gas lift valve are still on the full diameter portion of the probe above the shoulder **617***c* so that the locking keys of the upper latch remain fully retracted as shown in FIG. 3C and thus are not contacting and dragging along the tubing wall. The lower latch **40***a* is lifted into the sleeve valve and when the locking keys **624** of the latch are aligned with the locking recess L, FIG. 11, the keys are free to expand farther outwardly. The shape of the locking recess in the tubing generally conforms to the outer surface shape or contour of the locking keys so that the keys are freely received within the locking recesses. As shown in FIG. 11 and as distinguished from the schematic showing of FIG. 1 the locking recess L has upper and lower portions which are shaped to receive the bosses **650** and **651** of the latch keys. When the keys are thus aligned with the locking recess and free to expand, the spring **671** forces the operator sleeve **622** farther upwardly until the keys are fully expanded into the locking recess and the sleeve is disposed in a locking relationship within and behind the keys as shown in FIG. 11. The outer surface of the sleeve **622** immediately below the tapered lower window surfaces **643** is behind the lower portion of the inner surface **652** of the keys while, similarly, outer surface portions of the sleeve ring **646** at the upper end of the sleeve are inserted behind the upper inner surface portion **654***a* on each key so that the sleeve holds both keys at their fully expanded positions and until the sleeve is moved downwardly the keys cannot be compressed or contracted inwardly. At this expanded position of the keys the upper locking lugs **633** are aligned with the upper locking recess **633** while the lower locking lugs **623***a* are disposed along the sleeve locking surface **637** and thus are held by this locking surface at a contracted position around the reduced diameter portion of the probe below the probe boss **617***d*. At the expanded positions of the keys, the retainer flanges **657** on each of the keys are aligned with and behind the retainer flanges **642** of the operator sleeve **622**. The key and sleeve retainer flanges limit the outward movement of the keys and prevent their coming fully out of the operator sleeve windows in the event that the keys are expanded to the maximum extent allowable by the latch structure.

At the time the latch keys **624** of the lower latch fully expand into and lock at the locking recess L at the lower sleeve valve, the boss **617***d* on the running probe cams the upper operator lugs **623** farther outwardly into the recess **633** of the latch sleeve **621** allowing the boss to pass the lugs and the running probe to be lifted upwardly relative to the lower latch. The relative positions of the various parts of the latch and the running probe immediately before and immediately after full expansion and locking of the latch keys are represented by FIGS. 10B and 11, respectively. FIG. 10B shows the relative parts positions immediately before key expansion while FIG. 11 shows the relative parts positions with the probe boss above the upper operator lugs immediately after key expansion. The movement of the probe boss above the upper operator lugs fully releases the running probe from the lower latch leaving the lower latch locked at the locking recess L with its lower gas lift valve assembly **41***a* supported therefrom through the lower sleeve valve **65** so that the gas lift valve ports **696** are aligned with the cross-over connection **624** and the upper and lower seal assemblies on the gas lift valve are above and below the cross-over connection. Lift gas may be admitted from the tubing string **54** across into the tubing **50** through the lower gas lift valve.

When the running probe fully releases from the lower latch, FIG. 11, leaving the latch locked at the sleeve valve, the running probe is lifted by the piston relative to the entire string of latches and gas lift valves which are held against upper movement by the locking of the lower latch at the lower sleeve valve as already described. The running probe is lifted until the upper latch is "armed" with its locking keys expanded against the tubing wall. The collet **632** holds the lower end of the upper gas lift valve assembly engaged with the upper end of the lower latch while running probe is being lifted. When the running probe shoulder **617***c* and the boss **617***d* are raised above the relationship shown in FIG. 3D with respect to the operating lugs of the upper latch, the shoulder **617***c* moves above the upper operating lugs while the boss **617***d* cams the lower operating lugs outwardly into the sleeve recess **635**. When the shoulder **617***c* passes above the lugs **623** they release the operating sleeve **622** of the upper latch permitting the spring **671** to raise the operator

sleeve partially expanding the operator keys of the upper latch to the tubing wall so that the relationship of the parts is shifted to that shown in FIG. 10B. At this stage the upper latch is now releasably locked on the running probe with the boss **617***d* engaging the upper operator lugs applying an upward lifting force on the upper latch. The lower reduced diameter portion of the probe is now within the collet fingers **632***c*, FIG. 3C, so that the collet fingers are cammed inwardly due to the upward force on the upper gas lift valve and latch withdrawing the collet fingers from the coupling recess **631** on the head end of the mandrel of the lower latch uncoupling the lower end of the upper gas lift valve assembly from the lower latch. The upper latch and gas lift valve are released from the lower latch and gas lift valve so that the running probe lifts the upper latch and gas lift valve upwardly in the condition represented in FIG. 10B until the next sliding sleeve valve **65** and its locking recess are reached when the steps of fully disengaging the upper latch from the running probe and locking the latch at the locking recess and sliding sleeve is effected as already described in connection with the lower latch.

When the locking keys of the upper latch fully expand into the locking recess at the next sleeve valve, the valve will already have been shifted back to its upper position by the upshifter **33** preceding the arrival of the upper latch. The locking of the upper latch fully releases the running probe in the manner already described and the running tool string including the power piston **31**, sleeve shifters, and the running probe are pumped back to the surface where they are removed from the lubricator **92**.

It will be noted that only two latch-gas lift valve combinations are supported on the running probe while the well system shown in FIG. 1 includes at least three sliding sleeve valve-crossover connections. With such an arrangement, if the two latches and their gas lift valves are released and locked at the two lower sliding sleeves, the upper sliding sleeve is shifted back by the sleeve shifter **33** to its upper open position as the running tool string is returned to the surface and thus would subsequently have to be closed in order to produce the well by gas lift. In actual practice, either three gas lift valves would be set in the well tubing of FIG. 1, one at each sliding sleeve valve, or another well tool such as a solid sleeve could be set at the sliding sleeve valve where no gas lift valve is set. Some means of closing the open sleeve valve would obviously be necessary to avoid bypassing by lift gas by short circuiting through the cross-over connection at which no lift valve is set and at which the sliding sleeve valve is left open.

It will be recognized that the contours of the outer surfaces of the locking keys of the latches and the shapes of the locking recesses at the various sliding sleeve valves in the well system may be matched so that each latch is releasable and lockable at only one selected sleeve valve.

The latches and gas lift valves coupled therewith are retrieved from the tubing **53** with the pulling tool string **80** which is introduced into the well system through the lubricator section **92** and pumped into the tubing from the surface installations **72** in the same manner as already described in connection with the running tool string **30**. In introducing the tool string **80** into the lubricator section of the tubing, the pulling probe **81** is inserted first so that the lower pointed free end portion of the probe leads as the tools string is pumped downwardly in the tubing. When the free end portion of the pulling probe is pumped into the upper latch, the conical end surface **617***g* on the probe, FIG. 14, passes between the upper operator lugs **623** of the upper latch. At this particular stage the various parts of the upper latch are positioned as represented in FIG. 11 so that as the probe point passes between the upper operator lugs **623** the lugs are cammed outwardly into the latch sleeve locking recess **633** allowing the probe point to move downwardly to the lower operating lug **623***a*. Since the lower operator lugs are aligned with the sleeve locking surface **637** the probe point cannot pass between them and therefore forces them downwardly forcing the operator sleeve **622** of the latch downwardly. As the operator lugs and sleeve move downwardly the upper operator lugs are cammed inwardly along the pulling probe head above the boss **617***h* along the reduced diameter probe head portion **617***i* allowing the upper operator lugs to retract sufficiently to pass the intermediate sleeve locking surface **636**. By the time the upper operator lugs have moved downwardly past the locking surface **636** the lower operator lugs have been forced by the probe head downwardly past the locking surface **637** so that the lower lugs are aligned with the lower sleeve recess **635** and the upper lugs are aligned with the intermediate sleeve recess **634**. Both sets of operator lugs are cammed outwardly permitting the probe head to move downwardly through the operator lugs so that the full diameter of the probe above the probe head passes between both sets of operating lugs. When the pulling probe head engaged the lower operator lugs and started forcing the operator sleeve **622** downwardly, the operator sleeve surfaces behind the keys above and below the sleeve windows in which the keys are disposed are moved downwardly until the sleeve surfaces **643** are below the lower ends of the keys and the ring portions **645** at the upper end of the operating sleeve are again aligned with the key recesses **653** so that the keys are not locked at their expanded positions by the sleeve. The lower ends of the flanges **642** on each side of the windows in the operator sleeve each engage a cam surface **656** along the key edges camming the lower ends of the keys inwardly while simultaneously each key ear **659** moving downwardly along its retainer recess **667** in the latch mandrel head cams the upper end of each key inwardly so that by the time the operator lugs **623** and **623***a* are aligned respectively with the sleeve recesses **634** and **635** of the latch, the keys are retracted and thereby disengaged from the locking recess L so that the latch and upper gas lift valve are on the pulling probe to be forced downwardly with the pulling tool string toward the bottom end of the tubing. The frictional resistance of the seal assemblies on the gas lift valve generally will resist downward movement of the gas lift valve and latch with sufficient force that the pulling probe is fully inserted through the latch until the probe head engages the upper end of the latch mandrel with the pulling probe and the disengaged latch and gas lift valve being forced downwardly by the power piston **31**. Of course, for the operator lugs to fully retract the latch keys as described the spring **671** must be compressed. If the seal assemblies on the gas lift valve do not exert enough friction with the tubing wall to resist the compressive force of the spring, the latch keys are retracted until they are just withdrawn from the locking recess in the tubing. The engagement between the lower head end of the pulling probe and the lower operator lugs forces the gas lift valve and latch downwardly with the latch keys dragging the tubing wall until the latch and gas lift valve engage the next lower latch at which time the probe will be forced on through the latch and gas lift valve fully retracting the keys as already described.

Following release of the upper latch, when the downshifting tool **34** passes through the sleeve valve the valve is shifted downwardly to its closed position so that the pumping fluid does not bypass across into the tubing **54**.

If the upper latch and gas lift valve, after release, are forced downwardly by the tip end of the pulling probe with the probe not fully inserted through the gas lift valve the collet **632** at the lower end of the gas lift valve may be pushed into and recoupled with the head of the mandrel of the next lower locked latch. Alternatively, however, if the probe has been fully inserted through the released upper latch and gas lift valve, the full diameter portion of the probe will extend through the collet so that the collet cannot contract inwardly to recouple with the upper end of the next latch and thus will simply contact the

upper end of the latch mandrel at the entry into its coupling recess. In any event, when the pulling probe drives the released upper latch and gas lift valve downwardly against the upper end of the next lower latch the probe is forced through into the next lower latch to release it in the same manner as already described in releasing the upper latch. The latches are thus sequentially released by the probe as it is forced downwardly and each sleeve valve is closed after release of the latch in it.

When the lowest latch and gas lift valve have been released in the tubing and the running probe has been forced downwardly until its tip end enters the bottom sub on the lower end of the lowest gas lift valve, the pulling probe is coupled into the bottom sub by means of the collet **722**. This coupling may occur immediately after the release of the lowest latch and gas lift valve without driving the latch and valve all the way to the bottom stop **61** in the tubing if the frictional resistance provided by the seal assemblies on the gas lift valve is sufficient. If not, the lowest latch and gas lift valve are pushed to the bottom stop **61** which holds them against further downward movement while the pulling probe is latched into the sub. Whether the lower latch and gas lift valve are held by friction or engage the bottom stop **61**, the pointed lower end of the pulling probe is forced downwardly as shown in FIG. 14 through the heads of the collet fingers of the collet **722** until the pulling probe has been forced downwardly as far as it will go in the bottom sub of the lowermost gas lift valve. Generally this occurs after the string of tools has reached the bottom stop **61** to give a clear pressure indication at the surface in the displacing fluid pumping the pulling tool string downwardly in the tubing. When such pressure increase occurs indicating that the tool string has reached the bottom of the tubing, the boss portion **617***h* on the lower tip of the pulling probe is below the pulling collet **722** and the fluid flow in the tubings is reversed from the surface installation so that the displacing of the fluid is pumped into the tubing **54** and returned through the tubing **50**. The power piston is pumped upwardly in the tubing **53** lifting the pulling probe so that the tip boss portion of **617***h* of the probe engages and lifts the pulling collet **722** raising its finger heads into the counterbore **713** of the bottom sub thereby wedging the tip end of the pulling probe into the collet so that the pulling probe lifts the lower gas lift valve and latch and the previously released gas lift valves and latches on the probe toward the surface. When the tip end of the probe becomes fully engaged as shown in FIG. 15, the string of latches and gas lift valves which has been sequentially released and the probe inserted through them will be arranged in essentially the same end-to-end array on the probe as shown in FIGS. 3A–3E during the running-in of the tools. With the latches and well tools so assembled and locked on the pulling probe, the probe and tools are pumped back to the surface and removed from the system at the lubricator section **95**.

The pulling probe **81***a*, FIGS. 16–20, functions in the same manner as the pulling probe **81** but is distinguished by the capability of being releasable from the latches and gas lift valves in the event that the string of latches and tools cannot be pumped upwardly due to an obstruction or the lodging or wedging of some of the tools in the tubing. During the downward movement of the pulling probe **81***a* it functions in the normal previously described manner to release each of the latches. During the downward movement of the probe the pulling collet **754** on the probe normally hangs with its upper ring **755** resting on the ring **759** which is held by the shear pin **760** to the probe. When the tip end of the probe enters the bottom sub coupling **710** the collet **754** and the tip of the probe pass downwardly in the coupling until the bosses **758** on the collet engage the internal flange **710***a* of the coupling holding the collet against further downward movement until the probe tip moves downwardly engaging the lower end of the probe sleeve **617***j* with the upper end of the upper collet ring **755**. The collet is forced downwardly so that its bosses **758** are cammed inwardly around the probe tip above the enlargement **752** causing the collet to snap downwardly through the annular flange **710***a* until the collet bosses **758** are below the flange as shown in FIG. 17. The probe and collet may be forced on downwardly until the tip end of the probe is stopped by the lower end portion of the bottom sub **717** at which time a pressure increase at the surface indicates that the fluid flow direction may be reversed in the well system.

The pulling tool string with the pulling probe **81***a* is then pumped upwardly lifting the pulling probe so that the ring **759** is raised to engage the upper collet ring **755** lifting the collet until its bosses **758** engage the bottom surface of the coupling flange **710***a* holding the collet against further upward movement. When the probe tip is raised to engage the ring **759** with the collet ring **755**, the probe tip boss **752** is aligned within the pulling collet bosses **758** so that the pulling collet fingers cannot be cammed inwardly when the collet bosses **758** engage the coupling flange **710***a* on the upper stroke of the probe and pulling collet. The pulling collet bosses thus lift the lowest gas lift valve and latch along with the other latches and gas lift valves previously released and assembled on the probe during the downward trip of the pulling tool string and the tool string is pumped back to the surface and removed from the tubing as already described.

When the pulling collet parts are arranged as shown in FIG. 17, and if the tools cannot be pumped upwardly, the pumping force on the power piston **31**, lifts the probe shearing the pin **760** so that the probe is raised within the pulling collet until the probe enlargement **752** engages the lower end of the ring **759** which is engaged with the collet ring **755** as shown in FIG. 18. An upward force from the boss **752** is applied through the ring **759** to the collet ring **755**. The pulling probe boss **752** is above the pulling collet bosses **758** so that the upward force on the pulling collet cams the pulling collet bosses inwardly at the coupling flange **710***a* compressing the collet fingers and bosses around the pulling collet tip below its boss **752** so that the pulling collet releases from the flange **710***a* of the coupling **710** as shown in FIG. 19 thereby freeing the pulling collet from the bottom sub of the lower gas lift valve. After being so released, the pulling collet may be pumped back to the surface and other tools and procedures not involved in the invention applied to the problem of removing the stuck well tools from the tubing.

When it is desired in installing the latches and gas lift valves in the tubing that the running tool string not be pumped to the bottom stop **61**, such as when a valve is to be installed in one of the upper locking recesses only, the running probe **35***a* shown in FIGS. 21–23 may be used in place of the running probe **35**. The running tool string utilizing the modified probe supporting the latches and gas lift valves is assembled in the same manner as the tool string **30** for insertion into the well system through the lubricator **92** as already described. The piston **31** with the sleeve shifting tools **33** and **34** are connected as shown in FIG. 2 with the coupling **32** at the lower end of the sleeve shifter **34** being connected with the coupling recess **771** in the head of the probe **35***a*. The latches **40** and gas lift valves **41** are assembled on the probe in the relationship shown in FIGS. 3A–3E with the lower end of the probe being secured by the shear pin **730** to the bottom sub **717** as shown at the lower end of FIG. 21. When the tool string is inserted into the well system at the surface the pressure within the cylinder **772** in the head **770** of the running probe **35***a* is atmospheric. The tool string is pumped through the tubing to a depth below the locking recess at which the bottom latch on the probe is to be installed in the tubing. In the event only one latch is on the probe the tool string would be pumped below the particular locking recess at which the latch is to be released and locked in the tubing. The determination of the depth of the tool string at any given time during the

running-in procedure is ascertained by standard techniques including measuring the quantity of fluid pumped into the tubing behind the tool string to displace the tool string to the desired depth. Knowing the specifications of the tubing and the volume of the displacing fluid pumped into the tubing behind the tool string, the depth at which the tool string is located at a given time is readily determined. When the tool string is at the desired depth, the pressure in the tubing is raised to a level sufficient to shear the pin **776** and force the piston **773** farther into the probe head cylinder chamber **772**. The pressure level in the tubing may be increased by several techniques. The fluid return through the tubing **54** may be closed by shutting the valve **93** or **94**. Alternatively, the pressure may be raised sufficiently in the fluid being introduced into the tubing **53** behind the tool string. The pressure level in the tubing at the tool string is thus increased until it is sufficiently high that the pressure differential across the piston **773** between the pressure level within the tubing around the tool string and the atmospheric pressure within the cylinder **772** is high enough to apply enough force on the piston to shear the pin **776**. When the pin is sheared, the piston is forced farther into the chamber lifting the connector **779** and the head end of the running probe rod causing the running probe to be pulled upwardly, FIG. 22, thereby shearing the pin **730** at the lower end of the probe rod within the sub **717**. The release of the lower end of the probe is followed by the arming of the lower latch causing its locking keys to be expanded against the tubing wall in the same manner as already described. The increased pressure within the tubing is then reduced and the direction of fluid flow in the system is reversed so that the tool string is pumped back upwardly in the tubing **53** releasing and locking the latch or latches on the probe after which the running tool string is returned to the surface and removed from the system by the procedures already described. Thus, the running probe **35***a* may be operated to release the latch or latches and the well tools connected with the latches at any desired depth in the tubing without the necessity of pumping the tool string to the bottom end of the tubing at the stop **61**. Of course, it will be recognized that as the modified probe is pumped downwardly and back upwardly in the tubing, the sleeve shifting tools **33** and **34** in the tool string open and close the sliding sleeve valves as described.

The probe **35***a* may function in the running tool string in the same manner as the probe **35** by striking the stop **61** to shear the pin **730** at the lower end of the probe. FIG. 23 represents the relative positions of the probe parts after the probe **35***a* has been used to release the latches by the same procedures used with the probe **32**. When the collet **729** strikes the stop **761** holding the tool string against further downward movement, the force of the power piston against the upper end of the head of the probe applies a downward force through the head housing **785** against the upper end **625** of the mandrel of the top latch on the probe. The force against the top latch drives the latch and tools on the probe downwardly relative to the probe shearing the pin **730** so that the bottom sub **717** moves downwardly along the probe as represented in FIG. 8. As the probe head is forced downwardly relative to the probe rod, the sleeve **777** on the piston **773** is telescoped downwardly over the nut **780** on the upper end of the probe rod head **779** as shown in FIG. 23. The sleeve **777** moves downwardly over the probe rod head the same distance as the travel of the string of tools downwardly on the probe after shearing the pin **730**. The port **778** in the sleeve **777** allows liquid movement out of the sleeve avoiding any piston-like effect as the nut **780** moves upwardly. Subsequent to the shearing of the pin **730** by the procedure represented in FIG. 23 the tool string is pumped back upwardly in the tubing to release and set each of the latches in the tubing after which the tool string is returned to the surface and removed from the system. Thus, the alternate form of running probe **35***a* is useful either as a hydraulically actuated probe at a desired depth without mechanical impact force or by use of impact force at the bottom of the tubing at the stop **61**.

A gas lift valve system having gas lift valves installed and removed using the technique and apparatus described and illustrated herein is operated in a substantially conventional manner. With the lift valves supported from the latches in the tubing **53**, lift gas is introduced into the well through the parallel tubing string **54**. Prior to injection of the lift gas, the well fluids rise due to formation pressure to some predetermined level in the tubing strings. The liquid level is depressed somewhat in the tubing **54** when the lift gas pressure is increased with some U-tube effect occurring to raise the "working level" in the tubing **53** somewhat above the normal static level of the liquids in the tubing. Generally, the gas lift valves below the liquid level will be open due to hydrostatic pressure while those above the liquid level generally are closed. The valve functioning to admit lift gas is the one above and nearest the operating level of the liquid in the tubing **53**. When the pressure of the lift gas around the gas lift valve between its upper and lower seal assemblies is sufficient to overcome the dome gas pressure in the chamber **689**, the flexible valve member **693** is forced inwardly away from the ports **696**, to admit the lift gas which flows downwardly past the check valve **693** entering the tubing through the ports **699** to aid in lifting the column of liquid in the tubing **53** to the surface.

While a well system embodying the invention including the tubing latches and handling tool strings has been described in terms of a gas lift system where each of the gas lift valves is supported from one of the latches installed and removed on the probe, it is to be understood, that the latch may be used to support a number of other well tools within a tubing. The latch may be installed and removed utilizing probes of the type described and illustrated herein operated either by conventional wireline methods or by pump down techniques of the types already discussed. Among the well tools which may be supported in a tubing from latches embodying the invention are plug chokes, tubing safety valves and standing valves. It will be apparent that some tools such as a plug choke when supported on a latch installed and retrieved by pump down techniques requires setting at a depth relative to a circulating cross-over connection which will locate the power piston of the installing and retrieving tool strings above the cross-over connection so that a complete fluid circuit may be established for both pumping in and retrieving the piston with the probes used for installation and retrieval. In the case of tubing safety valves of the type which permit pumping therethrough, the valve and latch may be placed at any desired depth in the tubing. Since such a safety valve may be pumped through, it may be supported above the cross-over connection between the tubing strings of the well system.

It will now be seen that a new and improved method and apparatus for installing and removing well tools has been described and illustrated. The system includes a new and novel improved latch for supporting well tools in a tubing. The well tool system is operable by pump down techniques which particularly adapt it to remote installation and retrieval such as in an offshore well communicated with and controlled from a surface located station situated at the water surface or at an onshore site. It will also be seen that the tool system includes running and pulling probes on which the latches and well tools are releasably supported during installation and retrieval steps.

It will be further seen that the well tools including the latches supported on the running probe are moved through the tubing to a bottom stop within the tubing or to a depth below the location of the lowest of the latches to be released and locked in the tubing, depending upon which forms of running probe is employed. The latches

and well tools supported therefrom are then sequentially released from the running string and locked in the tubing during the return trip in the tubing toward the surface. Thus, the running tool string is actuated to "arm" or otherwise prepare the latches for release and locking by either manipulation of fluid pressure with the tubing at the tool string or by mechanical impact with a stop member in the tubing situated below the lowest location at which a latch is to be released from the probe and locked in the tubing.

It will be further seen that the new and improved well tool system for installing and retrieving releasable latches in a tubing in its simplest form includes power means for supporting and moving a running or pulling probe through a tubing, a running or pulling probe supported therefrom, and the latches of the invention supported on such probe. In its more complex form, for use in well systems having sliding sleeve valves, the running tool string includes a sleeve shifting unit for moving sliding sleeve valves along a tubing from an upper open to a lower closed position and a sleeve shifting unit for returning the sleeve valves from the lower closed back to the upper open position. It will be also seen that the tool system for retrieving the latches and well tools from such a well system includes a sleeve shifting unit for moving the sleeve valves from their upper open to their lower closed positions as the latches are released from their respective locking recesses in the well tubing and assembled on the pulling probe for removal from the tubing. It will additionally be seen that the new and improved latch includes expandable and contractable locking keys which are operable by lug and sleeve members manipulated by a running or pulling probe for releasing and locking the latches for releasing the latches from the running probe and locking them in a tubing at a locking recess and for releasing the latches from the locking recess when reassembling them on the probe in the tubing. It will also be seen that the latch has a substantially full bore opening throughout its length for pumping a maximum volume of well fluids therethrough and for running other tools therethrough for performing various well functions while the latches are locked within a well tubing.

It will be further seen that the new and improved latch is useful for supporting gas lift valves, safety valves, and other well tools in a well tubing. It will be recognized that the latches and running and pulling probes may be handled both by pump down equipment and wireline equipment in well tubing.

The foregoing description of the invention is explanatory only and changes in the details of the construction illustrated may be made by those skilled within 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 supporting, installing, and removing well tools in a flow conductor comprising: latch means for releasably supporting said well tools in said flow conductor; support means for releasably engaging and holding said latch means for movement through said flow conductor during installation and retrieval of said latch means; said latch means including first securing means for releasable engagement with said flow conductor, second securing means for releasable engagement with said support means, and operator means coupled with said first and second securing means and engageable by said support means for releasing said first securing means from said flow conductor and reactivating said second securing means re-engaging said latch means on said support means; and said support means having operator surfaces engageable with said second latch securing means and said latch operator means whereby said latch means is lockable with and releasable from said support means and from said flow conductor by co-action between said second securing means and operator means and said operator surfaces responsive to the position of said support means relative to said operator means.

2. Apparatus in accordance with claim **1** wherein said support means comprises a probe for releasably supporting said latch means during handling of said latch means.

3. Apparatus in accordance with claim **2** including means for supporting and moving said probe through said flow conductor during handling of said latch means.

4. Apparatus in accordance with claim **3** wherein said means for supporting and moving said probe comprises a pumpable piston adapted to be displaced through said tubing responsive to the fluid pressure applied across said piston.

5. Apparatus in accordance with claim **3** wherein said supporting and moving means comprises wireline apparatus.

6. Apparatus in accordance with claim **2** wherein said probe is disposed through said latch means and releasably connectible with said latch means when moving said latch means through said flow conductor.

7. Apparatus in accordance with claim **6** wherein said probe means is provided with operator surfaces operable with said operator means and said second securing means whereby the relative positions of said probe and said latch means control the release and locking of said latch means relative to both said probe and said flow conductor.

8. Apparatus in accordance with claim **7** including a fluid pressure displaceable piston connected with said probe for supporting and moving said probe through said flow conductor.

9. Apparatus in accordance with claim **8** including sleeve valve shifting means for moving a slidable sleeve valve in said flow conductor between positions, said piston, said sleeve valve shifting means and said probe being coupled to form an articulated tool train adapted to traverse curved flow conductor sections.

10. Apparatus in accordance with claim **9** wherein said sleeve shifting means comprises means for moving a sliding sleeve from a first end position to a second end position and means for moving said sliding sleeve back from said second end position to said first end position.

11. Apparatus in accordance with claim **9** wherein said sleeve shifting means comprises means for moving said sleeve from a first end position to a second end position.

12. Apparatus in accordance with claim **9** including gas lift valve means connected with each latch means of said apparatus for controlling admission of lift gas to said flow conductor at each level in said flow conductor at which said latch means and said gas lift valve means are releasably locked in said flow conductor means.

13. Apparatus in accordance with claim **6** including a gas lift valve supported from each latch means in said apparatus for controlling admission of lift gas to said flow conductor when said valve is locked in said conductor.

14. Apparatus for supporting and handling well tools in a flow conductor comprising: motive means for supporting and propelling said apparatus through said flow conductor; a probe connected with said motive means for releasably supporting well tool latches for movement through said flow conductor, said probe having supporting and control surfaces; and a latch releasably supportable on said probe for movement through said flow conductor and releasably engageable in said flow conductor, said latch including expandable and contractible locking keys for releasably locking said latch in said flow conductor, a first operator member for co-acting at one operator member position with said supporting and control surfaces on said probe for restraining said keys contracted and at another operator member position for supporting said latch on said probe, and a second operator member interconnected with said first operator member

for co-acting with said supporting and control surfaces on said probe for retracting said keys and moving said first operator member to a probe engaging position for resupporting said latch on said probe responsive to movement of said probe in said latch.

15. Apparatus in accordance with claim 14 wherein said latch includes an operator sleeve operatively associated with said operator members and said locking keys for expanding and contracting said keys responsive to the position of said operator members.

16. Apparatus in accordance with claim 15 wherein said probe is articulated for tranversing curved portions of said flow conductor.

17. Apparatus in accordance with claim 16 including sleeve shifting means pivotally connected between said motive means and said probe for moving sliding sleeves in said flow conductor between positions during handling of said latch in said flow conductor.

18. Apparatus in accordance with claim 17 wherein said sleeve shifting means includes a sleeve shifting unit for moving a sliding sleeve in said flow conductor from a first to a second position and a sleeve shifting unit for moving said sliding sleeve back from said second position to said first position.

19. Apparatus in accordance with claim 18 wherein said probe means includes means for securing said latch on said probe means and holding said latch thereon when moving said apparatus in a first direction in said flow conductor, means for activating said latch to an intermediate release condition on said probe, and means for releasing said latch from said probe means during movement in said flow conductor in an opposite direction.

20. Apparatus in accordance with claim 19 including a gas lift valve coupled with said latch for controlling injection of lift gas into said flow conductor when locked in said conductor by said latch.

21. Apparatus in accordance with claim 20 including a plurality of latch-gas lift valve assemblies supported in end-to-end array on said probe.

22. Apparatus in accordance with claim 16 wherein said probe is adapted to be inserted through said latch when said latch is releasably supported in said flow conductor for releasing said latch from said flow conductor and said probe includes means for coupling with said latch for removing said latch from said flow conductor.

23. Apparatus in accordance with claim 22 wherein said probe includes means for release from said latch within said flow conductor after coupling with said latch for removing said latch from said flow conductor responsive to a predetermined resistance of said latch to removal from said flow conductor.

24. Apparatus in accordance with claim 22 including retrieving surface portions on said probe and collet means associated with said latch engageable by said retrieving surface portions for coupling said probe with said latch for removing said latch from said flow conductor.

25. A latch adapted to be releasably engaged in a flow conductor and to be installed in and retrieved from said conductor from a remote location comprising: a body mandrel having a longitudinal passage therethrough; expandable and contractible locking means supported on said body mandrel for releasably locking said latch in said flow conductor; and operator member means operatively coupled with said locking means for controlling the expansion and contraction of said locking means responsive to the relative position of a removable support and control member disposed through said longitudinal flow passage of said mandrel and for securing said latch on said support and control member during movement of said latch through said flow conductor on said support and control member, said operator member means including first operator means for restraining said locking means contracted at a first position of said support and control member in said flow passage and for releasing said locking means for expansion and supporting said latch on said support and control member at a second position of said support and control member in said passage, and said operator member means having a second operator means interconnected with said first operator means and engageable by said support and control member at a third position of said support and control member in said passage to move said first operator means to release and contract said locking means from said flow conductor and resupport said latch on said support and control member.

26. The latch of claim 25 in combination with a running probe comprising said control member adapted to be disposed through said longitudinal flow passage of said body mandrel and releasably secured with said apparatus, said probe having surface portions operatively engageable with said operator member means for controlling the release of said apparatus from said probe and locking of said apparatus in said flow conductor responsive to the relative position of said probe in said flow passage of said mandrel.

27. Apparatus in accordance with claim 25 including a well tool coupled with said body mandrel whereby said well tool is supported by said latch in said flow conductor.

28. Apparatus according to claim 27 including means connected with said well tool for releasably connecting said well tool with said control member for installing and retrieving said latch apparatus and said well tool.

29. Apparatus in accordance with claim 28 in combination with a running probe comprising said control member disposable through said longitudinal flow passage of said body mandrel means of said probe comprising said control member and having operating surface portions for coacting with said operator member means for controlling said expandable and contractible locking means responsive to the position of said probe through said longitudinal flow passage.

30. Apparatus in accordance with claim 29 including motive means for supporting said running probe in and moving said probe through said flow conductor.

31. Apparatus in accordance with claim 27 wherein a plurality of said latches and coupled well tools are arranged in end-to-end array for sequential release and locking in said flow conductor in longitudinal spaced relation and sequential release from said flow conductor and retrieval from said flow conductor.

32. Apparatus in accordance with claim 29 including a retrieving probe insertable through said longitudinal flow passage of said body mandrel, said probe having operator surface portions for engaging said operator member means for releasing said latch from said flow conductor and means for coupling said probe with said latch for retrieving said latch from said flow conductor.

33. Apparatus in accordance with claim 32 including means for supporting and moving said retrieving probe through said flow conductor.

34. A latch adapted to be releasably engaged in a flow conductor and to be installed in and retrieved from said conductor from a remote location comprising: a body mandrel having a longitudinal flow passage therethrough and provided with lateral windows communicating with said flow passage; an operator sleeve disposed for longitudinal movement on said body mandrel, said operator sleeve being provided with first lateral windows along one end portion and second lateral windows along the other end portion; a locking key disposed in each of the said first lateral windows of said operator sleeve for longitudinal and radial movement for expansion and contraction to releasably lock and release said latch along said flow conductor; said operator sleeve and said locking keys having cooperating control and retainer surface portions whereby said keys are expanded and contracted responsive to longitudinal movement of said sleeve and said keys are held in said windows of said sleeve by said retainer surface portions; a housing sleeve telescopically disposed over a portion of said operator sleeve

and provided with internal control surface and recess portions; sleeve control member means disposed through said second windows of said operator sleeve and said windows of said body mandrel into said flow passage of said mandrel and adapted for radial movement therein for coacting with said control surface portions and said recess in said housing sleeve for controlling the longitudinal position of said operator sleeve relative to said housing sleeve for expanding and contracting said locking keys; said body mandrel and said outer housing sleeve being coupled together along corresponding end portions thereof in concentric spaced relationship with said operator sleeve portion disposed on said body mandrel and extendable into said housing sleeve; and means operatively coupled with said operator sleeve for biasing said sleeve toward said locking keys for moving said sleeve away from said housing sleeve on said body mandrel for expanding said locking keys; and said sleeve control member means inner portion in said flow passage through said body mandrel being engageable by a support and control member removably disposable through said central flow passage for supporting said latch during installation and retrieval and for controlling said sleeve control member means for expansion and contraction of said keys and for locking and releasing said latch on said support and control member.

35. A latch as defined in claim **34** wherein said operator member means comprises lugs having outer portions receivable in said recesses of said housing sleeve at one longitudinal position of said lugs in said sleeve and engageable with said control surfaces of said housing sleeve at another longitudinal position of said lugs in said sleeve, said lugs having inner portions projecting inwardly of said body mandrel into said longitudinal flow passage of said mandrel for engagement with surface portions on said support and control member when said member is disposed through said flow passage of said mandrel, the coaction between said lugs and said recesses and said control surface portions in said housing sleeve controlling the longitudinal position of said operator sleeve relative to said housing sleeve for controlling said latch relative to said flow conductor and to said support and control member.

36. The latch of claim **35** wherein said operator lugs comprise at least a first operator lug and a second operator lug and said recesses and control surface portions of said housing sleeve comprise spaced first, second, and third recesses separated by first and second control surface portions for coacting with said operator lugs for controlling position of said inner control sleeve.

37. The latch of claim **36** in combination with a running probe having a head portion and a rod portion disposable through said longitudinal flow passage of said body mandrel of said latch, said rod portion having a full diameter section having a surface portion engageable by said operator lugs for holding said lugs at maximum expanded positions for locking said operator sleeve at a longitudinal position holding said locking keys fully contracted inwardly, said probe having a reduced diameter section to allow said operator lugs to move radially inwardly for releasing said operator sleeve for movement to expand said locking keys, and said running probe having a locking boss along said reduced diameter section for engagement with at least one of said operator lugs for supporting said latch at an intermediate position on said probe when landing and locking said latch in said flow conductor.

38. The apparatus of claim **37** including means for releasably securing said latch with said probe with said locking keys of said latch fully retracted for movement through said flow conductor.

39. The apparatus of claim **38** wherein said running probe includes fluid pressure actuated means to effect longitudinal movement between said probe and said latch at a predetermined fluid pressure within said flow conductor for releasing said latch from said probe when running and locking said latch in said flow conductor.

40. The apparatus of claim **39** wherein the head portion of said probe is provided with a fluid pressure actuated piston coupled with the rod portion of said probe for moving said rod portion relative to the head portion of said probe for releasing said probe from said latch.

41. The latch of claim **36** in combination with a pulling probe having a head and rod portions, said rod portion having a free end portion provided with control shoulder surfaces for engaging one of said operator lugs of said latch for moving said operator sleeve for retracting said keys to release said latch from a locked relation in said flow conductor and means for coupling said pulling probe with said latch after said latch is released from said flow conductor for retrieving said latch from said flow conductor.

42. The apparatus in claim **41** wherein a locking collet is supported from said latch and said pulling probe includes a locking boss insertable into said locking collet for coupling said probe with said latch for retrieving said latch from said flow conductor.

43. The apparatus of claim **41** wherein said pulling probe includes a locking collet adapted to engage a locking surface associated with said latch for coupling said probe with said latch when retrieving said latch from said flow conductor and said locking collet is held at a longitudinal position on said pulling collet by releasable means adapted to be actuated responsive to a force in excess of a predetermined value exerted between said pulling collet and a locking surface associated with said latch to permit said locking collet to move to a release position on said probe for releasing said probe from said latch when the pulling force between said probe and said latch exceeds a predetermined value.

44. The latch of claim **36** wherein the head portion of said body mandrel includes tapered key expander surfaces engageable with adjacent cam surfaces on a first end of said locking keys, said operator sleeve has cam surfaces defining the ends of said windows at the second ends of said locking keys for engaging cam surfaces on said ends of said locking keys in expanding said keys, said head portion of said housing mandrel is provided with retainer recesses, said locking keys are each provided with a retainer ear at said first end of said keys receivable in said retainer recesses of said housing mandrel for holding said first ends of said keys for movement along a confined path during expansion and contraction, said operator sleeve is provided with retainer flanges on opposite sides of each window in said sleeve for engaging retractor cam surfaces on said keys during contraction of said keys and for engaging retainer flanges on said keys to limit the outward movement of said keys in said windows, and said keys are provided with retractor cam surfaces and retainer flanges engageable with said flanges of said operator sleeves.

45. Apparatus including a plurality of latches as defined in claim **36** interconnected in end-to-end array forming an elongate, articulated, tool train, said latches being releasably coupled together for separation in said flow conductor whereby said latches are run in articulated tool train form and released and locked in said flow conductor in sequential steps.

46. The apparatus in claim **45** wherein the coupling between said latches includes a collet releasable for disengaging adjacent latches from each other and the latch nearest the foot end of said tool string is coupled with means for releasably connecting the tool string with a running probe for holding the string on said probe for moving the string through said flow conductor.

47. The apparatus in claim **46** wherein a gas lift valve is coupled with each of said latches whereby each said latch supports a gas lift valve in said flow conductor when said latches are released and locked in said flow conductor.

48. An articulated tool train comprising in combination: a seal means slidable in a flow conductor and adapted

to be moved through said flow conductor responsive to a fluid pressure differential applied across said seal means; a first sleeve shifter pivotally connected with said seal means for shifting a sliding sleeve valve in a flow conductor from a first end position to a second end position; a second shifter pivotally connected with said first sleeve shifter for shifting said sliding sleeve in said flow conductor from said second position back to said first position; a running probe pivotally connected with said second sleeve shifter, said running probe having a head portion coupled with said second sleeve shifter and a rod portion pendant from said head portion and being flexible for traversing curved portions of said flow conductor, said rod portion having control surface portions for coacting with operator members of a latch supported on said rod portion, the free end portion of said rod portion including means for releasably connecting said rod portion with a latch supported thereon; a latch supported on said rod portion for releasably supporting a well tool on said rod portion and being adapted to be released from said rod portion and releasably locked in said flow conductor, said latch comprising a body mandrel having a longitudinal flow passage therethrough and provided with lateral windows communicating with said flow passage; an operator sleeve disposed for longitudinal movement of said body mandrel, said operator sleeve being provided with first lateral windows along one end portion and second lateral windows along the other end portion; a locking key disposed in each of the said windows of said operator sleeve for longitudinal and radial movement for expansion and contraction to releasably lock and release said latch along said flow conductor; said operator sleeve and said locking keys having cooperating control and retainer surface portions whereby said keys are expanded and contracted responsive to longitudinal movement of said sleeve and said keys are held in said windows of said sleeve by said retainer surface portions; a housing sleeve telescopically disposed over a portion of said operator sleeve and provided with internal control surface and recess portions; sleeve control member means disposed through said second windows of said operator sleeve and said windows of said body mandrel into said flow passage of said mandrel and adapted for radial movement therein for coacting with said control surface portions and said recesses in said housing sleeve for controlling the longitudinal position of said operator sleeve relative to said housing sleeve for expanding and contracting said locking keys; said body mandrel and said outer housing sleeve being coupled together along corresponding end portions thereof in concentric spaced relationship with said operator sleeve portion disposed on said body mandrel and extendable into said housing sleeve; and means operatively coupled with said operator sleeve for biasing said sleeve toward said locking keys for moving said sleeve away from said housing sleeve on said body mandrel for expanding said locking keys; said sleeve control member means inner portion in said flow passage through said body mandrel being engageable by a support and control member removably disposable through said central flow passage for supporting said latch during installation and retrieval and for controlling said sleeve control member means for expansion and contraction of said keys and for locking and releasing said latch on said support and control member; a well tool having a flow passage therethrough pivotally connected with said latch whereby said latch supports said well tool in said flow conductor when said latch is released from said probe; and means supported from said well tool for releasably coupling said latch and said well tool on said free end portion of said running probe during the installation of said latch in said well tool in said flow conductor on said running probe.

49. A well system including: 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 and releasably locking well tool means in each of said sliding sleeve valve means including a latch for releasably locking said well tool means at each sliding sleeve valve means, said latch being adapted to be inserted into and removed from each said sliding sleeve valve means on probe means and comprising a body mandrel having longitudinal flow passage therethrough for flow of fluids and to receive said probe means, an operator sleeve movably disposed on said mandrel, expandable and contractable locking keys supported by said operator sleeve, said operator sleeve and said keys having control surfaces cooperating to expand and contract said keys responsive to longitudinal movement of said control sleeve, operator members supported through said control sleeve and said mandrel projecting into said flow passage through said mandrel for engagement with said probe means for releasably supporting said latch on said probe means and for controlling expansion and contraction of said locking keys, and a housing sleeve concentrically connected with said body mandrel in concentric spaced relationship around said mandrel, said housing sleeve having internal locking surfaces and recesses adapted to function with said operator members for controlling the position of said operator sleeve for expanding and contracting said locking keys.

50. A method of installing a releasable latch in a flow conductor of a well having locking recesses therein comprising: releasably supporting said latch on a running probe having hydraulic means for shifting said probe relative to said latch for disengaging said probe from said latch, said probe being supported from fluid pressure displaceable seal means forming a tool train; pumping said tool train through said flow conductor from a first end thereof until said tool train has been displaced past the locking recess at which said latch is to be released and locked; increasing the fluid pressure within said flow conductor to a level sufficient to actuate said hydraulic means of said running probe for moving said probe relative to said latch to release said probe in said latch; reversing the flow direction in said flow conductor to displace said tool train toward said first end of said flow conductor until said latch engages said locking recess in said flow conductor; and pumping said seal means and said running probe toward said first end of said flow conductor thereby withdrawing said probe from said latch leaving said latch releasably locked in said flow conductor at said locking recess.

51. Apparatus for supporting and handling well tools in a flow conductor comprising: motive means for supporting and propelling said apparatus through said flow conductors; sleeve shifting means pivotally connected with said motive means including a sleeve shifting unit for moving a sliding sleeve in said flow conductor from a first to a second position and a sleeve shifting unit for moving said sliding sleeve back from said second position to said first position; an articulated probe for traversing curved portions of said flow conductor connected with said sleeve shifting means for releasably supporting a well tool latch for movement through said flow conductor, said probe having supporting and control surfaces; said probe having means for securing a well tool latch thereon and holding said latch when moving said apparatus in a first direction in said flow conductor, means for activating said latch to an intermediate release condition on said probe, and means for releasing said latch from said probe during movement in said flow conductor in an opposite direction; said probe including means for releasing said latch responsive to an impact force upon contact of said apparatus with a stop member in said flow conductor; and a latch releasably supportable on said probe for movement through said flow conductor and releasably engageable in said flow conductor, said latch including operator

members for securing said latch on said probe and for controlling said latch responsive to the relative position of said probe through said latch, expandable and contractible locking keys for releasably locking said latch in said flow conductor, said locking keys being controlled by said operator members, and an operator sleeve associated with said operator members and said locking keys for expanding and contracting said keys responsive to the positions of said operator members.

52. Apparatus for supporting and handling well tools in a flow conductor comprising: motive means for supporting and propelling asid apparatus through said flow conductor; sleeve shifting means pivotally connected with said motive means including a sleeve shifting unit for moving a sliding sleeve in said flow conductor from a first to a second position and a sleeve shifting unit for moving said sliding sleeve back from said second position to said first position; an articulated probe for traversing curved portions of said flow conductor connected with said sleeve shifting means for releasably supporting a well tool latch for movement through said flow conductor, said probe having supporting and control surfaces; said probe having means for securing a well tool latch thereon and holding said latch when moving said apparatus in a first direction in said flow conductor, means for activating said latch to an intermediate release condition on said probe, and means for releasing said latch from said probe during movement in said flow conductor in an opposite direction; said probe including means for releasing said latch responsive to a fluid pressure change in said flow conductor; and a latch releasably supportable on said probe for movement through said flow conductor and releasably engageable in said flow conductor, said latch including operator members for securing said latch on said probe and for controlling said latch responsive to the relative position of said probe through said latch, expandable and contractible locking keys for releasably locking said latch in said flow conductor, said locking keys being controlled by said operator members, and an operator sleeve associated with said operator members and said locking keys for expanding and contracting said keys responsive to the positions of said operator members.

53. A latch in accordance with claim 25 wherein said locking means on said body mandrel comprises normally expanded retractable locking keys.

54. The apparatus of claim 53 in combination with a support and control member provided with a first operator surface for engaging said first operator means of said latch for restraining said keys at retracted positions, a second operator surface for engagement by said first operator means of said latch to releasably support said latch on said support and control member, and a third operator surface to engage and move said second operator means for retracting said keys and releasing said latch in said flow conductor and re-engaging said second operator surface with said first operator means for re-supporting said latch on said support and control member for moving said latch in either direction along said flow conductor.

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IAN A. CALVERT, Primary Examiner

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