Feb. 10, 1970 A. A. MULLINS 3,494,419

SELECTIVELY-OPERABLE WELL TOOLS

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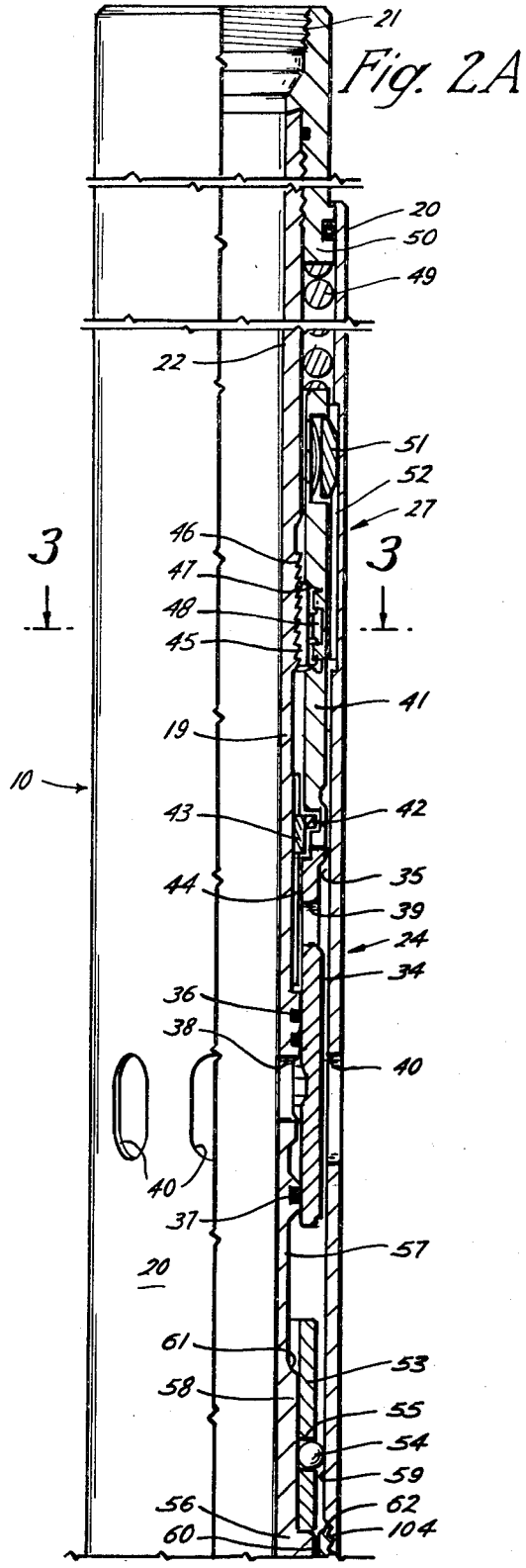


Fig. 2A

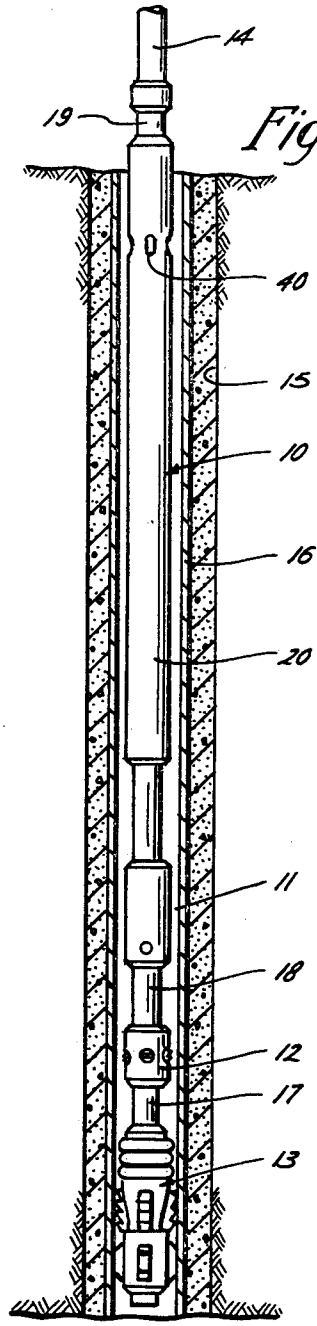


Fig. 1

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Fig. 2B

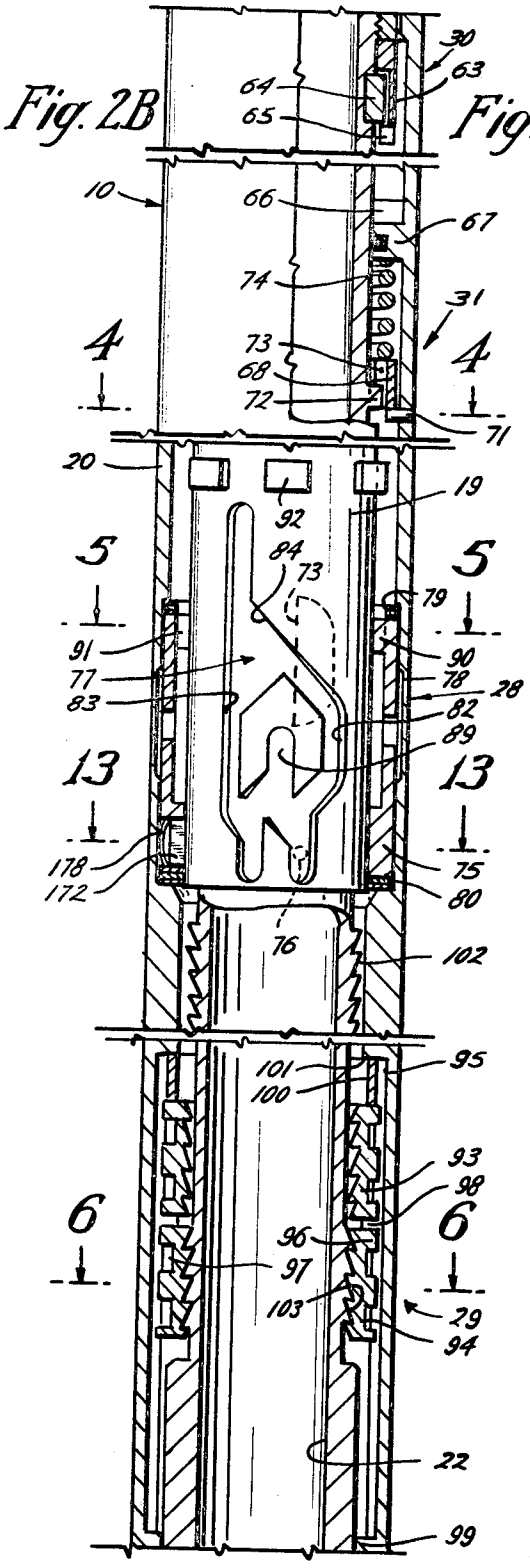
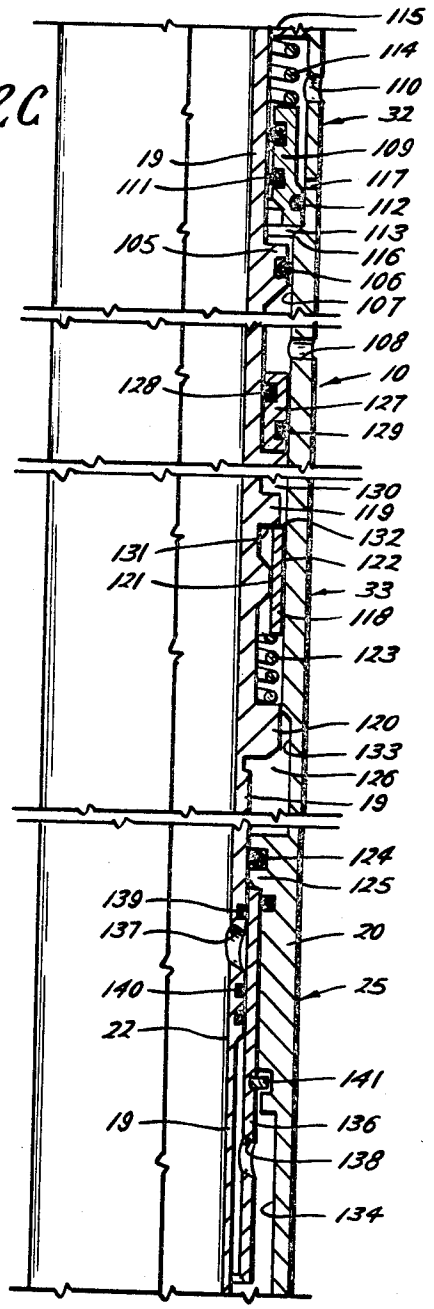


Fig. 2C



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SELECTIVELY-OPERABLE WELL TOOLS

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Fig. 2D

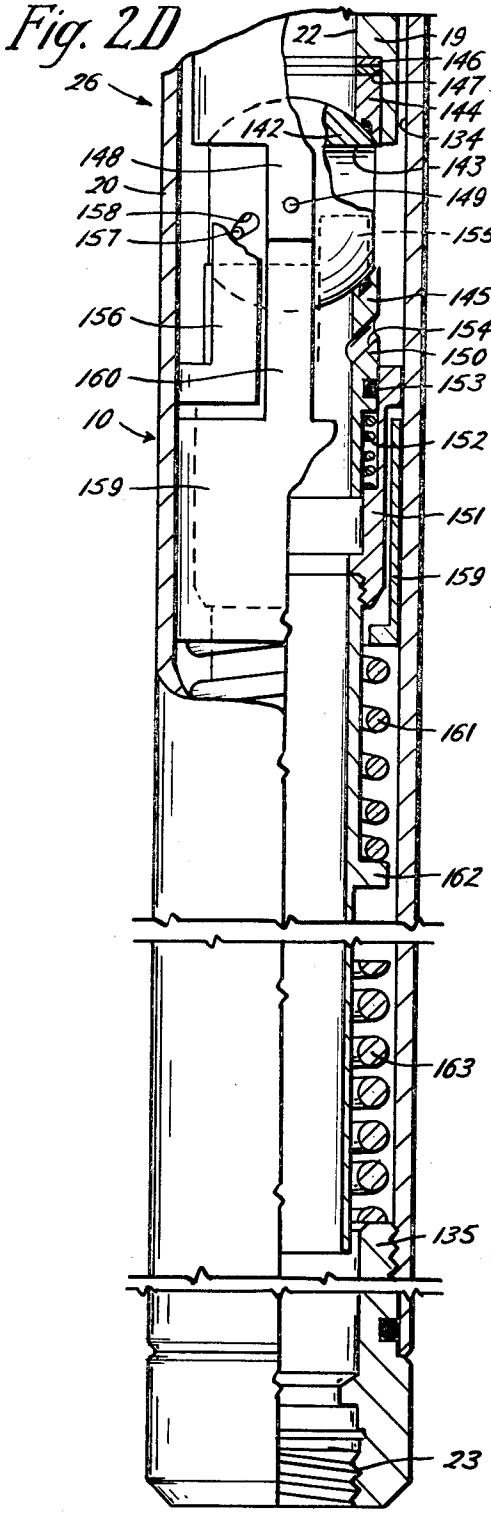


Fig. 12A

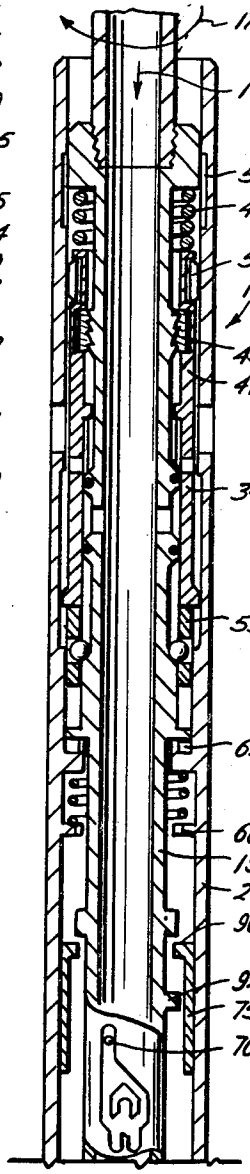
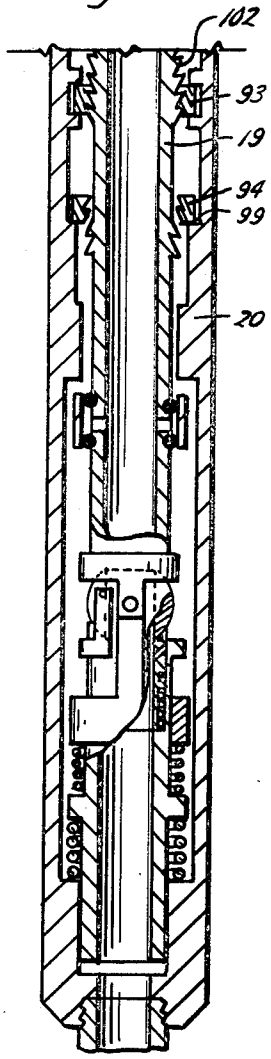


Fig. 12B



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Fig. 3

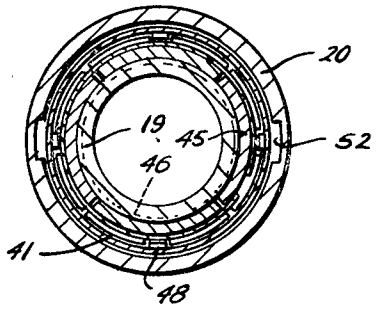


Fig. 4

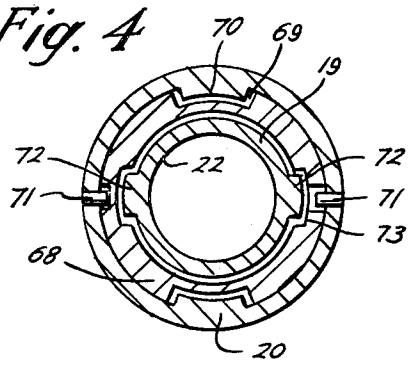


Fig. 5

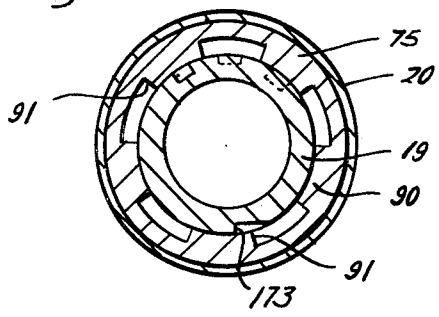


Fig. 6

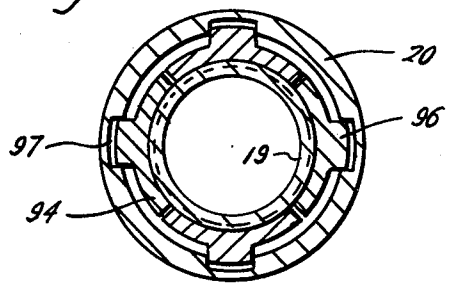


Fig. 7

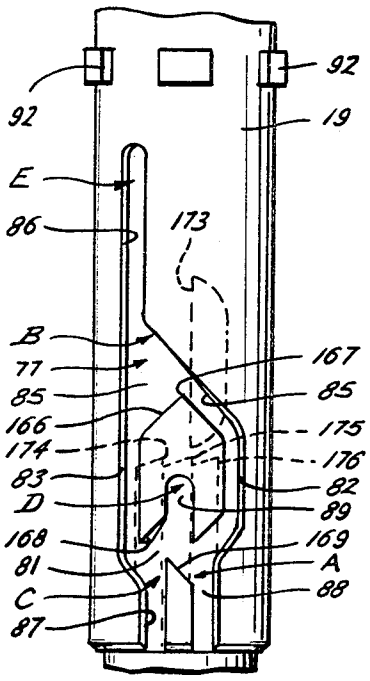
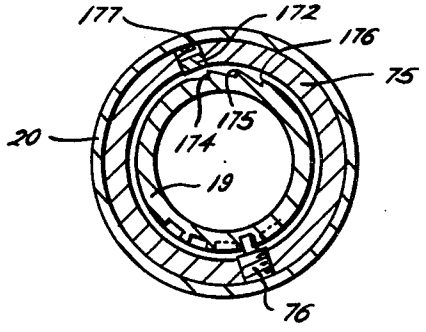


Fig. 13



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SELECTIVELY-OPERABLE WELL TOOLS

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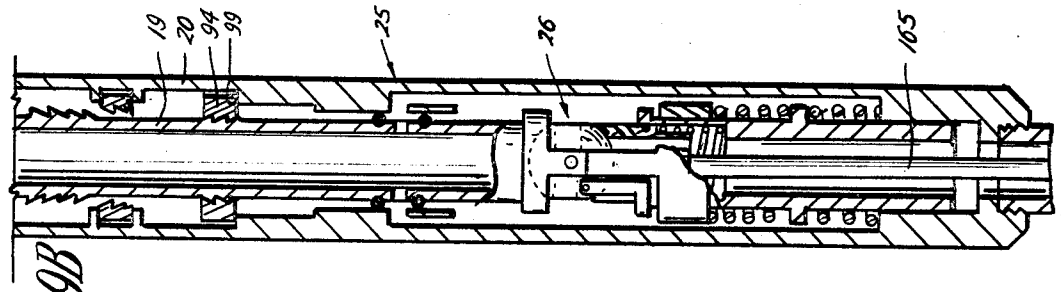


Fig. 9B

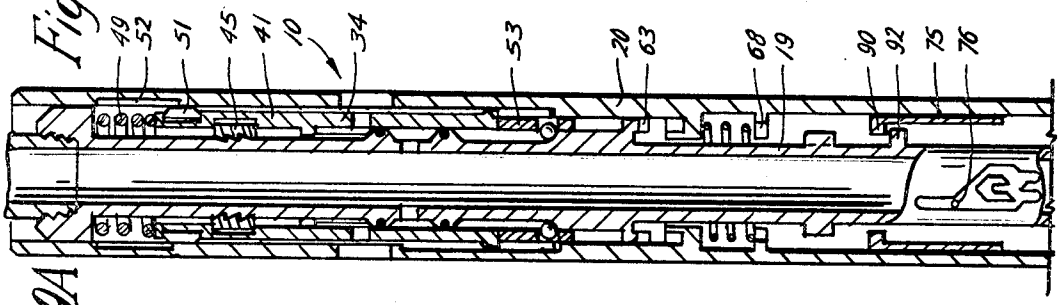


Fig. 9A

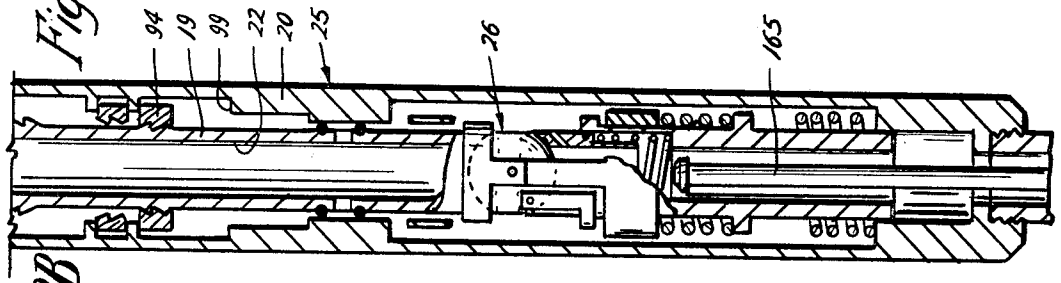


Fig. 8B

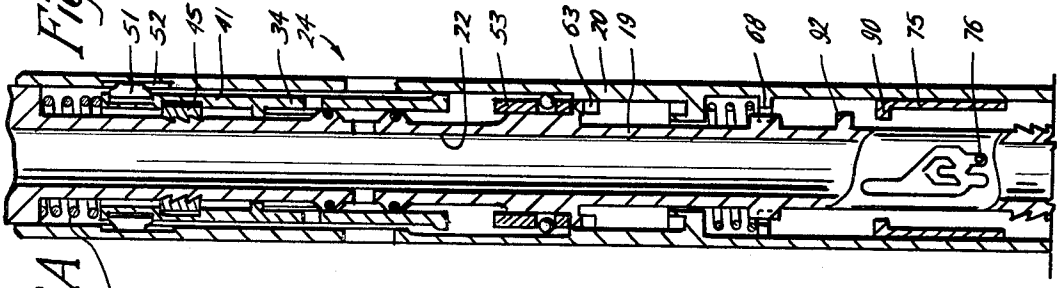


Fig. 8A

49

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SELECTIVELY-OPERABLE WELL TOOLS

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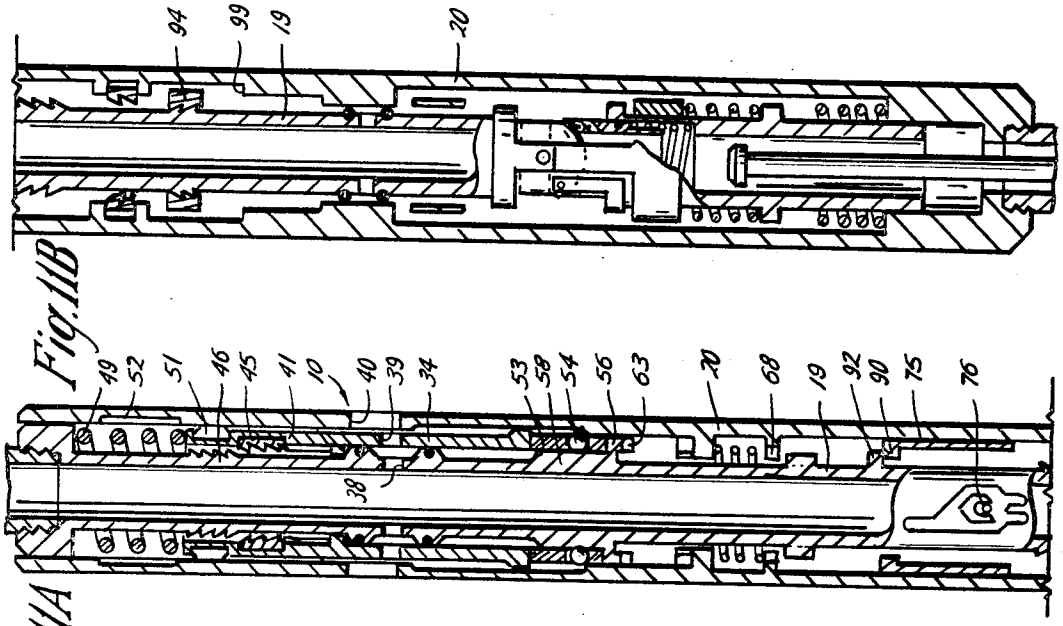


Fig. 11B

Fig. 11A

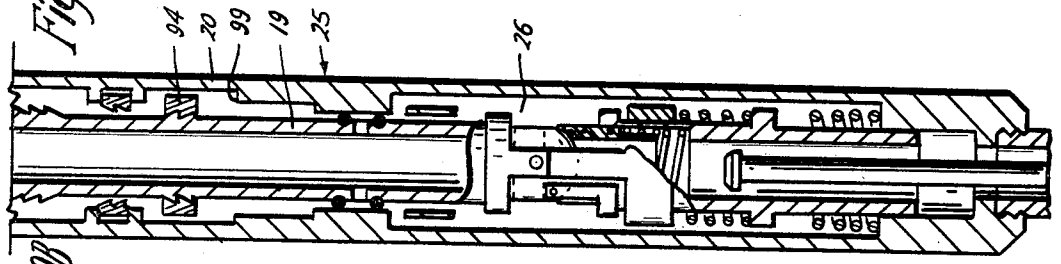


Fig. 10B

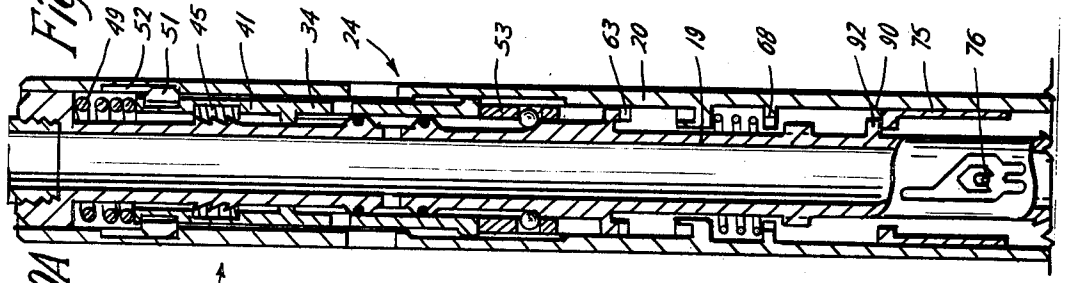


Fig. 10A

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United States Patent Office 3,494,419
Patented Feb. 10, 1970

3,494,419

SELECTIVELY-OPERABLE WELL TOOLS

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Int. Cl. E21b 33/12, 43/00
U.S. Cl. 166—150 41 Claims

ABSTRACT OF THE DISCLOSURE

The invention disclosed herein is directed to well tools having one or more selectively-operable valves therein. More particularly, the apparatus disclosed herein as a preferred embodiment of the invention is comprised of telescoped tubular members cooperatively arranged with three valves that are to be selectively operated by movement of the tubular members. Positioning means are cooperatively associated with the valves and tubular members so that each of the valves can be selectively operated independently of one another with only longitudinal movement and relative rotation of the tubular members.

It is customary to employ a number of different full-bore tools coupled together for performing such well-testing and well-completion operations as testing earth formations under both flowing and static conditions, squeeze cementing, acidizing, and fluid fracturing. As is typical, such a string of full-bore tools includes a full-bore packer for packing-off the well bore, a bypass valve for selectively controlling communication between the well bore annulus and the interior of the tubing string, and one or more testing or completion tools for selectively controlling communication between the well bore above and below the packer and the tubing string as well as providing an unrestricted full-diameter passage into the well bore below the packer. To shift these tools into position to conduct such operations as well as to go from one operation to another, the tubing string is generally manipulated as required to move the tools into their various relative positions. It will be recognized, of course, that only four basic manipulative movements (i.e., longitudinal shifting in both vertical directions or else rotation in the two rotative directions) are available to operate these tools.

Those skilled in the art recognize, however, that it is not always feasible to use even all four of these basic manipulations. For example, many operators object to so-called "left-hand" torque since rotation in this direction may inadvertently unthread one or more of the collars coupling the tubing string. Moreover, it is not too desirable to operate a well tool by continued "right-hand" rotation where only a predetermined number of revolutions establishes the particular operating positions of the tool. For, in addition to the possibility that some of this right-hand torque may only further tighten the collars coupling the tubing string, the inherent capability of the tubing string to absorb a certain amount of torque usually makes it quite difficult, if not altogether impossible, to reliably determine from the surface whether a predetermined number of rotations have been faithfully translated through the tubing string to a tool several thousands of feet therebelow. In such instances, it is best not to over-rotate the upper end of the tubing string just to be sure that a particular number of rotations have in fact reached the tool at the lower end of the string.

In most instances, it is also preferred to maintain a substantial downward force on the packer to insure that it remains fully set during a typical testing operation so that the well can be kept under control. This, of course,

minimizes the amount of upward force that can be safely applied through the tubing string. Accordingly, although the tubing string can usually be moved upwardly to shift one or more of the tools into different operating positions, it is generally preferred to maintain a downward force on the tubing string once each of these operating positions are reached to be certain that the packer remains set.

Thus, for these and other reasons, whenever several operating positions must be assumed by the tools, at least some manipulative movements must be duplicated with only variations in these few available movements being used to establish the several operative positions of the tools. Accordingly, many well tools of this nature are operated by shifting the tool mandrels into various longitudinally spaced positions, with only a minimum number of these operating positions being reached by rotating the tubing string. Typical of such control arrangements is a so-called "J-slot" system in which a lateral pin projecting from one relatively-movable tool member is received within a labyrinth arrangement of grooves formed on an adjacent surface of another tool member. By providing several longitudinally-spaced branch portions in such J-slot systems, a variety of distinct operating positions are obtained by shifting one tool member longitudinally in relation to another tool member either with or without an accompanying rotative movement.

Although such J-slot systems are widely used, they nevertheless still have certain disadvantages. For example, it is difficult to devise compatible J-slot arrangements for each of several tools in a common string that will enable one tool in the string to be moved into some of its operative positions without simultaneously shifting at least one of the other tools into an unwanted position. This problem becomes even more complicated when it is realized that it is sometimes desired to move two tools in conjunction with one another at one point in a given sequence of operations; but, at other points in the same sequence, it may be preferred that only one of these tools move without a corresponding movement of the other tools. Moreover, since each of these tools have at least one telescoped joint, provisions must usually be made to releasably secure the telescoping members of one tool while the telescoping members in one or more tools in the common string are being repositioned.

Accordingly, it is an object of the present invention to provide new and improved well tools having a plurality of valve means and motion-responsive positioning means which permit these valve means to be selectively operated with only a minimum of different manipulations and require a minimum number of telescoping members in the tool string. This and other objects of the present invention are attained by providing a tool having inner and outer tubular members that are telescoped together and adapted for relative rotation as well as longitudinal movement between spaced positions. First valve means for controlling fluid communication between the interior and exterior of the tool are cooperatively arranged with first positioning means for selective operation by movement of the telescoped members. One or more valve means and their respective motion-responsive positioning means are also provided to selectively control communication between the interior portions of the telescoped members independently of the operation of the first valve means.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIGURE 1 shows a typical string of well tools in a well bore including a tool employing the principles of the present invention;

FIGURES 2A–2D are successive elevational views, partially in cross-section, of a preferred embodiment of a well tool arranged in accordance with the present invention;

FIGURES 3, 4, 5, 6 and 13 are cross-sectional views taken along the lines **3—3**, **4—4**, **5—5**, **6—6** and **13—13**, respectively, in FIGURES 2A and 2B;

FIGURE 7 is a developed view of the groove system for the well tool shown in FIGURES 2A–2D; and

FIGURES 8A–8B through 12A–12B are somewhat schematic views of the well tool shown in FIGURES 2A–2D and depict its successive operating positions.

Turning now to FIGURE 1, a number of full-bore well tools **10–13** are shown tandemly connected to one another and dependently coupled from the lower end of a string of pipe, such as a tubing string **14**, suspended in a cased well bore **15**. At the lower end of these tools, a conventional full-bore packer **13** is arranged for selectively packing-off the well casing **16**. A typical hydraulic holddown **12** is coupled to the mandrel **17** of the packer **13** and arranged to engage the casing **16** to secure the mandrel against upward movement whenever the packer is set and fluid pressure within the tubing string **14** exceeds the hydrostatic pressure of the well-control fluids in the well annulus. A typical bypass valve **11**, coupled by a tubing sub **18** above the holddown **12**, is suitably arranged to open and facilitate shifting of the tools **10–13** within the fluid-filled well bore **15** by diverting a substantial portion of the fluids through the central bore of the retracted packer **13**.

Connected at the upper end of the string of tools **11–13** is a tool **10** incorporating the principles of the present invention. Although the tools **11–13** may be those shown on page 3057 of the 1960–61 "Composite Catalog of Field Equipment and Services," it will be understood, of course, that other tools of this type may be used in conjunction with the tool **10** of the present invention. Moreover, the tools **11–13** may be replaced by a single packer (not shown) having a so-called "integral bypass" and may even include means for maintaining the packing element thereon set even when the pressure therebelow exceeds the hydrostatic pressure of the well control fluids above the packer.

Turning now to FIGURES 2A–2D, successive elevational views, with each being partially in cross-section, are shown of the tool **10**. It will be recognized, of course, that for ease of manufacture and assembly of tools of this nature, they are customarily made of a number of interconnected tubular sections. However, to facilitate the following description, various portions of the new and improved tool **10** have been shown as integral members rather than of such interconnected sections. The tool **10** includes a tubular member or mandrel **19** telescopically disposed within a tubular housing **20** and arranged for selective rotation as well as longitudinal movement therein between an extended position as shown in FIGURES 2A–2D, one or more selected intermediate positions, and a fully-telescoped position, all of which are subsequently described in more detail with reference to FIGURES 8A–8B through 12A–12B. An internally threaded connection **21** (FIGURE 2A) on the upper end of the mandrel **19** is appropriately arranged for coupling the mandrel to the tubing string **14** (FIGURE 1), with the central bore **22** (FIGURES 2A–2D) of the mandrel having substantially the same internal diameter as that of the tubing string. Similarly, threads **23** (FIGURE 2D) on the lower end of the housing **20** are arranged for coupling the tool **10** to other well tools therebelow such as, for example, the bypass valve **11** shown in FIGURE 1.

In general, the tool **10** of the present invention includes first, second and third valve means **24**, **25** and **26** (FIGURES 2A, 2C and 2D) that are selectively opened and closed either by shifting the mandrel **19** between different longitudinal positions in relation to the housing **20** or else by rotating the mandrel relative to the housing. Selectively-operable positioning means, such as shown at **27**, **28** and **29** (FIGURES 2A and 2B), are employed for controlling the tool **10**. Clutch means **30** and **31** are also provided to permit selective application of torque from the mandrel **19** through the housing **20** to the other tools **11–13** when the mandrel is in certain longitudinal positions. Biasing means **32** (FIGURE 2C) are preferably provided to maintain a downward force on the housing **20** to assist in keeping the packer **13** seated while the mandrel **19** is being moved as well as to apply an upward force on the mandrel to keep the clutch means **31** engaged whenever the mandrel is in its uppermost extended position with respect to the housing. Movement-retarding means **33** (FIGURE 2C) are also preferably provided to retard downward travel of the mandrel **19** with respect to the housing **20**.

As seen in FIGURE 2A, the valve means **24** are in the uppermost portion of the tool **10**. The valve means **24** and the associated positioning means **27** are cooperatively arranged to provide fluid communication between the internal mandrel bore **22** and the exterior of the tool **10** whenever the mandrel **19** is in a certain longitudinal position and is manipulated in a predetermined manner. Thus, as will subsequently be explained in greater detail, unless these movements are performed, the positioning means **27** will be effective to maintain the valve means **24** closed and block this fluid communication.

To accomplish this, the valve means **24** include co-engageable means such as a sleeve **34** that is slidably disposed in an enlarged annular clearance space **35** within the housing **20** and fluidly sealed to the mandrel **19** by sealing members **36** and **37** spatially mounted around the mandrel above and below one or more lateral ports **38** formed therein. One or more lateral ports **39** are also arranged in the upper portion of the sleeve **34** to be in communication with the mandrel ports **38** whenever the positioning means **27** function to shift the sleeve downwardly in relation to the mandrel **19** so as to bring the sleeve ports below the upper sealing member **36** on the mandrel. As will subsequently become more apparent, however, the positioning means **27** are arranged to normally secure the valve sleeve **34** in its elevated position illustrated in FIGURE 2A to block fluid communication between the mandrel ports **38** and one or more lateral ports **40** formed in the housing **20**.

The positioning means **27** are comprised of a sleeve member **41** that is slidably disposed in the annular housing space **35** above the valve sleeve **34** and preferably coupled thereto for longitudinal movement by means, such as a swivel connection **42**, allowing relative rotation between the two sleeves. Thus, by employing the swivel connection **42**, the positioning sleeve **41** is free to rotate in relation to the valve sleeve **34** and the valve sleeve can be co-rotatively secured to the mandrel **19** by means, such as a key or spline **43** slidably disposed in a longitudinal groove **44** in the mandrel. In this manner, the ports **38** and **39** will always be in registration with one another whenever the valve sleeve **34** is shifted downwardly by the positioning sleeve **41** to bring the sleeve ports below the sealing member **36**. Moreover, since the valve sleeve **34** will not have to be rotated in relation to the sealing members **36** and **37**, a more effective seal will be realized. The sleeves **34** and **41** could, of course, be integral for purposes of the present invention.

To selectively control longitudinal shifting of the sleeves **34** and **41** in relation to the mandrel **19**, the positioning sleeve is releasably coupled to the mandrel by means such as a radially-expansible segmented split-nut **45** that is maintained in threaded engagement with upwardly-directed external mandrel threads **46** by a circumferential spring and co-rotatively secured within an in-

wardly directed recess **47** in the positioning sleeve by a complementary longitudinal spline-and-groove arrangement **48**. For convenience, it is preferred that the mandrel threads **46** be so-called "left-hand" threads. A compression spring **49** is disposed in the annular space **35** between a downwardly-facing housing shoulder **50** and the upper end of the positioning sleeve **41** to maintain a downwardly-acting force thereon. The positioning means **27** further include selectively-releasable means for co-rotatively securing the positioning sleeve **41** to the housing **20** such as an outwardly-biased key **51** on the sleeve that is slidably fitted in a complementary longitudinal groove **52** in the interior wall of the housing so long as the positioning sleeve and the mandrel **19** are in their respective positions shown in FIGURE 2A. The significance of this selectively-releasable key **51** will subsequently become apparent.

Accordingly, it will be appreciated that so long as the tool **10** is in its initial operating position as depicted in FIGURES 2A–2D, the threaded co-engagement of the split-nut **45** and the mandrel threads **46** will prevent the spring **49** from shifting the valve sleeve **34** downwardly in relation to the mandrel **19**. This will, of course, block fluid communication through the mandrel ports **38** without restricting movement of the mandrel **19** in relation to the housing **20**. It will be realized, therefore, that the mandrel ports **38** cannot be uncovered until the split-nut **45** is disengaged from the mandrel threads **46** so that the spring **49** can urge the positioning sleeve **41** downwardly and shift the valve sleeve **34** downwardly to bring the sleeve ports **39** into registration with the mandrel ports when the valve sleeve has reached this lower position. The purpose for moving the valve sleeve **34** to this lower position will be subsequently explained in relation to FIGURES 8A–8B through 12A–12B.

For reasons that will also become more apparent, means are provided to selectively regulate the position of the valve sleeve **34** in various operating positions of the tool **10** once the valve sleeve is released. For the present, however, it is necessary only to point out that to selectively regulate the operating positions of the valve sleeve **34**, the positioning means **27** further include an annular abutment sleeve **53** that is preferably made separate from the valve sleeve and slidably disposed in the housing clearance space **35** below the valve sleeve. To selectively latch the abutment sleeve **53** to the mandrel **19** and housing **20**, one or more balls **54** are respectively loosely disposed in complementary lateral apertures **55** circumferentially spaced around the abutment sleeve. That portion of the mandrel **19** extending between the lower sealing member **37** and an upwardly-facing mandrel shoulder **56** therebelow is divided into an upper portion **57** of a relatively-reduced outer diameter and a lower portion **58** of a relatively-enlarged outer diameter. Similarly, the adjacent portion of the housing **20** is arranged to provide at the lower end of the annular clearance space **35** an upper portion **59** of a relatively-enlarged internal diameter and a lower portion **60** of a relatively-reduced internal diameter. It will be appreciated, therefore, that the junction of the reduced and enlarged-diameter mandrel portions **57** and **58** defines an upwardly-directed mandrel shoulder **61**. Similarly, the junction of the enlarged and reduced housing portions **59** and **60** defines an upwardly-directed housing shoulder **62**.

So long as the tool **10** is in the position depicted in FIGURES 2A–2D, the abutment sleeve **53** will be resting on top of the mandrel shoulder **56** and the latching balls **54** will be urged outwardly of the abutment sleeve by the enlarged-diameter mandrel portion **58** into the space defined by the enlarged-diameter housing portion **59**. The lower end of the valve sleeve **34** will be some distance above the upper end of the abutment sleeve **53** so that the abutment sleeve is at this time in an ineffective position. The significant function of this abutment sleeve **53** will, however, become apparent as the operation of the tool **10** is subsequently explained.

Turning now to FIGURE 2B, the clutch means **30** are arranged to co-rotatively secure the mandrel **19** to the housing **20** only when the mandrel is in its lowermost or fully-telescoped position while the clutch means **31** co-operate to co-rotatively secure these members when the mandrel is in its uppermost position in relation to the housing. In all other longitudinal positions, the mandrel **19** is free to rotate in a clockwise direction relative to the housing **20**.

To accomplish this, the upper clutch means **30** include an annular member **63** that is co-rotatively secured by means, such as a key **64**, to the mandrel **19** below the mandrel shoulder **56** and has a plurality of depending lugs **65** thereon adapted for reception in a corresponding number of upwardly-facing longitudinal slots **66** in an inwardly-projecting housing shoulder **67** whenever the mandrel is in its lowermost position. The lower clutch means **31** include an annular member **68** slidably mounted below the shoulder **67** in the housing **20** and co-rotatively secured thereto by external longitudinal grooves **69** thereon adapted to receive complementary inwardly-projecting housing splines **70** (FIGURE 4). Inwardly-projecting stop pins **71** on the housing **20** are appropriately arranged to halt the downward travel of the annular member **68**. External longitudinal splines **72** (FIGURE 2B) on the mandrel **19** are adapted for reception in complementary longitudinal spline grooves **73** (FIGURE 4) in the internal wall of the annular member **68**.

A spring **74** is arranged between the housing shoulder **67** and the upper end of the annular member **68** to normally urge the annular member downwardly against the stops **71** but permit it to retrogress should the mandrel splines **72** not be in registry with their complementary grooves **73** as the mandrel **19** is being moved upwardly. Thus, even though the mandrel splines **72** may not initially be in alignment with the spline grooves **73**, a slight rotation of the mandrel **19** in either direction will quickly bring the splines into orientation with their grooves and the spring **74** will then urge the annular clutch member **68** downwardly over the splines as the mandrel moves further upwardly.

Accordingly, it will be appreciated that so long as the mandrel **19** is in its extended position (as seen in FIGURES 2A–2D) with respect to the housing **20**, the mandrel is co-rotatively secured thereto by the lower clutch means **31**. Downward movement of the mandrel **19** with respect to the housing **20** will, however, shift the mandrel splines **72** out of the spline grooves **73** and allow the mandrel to be rotated relative to the housing until the mandrel reaches its fully-telescoped or lowermost position. Once it is moved to this lowermost position and the lugs **65** enter the slots **66**, the mandrel **19** will again be co-rotatively secured to the housing **20** by the upper clutch means **30**.

The intermediate positioning means **28** of the tool **10** are comprised of a sleeve member **75** that, as seen in FIGURE 2B, is rotatively mounted inside of the housing **20** and has an inwardly-projecting guide pin **76** which has its distal end disposed in a circuitous system of grooves **77** formed on the exterior of the mandrel **19**. To secure the sleeve **75** against shifting longitudinally relative to the housing **20**, the sleeve is confined between the opposed shoulders of a circumferential recess **78** formed around the interior housing wall. Wear rings **79** and **80** are placed between the upper and lower ends of the sleeve **75** and the opposed housing shoulders to facilitate the rotation of the sleeve with respect to the housing.

It will be appreciated, therefore, that since the guide pin **76** remains in the groove system **77**, the mandrel **19** can be moved longitudinally in relation to the housing **20** only so far as is permitted by the particular arrangement of the groove system. As best seen in the developed view in FIGURE 7, the groove system **77** includes an irregu-

larly shaped but generally transverse lower groove **81** joined at its opposite ends by upwardly directed, parallel, longitudinal grooves **82** and **83**, with the upper end of the groove **82** being connected to the groove **83** by a converging inclined groove **84** and an enlarged portion **85**. A longitudinal groove **86** is aligned with the groove **83** and continues further upwardly from the junction of the enlarged portion **85** and the grooves **82** and **83**. Thus, it will be appreciated that the maximum longitudinal distance which the mandrel **19** can be moved in relation to the housing **20** is represented by the longitudinal spacing between the uppermost end of the longitudinal groove **86** and the lowermost ends of two short parallel longitudinal grooves **87** and **88** extending downwardly from the lower transverse groove **81**. An intermediate position of the mandrel **19** with respect to the housing **20** is also provided by a centrally-located longitudinal groove **89** that extends upwardly a short distance from the middle of the lower transverse groove **81**. The significance of the depicted configuration of the groove system **77** will subsequently become more apparent.

The upper end of the sleeve **75** is inwardly enlarged as best seen in FIGURES 2B and 5 to provide an annular shoulder **90**. Circumferentially-spaced longitudinal slots **91** (FIGURE 5) around the inner portion of the shoulder **90** are arranged to pass outwardly directed lugs **92** (FIGURES 2B and 7) on the mandrel **19** whenever these lugs are aligned with the slots. Thus, by appropriately locating the guide pin **76** in relation to the shoulder slots **91** (all of which are on the sleeve **75**) on the one hand as well as arranging the circumferential spacing of the longitudinal grooves **82** and **83** in relation to the lugs **92** (all of which are on the mandrel **19**) on the other hand, whenever the guide pin is in either of the circumferentially spaced grooves **82** and **83**, the lugs **92** will be aligned with the slots **91** and, as the mandrel **19** is moved longitudinally in relation to the housing **20**, the lugs **92** will pass through the slots **91** in the shoulder **90**. The centrally located groove **89** is suitably arranged, however, so that when the guide pin **76** is in the position D (FIGURE 7), the lower surfaces of the lugs **92** will be abutted against those portions of the upper face of the shoulder **90** between the slots **91**. This will, of course, allow downward forces on the mandrel **19** to be transmitted through the lugs **92** and the sleeve **75** to the housing **20** without such forces having to be carried by the guide pin **76**. Thus, only when the guide pin **76** is in the above-described position D are the lugs **92** engaged on top of the sleeve **75** to transmit downward loads therethrough to the housing **20**. In all other positions of the mandrel **19**, the lugs **92** are either above or below the sleeve shoulder **90** or else (when the guide pin **76** is in either of the grooves **82** or **83**) the mandrel lugs are passing through the shoulder slots **91**.

Since the sleeve **75** cannot shift longitudinally relative to the housing **20**, the guide pin **76** will, of course, remain in the same transverse plane and the mandrel **19** and groove system **77** will be moved longitudinally in relation thereto. Thus, a straight longitudinal movement of the mandrel **19** will move the groove system **77** relative to the guide pin **76**. Any rotational movement of the mandrel **19** will be accommodated by the pin **76** and sleeve **75** rotating as required by the configuration of the slot system **77**. Thus, as the mandrel **19** is pushed straight downwardly from its position shown in FIGURE 2B, when the mandrel has moved sufficiently to bring the upper wall of the inclined groove **84** against the guide pin **76**, continued downward movement of the mandrel **19** will rotate the pin and sleeve **75** accordingly.

The lower positioning means **29** of the tool **10** are seen in FIGURE 2B below the positioning means **28** and are comprised of two inwardly biased, radially expansible, segmented split-nuts **93** and **94** placed at longitudinally spaced positions in the annular clearance space **95** between the mandrel **19** and housing **20**. As best seen in FIGURE 6, longitudinal external splines **96** on each of the segments of the nuts **93** and **94** are complementally interlocked in grooves **97** in the internal wall of the housing **20** to co-rotatively secure the split-nuts to the housing. As seen in FIGURE 2B, to limit the longitudinal travel of the lower split-nut **94**, inwardly-directed longitudinally-spaced housing shoulders **98** and **99** are provided above and below the nut. The longitudinal travel of the upper split-nut **93** is similarly limited by an annular spacer **100** that is removably placed between the upper end of the nut and an inwardly-directed housing shoulder **101** spaced above the nut.

Oppositely-directed buttress threads **102** and **103** are longitudinally spaced around the mandrel **19** and respectively arranged for selective engagement with complementary threads in the nuts **93** and **94** in certain longitudinal positions of the mandrel. The upper mandrel threads **102** are faced upwardly and are preferably so-called "left-hand" threads arranged to threadedly engage the downwardly-facing threads in the upper split-nut **93**. With this arrangement, downward longitudinal movement of the mandrel **19** will allow the upper mandrel threads **102** to be ratcheted freely into the upper split-nut **93** but prevent upward longitudinal movement of the mandrel until it is rotated in a clockwise or right-hand direction to unthread the upper mandrel threads from the upper split-nut. Similarly, the lower mandrel threads **103** are faced downwardly and are preferably so-called "right-hand" threads. To accommodate the lower mandrel threads **103**, the threads in the lower split-nut **94** are faced upwardly. Thus, release of the mandrel threads **103** from the lower split-nut **94** can be accomplished only by rotating the mandrel **19** in a clockwise direction to unthread these members. It will be appreciated, of course, that by facing the mandrel threads **103** and those in the lower split-nut **94** in opposite directions, upward movement of the mandrel **19** will cause the lower mandrel threads to freely ratchet through the lower split-nut.

For reasons that will subsequently become more apparent, the lower mandrel threads **103** are normally engaged with the lower split-nut **94** and the upper threads **102** are normally disengaged from the upper split-nut **93** and spaced a particular distance thereabove. Thus, with the lower mandrel threads **103** engaged with the lower split-nut **94** as shown in FIGURE 2B, the mandrel **19** is free to travel longitudinally with respect to the housing **20** only so far as is permitted by the spacing between the housing shoulders **98** and **99** respectively above and below the lower split-nut. Similarly, as will also subsequently become apparent, whenever the upper mandrel threads **102** are threadedly engaged with the upper split-nut **93**, the mandrel **19** will be secured in its lowermost telescoped position and cannot be returned to its intermediate or extended positions since the upper split-nut is immobilized by the spacer **100** and the co-engagement of the lugs **65** and slots **66** prevent rotation of the mandrel with respect to the upper split-nut and the housing **20**. In this case, it will be realized that the lugs **65** cannot be disengaged from the slots **66** until the tool **10** is returned to the surface and the housing **20** separated, as at a threaded joint **104** (FIGURE 2A) thereon, to permit movement of the clutch member **63**.

Turning now to FIGURE 2C, the next lower portion of the tool **10** is shown in which are located the pressure-biasing means **32** and the movement-retarding means **33**. The pressure-biasing means **32** are comprised of an enlarged-diameter shoulder **105** on the mandrel **19** that is fluidly sealed, as by O-rings **106**, within a reduced-diameter portion **107** of the housing **20** above an external housing port **108** and an annular slidable piston member **109** that is around the mandrel above its enlarged-diameter shoulder **105** and below another external housing port **110**. O-rings **111** and **112**, respectively, inside and outside of the slidable piston **109** fluidly seal the piston to the mandrel **19** and housing **20** so as to provide a

fluid-tight annular space **113** between the piston and the enlarged-diameter mandrel shoulder **105**, which space is normally at atmospheric pressure. A spring **114** between an inwardly-directed housing shoulder **115** and the upper end of the piston **109** normally urges the piston downwardly against a shoulder **116** defined by the upper end of the reduced-diameter housing portion **107**.

It will be recognized that well-control fluids will enter the ports **108** and **110** above the piston **109** and below the enlarged-diameter mandrel portion **105** as the tool **10** is being used. Inasmuch as the annular space **113** is normally at atmospheric pressure, the hydrostatic pressure of the well-control fluids will therefore tend to lift the mandrel **19** by a force equal to the difference between the hydrostatic and atmospheric pressures multiplied by the annular cross-sectional area of the enlarged-diameter mandrel shoulder **105** itself. The cross-sectional area of the mandrel **19** itself will, of course, be subjected to both upwardly and downwardly-acting pressure forces. Similarly, the piston **109** will be urged downwardly against the housing shoulder **116** by a force equal to the difference between the hydrostatic and atmospheric pressure multiplied by the annular cross-sectional area bounded by the O-rings **111** and **112**.

Thus, since the mandrel **19** is urged upwardly by this unbalanced pressure force, a force at least greater than this upwardly-directed pressure force must be applied to the mandrel in order to move it downwardly relative to the housing **20**. Similarly, it will be appreciated that the downwardly-acting pressure force on the piston **109** is effective through the housing shoulder **116** to impose a corresponding downwardly-directed force thereon which will be transmitted through the housing to the mandrel **17** of the packer **13** (FIGURE 1) to assist in keeping the packer seated.

Although the piston **109** could be made an integral portion of the housing **20**, it is preferred to make it a separate member as shown in FIGURE 2C and to provide a small lateral port **117** in the housing immediately above the normal position of the external O-ring **112**. In this manner, should well-control fluids leak into the enclosed annular space **113**, as the tool **10** is being removed from the well bore **15**, any excessive pressure in the enclosed space **113** will be vented through the port **117** whenever this trapped pressure is sufficient to lift the piston **109** against the restraint of the spring **114** a sufficient distance to move the O-ring **112** above the port **117**. This arrangement also insures that the mandrel **19** can be returned upwardly should fluids leak into the space **113** after the mandrel is lowered. Otherwise, the piston **109** could just as well be made an integral portion of the housing **20**.

The movement-retarding means **33** are comprised of a sleeve **118** loosely disposed between longitudinally-spaced enlarged-diameter portions **119** and **120** of the mandrel **19**, with only a limited annular clearance **121** being left between the mandrel and sleeve and a very minute annular clearance **122** being left between the sleeve and inner wall of the housing **20**. A compression spring **123** between the sleeve **118** and the lower enlarged-diameter mandrel portion **120** normally urges the sleeve upwardly against the upper enlarged-diameter mandrel portion **119**. An O-ring **124** around the internal wall of an inwardly-facing shoulder **125** in the housing **20** fluidly seals the mandrel **19** and housing relative to one another and defines a fluid-tight space **126** therebetween below the sleeve **118**. An annular piston **127** having internal and external O-rings **128** and **129** is provided just below the housing port **108** to fluidly seal the housing **20** relative to the mandrel **19** above the sleeve **118** and define a second fluid-tight space **130** therebetween in communication with the space **126** only by way of the annular clearance spaces **121** and **122** inside of and around the sleeve **118** respectively. A suitable hydraulic fluid, such as an oil or the like, fills the fluid-tight spaces **126** and **130**.

It will be appreciated that the hydrostatic pressure of the well-control fluids will be effective through the port **108** against the piston **127** to maintain the oil in the spaces **126** and **130** at the same pressure. Accordingly, the speed of longitudinal movement of the mandrel **19** with respect to the housing **20** will be governed by the rate at which the oil can be displaced from one or the other of the fluid-tight spaces **126** and **130**. Downward movement of the mandrel **19** with respect to the housing **20** will, of course, maintain the lower face **131** of the upper enlarged-diameter mandrel portion **119** tightly engaged against the adjacent upper face **132** of the sleeve **118**. By appropriately machining the abutting surfaces **131** and **132** of the shoulder **119** and sleeve **118**, a metal-to-metal seat is effected to close the internal annular space **121** and make the minute external annular clearance space **122** the only flow path by which oil can be transferred from the lower space **126** to the upper space **130** as the mandrel **19** is moved downwardly. In this manner, the time required to move the mandrel **19** downwardly with respect to the housing **20** will be directly related to the dimensions of the external annular clearance space **122** and the viscosity of the oil in the fluid-tight spaces **126** and **130**. If it is desired, the lower space **126** may be slightly enlarged, as at **133**, so that whenever the mandrel **19** has moved downwardly at this controlled rate a predetermined distance with respect to the housing **20**, it can continue moving further downwardly with added relative freedom.

To permit fairly rapid upward movement of the mandrel **19** with respect to the housing **20**, the internal clearance space **121** between the sleeve **118** and the mandrel is made somewhat larger than the external clearance space **122**. It will be understood, of course, that the spring **123** is not sufficiently strong to keep the sleeve end **132** abutted against its mating surface **131** on the shoulder **119** whenever the mandrel **19** is being moved upwardly. Thus, whenever the mandrel **19** is pulled upwardly with respect to the housing **20**, the sleeve **118** will shift slightly downwardly and move the seating surfaces **131** and **132** apart so as to allow oil from the upper space **130** to pass relatively free between these surfaces, through the larger annular clearance **121**, and on into the lower fluid-tight space **126**.

In FIGURES 2C and 2D, the lowermost portion of the tool **10** is shown in which are located the valve means **25** as well as the valve means **26**. The internal diameter of this portion of the housing **20** is preferably increased to provide an enlarged bore, as at **134**, below the enclosed space **126** and above an upwardly-directed housing shoulder **135** (FIGURE 2D) near the lower end of the housing.

The valve means **25** (FIGURE 2C) are preferably arranged as a co-engaged telescoping sleeve valve adapted to control fluid communication between the enlarged housing bore **134** and the internal bore **22** of the mandrel **19** so long as the valve means **26** therebelow are closed. The valve means **25** include a coaxially-arranged tubular member **136** that is dependently secured from the housing **20** and extended downwardly into the enlarged housing bore **134**. Lateral ports **137** in the mandrel **19** are adapted to be moved into registry with corresponding lateral ports **138** in the coaxially-arranged tubular member **136** whenever the mandrel is moved into one of its intermediate longitudinal positions with respect to the housing **20**. O-rings **139** and **140** respectively above and below the mandrel ports fluidly seal the mandrel **19** relative to the depending tubular member **136** to block flow through the ports **137** and **138** whenever they are not in registration in the other positions of the mandrel. If desired, the sleeve **136** may be rotatably mounted in relation to the housing **20**, as by a retainer ring **141** mounted in opposed complementary circumferential grooves in the sleeve and housing. To insure that the ports **137** and **138** are angularly oriented, a suitable longitudinal spline and groove (not shown) are provided in the sleeve **136** and mandrel **19** to co-rotatively secure the two members to one another.

As seen in FIGURE 2D, the valve means **26** include a cylindrical or a spherical valve member **142** having an axial passageway **143** therethrough along one of its central axes that is sized to correspond at least approximately to the internal mandrel bore **22**. The ball member **142** is operatively co-engaged between a pair of opposed, longitudinally-spaced, annular seats **144** and **145** having complementary spherical seating surfaces. The mandrel valve seat **144** is coaxially mounted with biasing means **146** in a complementary counterbore **147** in the lowermost end of the mandrel **19**. A pair of depending longitudinal lugs **148** (only one seen) extends downwardly from the mandrel **19** on opposite sides of the seat **144**. The ball member **142** is pivotally supported between the free ends of these depending mandrel lugs **148** about another of its central axes by appropriately-located transverse pivots **149** (only one seen) that are so positioned that (with the aid of the biasing means **146**) the seat **144** will remain engaged with the ball as the ball moves between its open and closed positions. The axis of these pivots **149** is, of course, perpendicular to the central axis of the passageway **143** so that as the ball member **142** is pivoted, the passageway will move into and out of registration with the valve seats **144** and **145**.

The other valve seat **145** is an upwardly-facing, spherical seat complementally formed on the upper end of a short sleeve member **150** that is telescopically disposed in the upper end of an elongated tubular member **151** and supported by a relatively-weak spring **152**. An O-ring **153** around the sleeve **150** and below one or more lateral ports **154** therein fluidly seals the sleeve in relation to the tubular member **151**. The spring **152** urges the lower seat **145** against the lower surface of the ball member **142** and normally maintains the ports **154** in position to allow fluid communication therethrough. This tubular member **151** is dependently supported by a pair of lugs **155** and **156** (only one of each pair seen) projecting upwardly from opposite sides of the tubular member and arranged to straddle the ball member **142**, with each of these lugs being extended upwardly alongside the opposite sides of the depending mandrel lugs **148** with their respective longitudinal edges in juxtaposition with one another. Inwardly-projecting transverse pins **157** (only one seen) on the free end of the lower lugs **156** are disposed parallel to the axis of the pivots **149** but longitudinally spaced therebelow and slightly offset to one side. The free ends of these coupling pins **157** are each confined within fairly short, inclined grooves **158** (only one seen) formed in the adjacent external surfaces of the ball member **142**.

A second sleeve **159** is telescopically disposed around the upper portion of the tubular member **151** and has a pair of upright lugs **160** (only one seen) on its upper end that are respectively extended upwardly between the lugs **155** and **156** and terminated immediately below the lower ends of the mandrel lugs **148**. A fairly strong compression spring **161** is disposed around the intermediate portion of the tubular member **151** and maintained in compression between the lower end of the short sleeve **159** and a shoulder **162** on the tubular member. For reasons that will subsequently become apparent, a stout compression spring **163** is disposed around the lower end of the tubular member **151** with its upper end well below the shoulder **162** and its lower end resting on the shoulder **135** near the lower end of the enlarged housing bore **134**.

With the tool **10** in the position shown in FIGURES 2A–2D, the spring **161** will, of course, impose a downwardly directed force through the shoulder **162** on the tubular member **151** and an upwardly directed force on the sleeve **159**. The upwardly-acting force will, of course, be transmitted through the opposed ends of the lugs **160** to the mandrel **19** by the lugs **148** so that no force is applied to the ball member **142** itself. The downwardly-acting force on the member **151** will, on the other hand, be effective through the lugs **156** to urge the coupling pins **157** downwardly against the lower end surfaces of the ball grooves **158** to impose a counterclockwise turning moment on the ball member **142** for maintaining the ball in its closed position. The coaction of the adjacent edges of the pins **157** and grooves **158** will, of course, insure that the ball member **142** will not be pulled further downwardly than its illustrated position. Thus, so long as the spring **161** is acting in this manner, the ball member **142** will be positively retained in its closed position and all fluid communication through the tool **10** must pass through the ports **154** and the valve means **25**.

The ball valve member **142** cannot, therefore, be rotated into its open position until the counterclockwise turning moment acting thereon is overcome and a clockwise turning moment is imposed on the ball member. Such action cannot occur, however, until the mandrel **19** is moved downwardly in relation to the housing **20** a distance sufficient to bring the shoulder **162** into engagement with the upper end of the spring **163** and halt the tubular member **151** and the transverse pins **157** carried thereby. Then, once the shoulder **162** engages the spring **163**, the mandrel **19** must be moved still further downwardly to move the pivot pins **149** below the transverse pins **157** and rotate the ball member **142** to its open position.

Once the downward motion of the tubular member **151** is arrested by engagement of the shoulder **162** with the spring **163**, it will be appreciated that continued downward movement of the mandrel **19** will further compress the spring **161**. It will also be recognized that once the shoulder **162** on the tubular member **151** engages the spring **163**, further compression of the spring **161** will begin reducing the counterclockwise turning moment serving to hold the ball **142** closed. Thus, the downward force applied through the opposed lugs **148** and **160** by the mandrel **19** will be effective to overcome the counterclockwise turning moment and begin developing a clockwise turning moment for rotating the ball member **142** to its open position as the load on the mandrel is increased. It will be appreciated, of course, that once the shoulder **162** engages the spring **163**, the relatively-weak spring **152** will be compressed which results in the ports **154** being moved below the upper end of the tubular member **151**. The inclined grooves **158** must, of course, be of sufficient length to accommodate the transverse pins **157** whenever the ball member **142** has rotated midway between its fully-closed and its fully-open positions.

It will be appreciated that to accomplish the above-described opening of the ball valve member **142**, the tubular member **151** must be either halted entirely or at least retarded sufficiently to enable the ball member to be moved downwardly in relation to the connecting pins **157** to impart a clockwise turning force on the ball member. The tubular member **151** could, of course, be completely arrested by allowing the shoulder **162** to come into engagement with a housing shoulder rather than the spring **163**. This is not desirable, however, since slight variations in manufacturing tolerances, for example, could cause such shoulders to come into engagement prematurely and result in unduly high loads being imposed on the pins **157**.

Accordingly, the spring **163** and the shoulder **162** are appropriately arranged to allow the tubular member **151** to move further downwardly by allowing the spring **163** to be at least slightly compressed. Should, however, a greater downward force be applied on the mandrel **19** to open the ball member **142**, the spring **163** will be further compressed to allow the tubular member **151** to move further downwardly. It will be appreciated, however, that in this event the spring **161** is still rendered ineffective and that the selective action provided by the development of additional spring force by such further

compression of the spring **163** will be fully effective to apply a greater upwardly-directed rotational force on the ball member **142** by way of the tubular member **151** and its pins **157** so that the ball must ultimately rotate to its open position without risking damage to the tool **10**. Moreover, in any event, no upward force will be applied against the underside of the ball member **142** as the clockwise rotational force is being developed. Instead, all upward reaction forces will be transmitted through the opposed lugs **148** and **160** and the ball member **142** will be free to rotate with little frictional force being applied thereto by its seats **144** and **145**.

Accordingly, it will be appreciated that when the mandrel **19** is fully extended with respect to the housing **20** (as shown in FIGURES 2A–2D), all of the valve means **24–26** will be closed. However, by moving the mandrel **19** downwardly with respect to the housing **20** (thereby shifting the guide pin **76** from its position at A to the position at B as shown in FIGURE 7), the second valve means **25** will be opened to provide fluid communication from the enlarged housing bore **134**, through the ports **154** below the ball **142** and the valve seat **145**, and the ports **137** and **138**, and on into the central bore **22** of the mandrel **19**. Return of the mandrel **19** upwardly (thereby shifting the guide pin **76** to the position at C in FIGURE 7) recloses the valve means **25**. The first and third valve means **24** and **26** will, however, remain closed in all of these positions of the mandrel **19**.

It will be recognized, therefore, that so long as the lower split-nut **94** is engaged with the mandrel threads **103**, the engagement of the split-nut with the housing shoulder **99** will prevent further downward travel of the mandrel **19** and thereby determine the position B of the guide pin **76**.

It will be appreciated, therefore, that so long as the lower split-nut **94** remains engaged with the mandrel threads **103**, the mandrel **19** can be moved longitudinally only a distance equal to the spacing between the lower split-nut and the housing shoulder **99**. This distance is also equal to the longitudinal spacing between the two positions of the guide pin **76** represented at A and B in FIGURE 7.

As will be subsequently described with greater detail, however, once the lower split-nut **94** is released from the threads **103**, the mandrel **19** can be moved further downwardly (to bring the guide pin to E in FIGURE 7) which will also close the second valve means **25** but now open the third valve means **26** as the mandrel reaches its lowermost, telescoped position. In this latter position, a full-opening passage is provided through the tool **10** since the passageway **143** in the ball member **142** will have been rotated into alignment with the central mandrel bore **22**. The first valve means **24** will still remain closed with the mandrel **19** in its lowermost position.

The operation of the valve means **24** is, therefore, wholly independent of the operation of the other valve means **25** and **26**. As will subsequently be described in greater detail, the valve sleeve **34** blocks communication through the mandrel ports **38** so long as the split-nut **45** is engaged with the mandrel threads **46** irrespective of the movements of the mandrel **19** in selectively opening and closing the valve means **25** and **26**. Thus, the valve means **24** are opened only when the positioning sleeve **41** is co-rotatively secured to the housing **20** so that rotation of the mandrel **19** will disengage the split-nut **45** from the mandrel threads **46**. Once the split-nut **45** is released, the spring **49** will, of course, shift the valve sleeve **34** to align the ports **38–40**.

The abutment sleeve **53** serves to stop downward travel of the release valve sleeve **34** as well as to halt the sleeve upon subsequent downward travel of the mandrel **19** to allow the mandrel threads **46** to re-engage the split-nut **45** and reclose the mandrel ports **38**. Although the abutment sleeve **53** could just as well be a depending integral extension of the valve sleeve **34**, for ease of manufacture and assembly it is preferred to make the two sleeves as separate members. In any event, the relative proportions of the various elements comprising the valve means **24** and positioning means **27** are suitably arranged that the key **51** is operatively coupled to the housing **20** by way of the groove **52** when the mandrel **19** is in one of its intermediate positions and the valve means **25** and **26** are closed. Then, upon rotation of the mandrel **19**, the split-nut **45** is released from the mandrel threads **46** and the spring **49** will move the sleeves **34** and **41** downwardly into abutment with the sleeve **53**. To reclose the valve means **24**, the mandrel **19** is simply lowered. As the mandrel **19** moves downwardly, the latching balls **54** are abutted with the housing shoulder **62** to hold the sleeves **34, 41** and **51** stationary and allow the mandrel threads **46** to ratchet back into the split-nut **45**. Once the split-nut **45** is re-engaged, the valve means **24** are reclosed. Thus, the operation of each of the valve means **24–26** is wholly independent of the operation of the others.

Turning now to FIGURES 8A–8B through 12A–12B, the tool **10** is schematically represented to illustrate its various positions during the course of a typical operating sequence. To facilitate the explanation of the positioning means **27–29** and their cooperative relation with the valve means **24–26**, the biasing means **32** and movement-retarding means **33** have not been shown in FIGURES 8A–8B through 12A–12B. It will be understood, however, that downward travel of the mandrel **19** will be regulated by the movement-retarding means **33** until the top of the sleeve **118** has entered the enlarged space **133** (FIGURE 2C). Similarly, it should be kept in mind that the biasing means **32** will continuously provide an upwardly directed force on the mandrel **19** and an equal, but downwardly directed, force on the housing **20** during the entire operation of the tool **10**.

In FIGURES 8A–8B, the tool **10** is shown with the mandrel **19** in its uppermost extended position with respect to the housing **20** as already described with reference to FIGURES 2A–2D. The first, second and third valve means **24, 25** and **26** are closed to block fluid communication into the mandrel bore **22** as the tools **10–13** are being moved into position in the cased well bore **15** (FIGURE 1). It will also be noted from FIGURE 8A that although the upper clutch member **63** is disengaged, the lower clutch member **68** is engaged to permit rotation to be applied from the tubing string **14**, through the tool **10**, and onto the other tools **11–13** therebelow. Accordingly, with the tool **10** secured in the position depicted in FIGURES 8A–8B, the tools **10–13** can be brought into position at any desired depth in the cased well bore **15**.

Once the tools **10–13** have reached a desired position in the well bore **15**, they are momentarily halted and the tubing string **14** is manipulated as required to set the packer **13** and close the bypass valve **11**. Although other tools may utilize different movements for their operation, it is preferred to arrange the bypass valve **11** and packer **13** so that the position-establishing means, such as J-slot systems (not shown), in each tool will work in cooperation to close the bypass valve as the packer is being set. Accordingly, with the tools **11** and **13** having cooperative J-slot systems arranged in this manner, the tubing string **14** is picked up slightly and torqued in a clockwise direction to "unjay" the bypass valve and packer. Then, by slacking-off at least part of the weight of the tubing string **14**, the packer **13** will be set and the bypass valve **11** closed. It will be recalled that the mandrel **19** cannot move downwardly relative to the housing **20** until the upward force provided on the mandrel by the biasing means **32** is overcome.

Once the packer **13** is set, it will be appreciated that it is capable of supporting the full weight of the tools **10–12** and the tubing string **14** thereabove. The housing **20** of the tool **10** will, of course, now be fixed relative to the

casing **16** until the packer **13** is unseated. It will be recalled, moreover, that the biasing means **32** will also be effective to maintain a substantial downward force through the housing **20** to aid in holding the packer **13** seated. Thus, the mandrel **19** of the tool **10** is now capable of being moved relative to the now-stationary housing **20** by corresponding motions of the tubing string **14** to bring the tool into its various operating positions.

Accordingly, as shown in FIGURES 9A–9B, application of sufficient weight to the mandrel **19** for setting the packer **13** will carry the mandrel a short distance downwardly (as shown by arrow **164**) until the lower split-nut **94** engages the upwardly-facing housing shoulder **99**. This downward movement will, however, be retarded by the motion-retarding means **33** and furthermore will require sufficient weight on the mandrel **19** to at least overcome the upwardly directed force on the mandrel provided by the biasing means **32**. It will be noted from FIGURES 9A–9B, however, that this initial downward travel of the mandrel **19** will open only the valve means **25** and disengage the lower clutch member **68**. Thus, by virtue of the position of the lower split-nut **94**, downward motion and rotation of the tubing string **14** in these first two operating positions of the tool **10** will be effective only to set the packer **13**, close the bypass valve **11**, and open the valve means **25** without introducing any risk whatsoever that either of the valve means **24** or **26** might be opened prematurely by over-movement of the mandrel **19**.

It will also be appreciated from FIGURES 9A–9B that further downward travel of the mandrel **19** relative to the housing **20** is not possible so long as the lower nut **94** is abutted on the housing shoulder **99**. On the other hand, upward travel of the mandrel **19** is unimpeded should, for example, it be necessary to re-engage the lower clutch member **68** to apply rotation from the tubing string **14** through the housing **20** to the tools **11–13**.

Once the valve means **25** are open, the guide pin **76** will be at its position B as shown in FIGURE 7. The mandrel **19** cannot, however, be moved further downwardly so as to bring the guide pin **76** to its position at E since the lower face of the lower split-nut **94** will be abutted against the housing shoulder **99**.

A typical testing operation usually includes one or more measurements of the so-called "shut-in" pressure of the formation interval being tested. To measure this and other pressures, one or more pressure recorders **165** are provided below the valve means **26**. If desired, these pressure recorders **165** may be arranged as shown in a copending application Ser. No. 620,943, now Patent No. 3,414,059 filed by the applicant on Mar. 6, 1967, for selective release from the tool **10** by opening the valve means **26**. In any event, to obtain a shut-in pressure, the mandrel **19** is pulled upwardly to reclose the valve means **25**. Once the guide pin **76** is in its position at B in the groove system **77** (FIGURE 7), upward movement of the mandrel **19** will bring the guide pin into the upper end of the longitudinal groove **83**. By extending the lower wall **166** of the enlarged groove portion **85** to a termination, as at **167**, beyond the lower end of the groove **86**, a straight upward pull on the mandrel **19** will be certain to carry the guide pin **76** into the groove **83** rather than back into the groove **84**.

The mandrel **19**, is therefore, picked-up until the guide pin reaches its position at C in the short groove **87**. This will, of course, also return the upper face of the split-nut **94** back into engagement with the housing shoulder **98** and reclose the ports **137** and **138**. It will also be recalled that once the guide pin **76** is in the groove **83**, the sleeve **75** will be appropriately positioned to align the mandrel lugs **92** with their respective shoulder slots **91** and allow the lugs to pass therethrough and move above the shoulder **90**.

Although the valve means **25** are closed by the time the guide pin **76** reaches its position at C and the initial shut-in pressure measurement is started, it is desirable to maintain a downward force on the packer **13** while the measurement is being taken. Thus, as already discussed, the sleeve shoulder **90** is appropriately located in relation to the lower surface of the mandrel lugs **92** so that a slight downward movement of the mandrel **19** will bring the lugs **92** into engagement with the shoulder **90**. Thus, as seen in FIGURES 10A–10B, once the mandrel lugs **92** are engaged on the shoulder **90**, a downward force on the tubing string **14** will be transmitted through the sleeve **75** to the housing **20** and on downwardly to the tools **11–13** therebelow.

Accordingly, by alternately lowering and raising the mandrel **19** as shown in FIGURES 8A–8B through 10A–10B, any number of flowing and shut-in tests can be made by repetitively opening and closing the second valve means **25** while the first and third valve means **24** and **26** remain securely closed. Moreover, each longitudinal movement of the mandrel **19** will provide a pronounced and easily detected indication at the surface when the mandrel reaches one extreme or another.

It will be realized, therefore, from FIGURES 8A–8B, 9A–9B and 10A–10B that the first and third valve means **24** and **26** have remained closed through all of the various operations described so far. This is, of course, necessary since so long as such shut-in and flowing tests are being made, it is essential that the packer **13** isolate that portion of the well bore **15** below the packer from the well-control fluids thereabove. Thus, the function of the second valve means **25** is to provide selective communication between the lower portion of the well bore **15** and the interior of the tubing string **14**.

Once these shut-in and flowing tests have been completed, however, one of four things will be done depending upon observations made at the surface during these tests. First of all, if these observations indicate that no oil and/or gas has been produced from one or more of the earth formations being tested, the usual procedure is to retrieve the tools **10–13** without further ado. On the other hand, should these tests indicate that connate fluids have been produced, it is best to "reverse out" the fluids that have entered the tubing string **13** during the testing operation. Such "reverse circulation" is necessary since, for example, should the tubing string **13** be later removed from the well bore **15** with formation fluids still in it, a potential fire hazard will be created should these fluids be inflammable. Moreover, the drilling crew would in any event be hampered by spillage of these formation fluids over the derrick floor and equipment as the stands of tubing are progressively disconnected and stacked.

Accordingly, when it is desired to reverse fluids from the tubing string **14**, it will be appreciated that the tool **10** will be in the "shut-in" position as seen in FIGURES 10A–10B. At this point, all three valve means **24**, **25** and **26** are closed and the clutch members **63** and **68** are disengaged. Thus, the mandrel **19** is free to rotate in relation to the housing **20** and the mandrel lugs **92** are abutted on the shoulder **90** on top of the sleeve **75** so that a downward force can be applied through the tool **10** to maintain the packer **13** seated. The engagement of the mandrel lugs **92** with the sleeve shoulder **90** will, of course, prevent the mandrel **19** from moving downwardly in relation to the housing **20**.

It will be noted in FIGURES 10A–10B that when the tool **10** is in its "shut-in" position, the positioning sleeve **41** is sufficiently elevated in relation to the housing **20** that the outwardly-biased key **51** carried by the sleeve is disposed in the housing groove **52** and corotatively secures the positioning sleeve to the housing. Accordingly, since the mandrel **19** is free to rotate in relation to the housing **20**, clockwise rotation of the mandrel will begin disengaging the mandrel threads **46** from the split-nut **45** carried by the positioning sleeve **41**. It will be recalled, however, that at this time, weight is being applied to the mandrel **19** to keep the mandrel lugs **92** engaged with the shoulder **90** on the rotatable

sleeve **75** so that the mandrel cannot move upwardly as the mandrel threads **46** are rotatably disengaged from the split-nut **45**. Thus, clockwise rotation of the mandrel **19** will instead cause the split-nut **45** to move downwardly in relation to the mandrel since the mandrel threads **46** are "left-handed."

It will be appreciated, therefore, that as the split-nut **45** is moved downwardly in relation to the rotating mandrel **19**, the positioning sleeve **41** will be correspondingly shifted thereby. Then, once the split-nut **45** is disengaged from the mandrel threads **46**, the spring **49** will urge the positioning sleeve **41** on downwardly in relation to both the mandrel **19** and the housing **20**.

Accordingly, as seen in FIGURES 11A–11B, downward travel of the positioning sleeve **41** will shift the valve sleeve **34** downwardly until the sleeve ports **39** are aligned with the mandrel ports **38** and the housing ports **40**. It will be appreciated, of course, that the mandrel ports **38** were aligned with the housing ports **40** whenever the tool **10** was moved to its "shut-in" position (FIGURES 10A–10B). Thus, once the tool **10** is in this "shut-in" position, clockwise rotation of the mandrel **19** is all that is required to selectively establish communication between the mandrel bore **22** and the well bore **15** above the packer **13** and begin the reversing procedure.

It should be noted that once the positioning sleeve **41** is moved downwardly by the spring **49**, the key **51** thereon will move out of the lower end of the housing groove **52** so that the positioning sleeve is no longer keyed to the housing **20** once the tool **10** is in the "reversing" position. The significance of this will subsequently become apparent. Moreover, it will be noted in FIGURES 11A–11B that downward travel of the valve sleeve **34** is halted whenever the lower end of the valve sleeve engages the top of the abutment sleeve **53** which is resting on the mandrel shoulder **56**. At this point, the latching balls **54** are moved outwardly by the enlarged mandrel portion **58** so that the balls are not in an operative position. Thus, it will be seen that the abutment sleeve **53** is, at this point in the operation, in position to halt the valve sleeve **34** in the position shown.

With the ports **38**, **39** and **40** all in alignment and the valve means **25** and **26** therebelow closed, the usual "reversing" procedure is to begin pumping additional well-control fluids into the well bore so that as well-control fluids enter these open ports, whatever fluids there are in the tubing string **14** will be displaced upwardly. Suitable steps are, of course, taken at the surface to insure that the fluids displaced from the tubing string **14** are safely disposed.

Accordingly, once the "reversing" operation is completed, either the second or the third of the previously mentioned four possibilities will occur. In some situations, the tools **10–13** are recovered once the reversing is accomplished. In other situations, the third alternate will be to open the full bore of the tool **10** either to conduct further completion operations or to recover the pressure recorders **165**. In either the second or the third situation, the mandrel **19** is raised slightly to return the guide pin **76** to its position at A and then the mandrel is again lowered to reclose the reversing valve **24**. This will, of course, reopen the valve means **25** (position B) as shown in FIGURES 9A–9B. Once this is done, the tools **10–13** are either recovered or the valve means **26** are then opened.

The tool **10** is, of course, now in the position shown in FIGURES 9A–9B. Accordingly, to continue further downward travel of the mandrel **19** for opening of the valve means **26**, it is necessary to first unthread the lower mandrel threads **103** from the lower nut **94**. It will be realized, of course, that unthreading rotation of the mandrel **19** would ordinarily tend to move the mandrel on downwardly and leave the lower split-nut **94** shouldered on its associated lower housing shoulder **99**. It should be noted, however, that as a matter of operating technique, it is preferred to relieve some of the downward load on the mandrel **19** while rotating the tubing string **14**. This is done by picking up the tubing string **14** somewhat but still leaving sufficient weight on the mandrel **19** to overcome the biasing means **32** which added weight will, of course, slowly overcome the movement-retarding means **33**. Thus, a sufficient time is assured to allow the lower split-nut **94** to climb the mandrel threads **103** before the movement-retarding means **33** are overcome.

Accordingly, as best seen in FIGURES 12A–12B, rotation of the mandrel **19** in the appropriate direction (as shown by arrow **170**) in cooperation with the movement-retarding means **33** will instead allow the nut **94** to climb the mandrel threads **103** and leave the mandrel in substantially the same longitudinal position as before. The nut **94** cannot, of course, rotate by virtue of the splines **96** (FIGURE 6) but it will nevertheless climb the threads **103** as the mandrel **19** rotates relative to the split-nut.

Once the lower split-nut **94** is freed from the lower mandrel threads **103**, the mandrel **19** is then free to travel on downwardly as permitted by the movement-retarding means **33**. Once the upper end of the sleeve **118** clears the enlarged-diameter housing portion **133**, the mandrel **19** will then move rapidly downwardly (as shown by arrow **171**) into the position depicted in FIGURES 12A–12B. This sudden movement will provide a substantial shock that is easily detected at the surface. As seen in FIGURES 12A–12B, movement of the mandrel **19** into this position will simultaneously co-engage the upper mandrel threads **102** with the upper split-nut **93**, close the valve means **24** and **25**, and pivot the ball member **142** into a position where its passageway **143** is coaxially aligned with the mandrel bore **22**. Then, if necessary, the tubing string **14** is rotated one or two rotations to insure engagement of the upper clutch member **63**. Once the clutch member **63** is engaged, this will also provide a positive indication at the surface that the ball member **142** is open and that the mandrel **19** and housing **20** are co-rotatively secured.

Once the ball member **142** is open, the seats **144** and **145** will be tightly seated around the opposite ends of the passage **143** to prevent entrance of fluids in the mandrel bore **22** into the enlarged housing space **134**. It will also be noted that since the ports **137** and **138** are no longer in registration, solids or fluids in the mandrel bore **22** are similarly blocked from entering the enlarged space **134**. Similarly, the ports **154** will also be closed.

The fourth alternate is, of course, to open the valve means **26** without opening the valve means **24**. This is simply done by moving the tool **10** from the position shown in FIGURES 10A–10B directly to that shown in FIGURES 9A–9B and then FIGURES 12A–12B without passing through the position shown in FIGURES 11A–11B.

As already mentioned, as the mandrel **19** is moved downwardly (from the position of FIGURES 11A–11B back to that shown in FIGURES 9A–9B), the valve means **24** are reclosed. It is at this point, therefore, that the selectively-operable abutment sleeve **53** comes into play. Accordingly, as the mandrel **19** moves downwardly, the enlarged-diameter mandrel portion **58** will hold the balls **54** outwardly and on the housing shoulder **62** so that the abutment sleeve **53** will prevent the valve sleeve **34** from moving downwardly. This, of course, allows the mandrel **19** to move downwardly in relation to all three of the sleeves **34**, **41** and **53** so that the mandrel seal **36** can again be moved below the sleeve ports **39** to again block fluid communication through the mandrel ports **38**. It will also be noted that as the mandrel **19** moves downwardly in relation to the positioning sleeve **41**, the mandrel threads **46** will ratchet back into the split-nut **45** to recouple the positioning sleeve and valve sleeve **34** to the mandrel. To properly position the sleeves **34**, **41** and **53** in relation to the mandrel **19**, the mandrel shoul-

der **61** is suitably located to be immediately under the latching balls **54** once the split-nut **45** is re-engaged with the mandrel threads **46**. The balls **54** are urged inwardly in latching engagement with the mandrel shoulder **61** by the reduced-diameter housing portion **60**. Thus, once the tool **10** is in the position shown in FIGURES 12A–12B, the balls **54** will be effective to support the sleeves **34**, **41** and **53** against further travel downwardly by the biasing spring **49**.

It should be noted at this point that the valve sleeve **34** is preferably arranged to provide a downwardly-acting unbalanced-pressure force to assist the spring **49** in opening the valve sleeve. To provide this additional pressure bias, the mandrel portion carrying the upper sealing member **36** is made to have a slightly smaller outside diameter than the mandrel portion carrying the lower sealing member **37**. The interior diameters of those portions of the valve sleeve **34** normally engaged with the sealing members **36** and **37** when the mandrel ports **38** are blocked are, of course, sized to complementally receive the sealing members. Accordingly, the upper portion of the valve sleeve **34** will present a slightly larger effective cross-sectional area than the lower portion and the hydrostatic pressure of the well-control fluids will provide a slight downward force on the valve sleeve so long as the mandrel ports **38** are closed. It will be understood, of course, that by making the diameters of the two mandrel portions carrying the seals **36** and **37** equal, no unbalanced pressure force will be provided.

Once the tool **10** is in the position shown in FIGURES 12A–12B, the mandrel **19** will be prevented from traveling upwardly by the co-engagement of the upper mandrel threads **102** in the upper split-nut **93**. Release of the threads **102** from the nut **93** could, of course, be accomplished by rotation of the mandrel **19** were it not for the engagement of the upper clutch member **63** which now prevents further rotation of the mandrel relative to the housing **20**. Thus, once the mandrel **19** reaches its lowermost telescoped position shown in FIGURES 12A–12B, the tool **10** is locked in this position with the ball-valve means **26** open and the sleeve-valve means **25** closed. This will provide a substantially continuous and uninterrupted passage from the tubing string **14** for introduction of various well tools (not shown), completion fluids such as cement or fracturing fluids requiring high flow rates, and for other reasons that may be encountered during the course of typical remedial or well-completion operations. The tools **10–13** must be retrieved to the surface in order to return the mandrel **19** to its original position. To do this, the upper clutch member **63** is quickly released by separating the housing **20** at the threads **104** thereon and shifting the annular member upwardly to disengege the lugs **65** from the slots **66**.

The annular spacer **100** is, of course, employed to prevent the mandrel **19** from being picked upwardly once the ball valve **142** is opened and the upper mandrel threads **102** have become engaged with the upper split-nut **93** as shown in FIGURES 12A–12B. It will be appreciated, therefore, that by omitting this spacer **100**, the mandrel **19** could be moved upwardly a sufficient distance to disengage the lugs **65** from their receptive slots **66**. This movement would, however, be insufficient to allow either the ball member **142** to be rotated back into its closed position or for the ports **137** and **138** to realign as shown in FIGURES 9A–9B so long as the mandrel **19** was not rotated. The valve means **24** would, of course, remain closed. Yet, once the lugs **65** were free of their slots **66**, the mandrel **19** could be rotated sufficiently to disengage the upper split-nut **93** from the mandrel threads **102** and permit the valve means **24**, **25** and **26** to be alternately opened and closed as many times as desired between the positions shown in FIGURES 9A–9B, 11A–11B and 12A–12B. Moreover, with the spacer **100** omitted, once the mandrel **19** is rotated sufficiently to disengage the upper split-nut **93** from the upper mandrel threads **102**, the mandrel could also be returned to any of the positions shown in FIGURES 8A–8B and 10A–10B as well.

Omission of the spacer **100** is not too desirable, however, where the bypass valve **11** and packer **13** are of the types described above in reference to FIGURE 1. For example, following a so-called "squeeze job," it is almost essential to rapidly flush-out the excess cement remaining in the tubing string **14** by applying pressure to the well-control fluids in the well annulus and forcing these fluids up into the lower end of the tubing string and on upwardly therein. Access to the tubing string **14** is typically gained by either unsetting the packer **13** or, as a last resort, opening the bypass valve **11** or the reversing valve **24** should the packer not be readily unseated. It will be realized, of course, that in either event, the ball valve **26** must be left open to permit a high flow rate of these fluids to be maintained. With bypass valves and packers of the types described, however, the tubing string **14** usually must be at least partially rotated and then picked up with considerable force to either open the bypass valve **11** or unseat the packer **13**. These motions could, therefore, serve to reclose the ball valve **26** and prevent the desired flushing operation if either the packer **13** or bypass valve **11** were not completely free of foreign matter and readily movable. Thus, unless the packer **13** and bypass valve **11** are of a style requiring only a straight upward pull to unseat the packer or open the bypass valve, it is preferred to include the spacer **100** so that the ball member **142** will unquestionably remain securely locked in its open position once the tool **10** is moved into the position depicted in FIGURES 12A–12B.

It will be appreciated from the foregoing description that the depicted arrangement of the groove system **77** of the positioning means **28** allows the sleeve-valve **25** to be selectively opened and closed by simple reciprocation of the mandrel **19**. Moreover, by appropriately locating such stops as the surfaces **166** and **168** adjacent to the entrance of one of the grooves (e.g., groove **89**), as the mandrel **19** is moved to reposition the guide pin **76** (e.g., from position C to position D), longitudinal movement of the mandrel will result in the guide pin reaching the proper subsequent position.

It will be realized, however, that the proper functioning of the positioning means **28** requires that the mandrel **19** be moved longitudinally with little or no rotation so long as the lower split-nut **94** is engaged with the lower mandrel threads **103**. Those skilled in the art will understand, however, that torsional forces will often be developed in the tubing string **14** as the tools **10–13** are being positioned in the well bore **15**. Thus, even though no rotation is deliberately imparted to the tubing string **14** at the earth's surface during the operation of the tool **10**, sufficient torsional forces may have been stored by the tubing string to impart at least a partial rotation to the mandrel **19** as it is being moved longitudinally from the surface.

It will be realized, therefore, that should the mandrel **19** rotate in a clockwise direction as it is being raised to shift the guide pin **76** from its position at B to its position at C, the guide pin could clear the end **167** of the surface **166** and reenter the groove **84** rather than being moved into the groove **83** (FIGURE 7). Should this occur, the guide pin **76** would return to its position at A without the operator's knowledge. Then, when the mandrel **19** was again lowered to supposedly shift the guide pin **76** from its position at C to its position at D, the guide pin would instead be returned to its position at B. Thus, instead of closing the valve means **25** to take a shut-in pressure measurement, the valve means **25** would be reopened. Similar malfunctions due to residual torsional movements of the mandrel **19** could just as well occur at other points in the operating sequence of the tool **10**.

Accordingly, to insure positive operation of the positioning means **28**, stop means, such as an inwardly biased key **172** on the sleeve **75** and a plurality of vertically disposed stops or shoulders **173–176** on the mandrel **19**, are provided to prevent inadvertent rotation of the mandrel from bringing the guide pin **76** into an incorrect position as the tool **10** is being operated. As best seen in FIGURE 13, the key **172** is mounted upright in a longitudinal sleeve recess **177** diametrically opposite the guide pin **76**. It should be noted that although the key **172** has been shown in FIGURE 2B to better illustrate the invention, the key is actually angularly oriented as shown in FIGURE 13. An arcuate spring **178** or similar biasing means behind the key **172** normally urges the key into contact with that portion of the mandrel **19** diametrically opposite the groove system **77** thereon.

The first stop shoulder **173** on the mandrel **19** is at about the same level as the enlarged portion **85** of the groove system **77** and is about diametrically opposite therefrom. It will be appreciated moreover from FIGURES 2B, 5 and 7 that the vertical shoulder surface **173** is so arranged in relation to the key **172** that whenever the guide pin **76** is in either the groove **86** or enlarged groove portion **85**, the mandrel **19** cannot rotate in relation to the sleeve **75** sufficiently far in a clockwise direction that the guide pin can pass the terminal groove surface **167** and re-enter the groove **84**. Thus, once the guide pin **76** is in the position B shown in FIGURE 7, inadverent rotation of the mandrel **19** in a clockwise direction will only bring the key **172** against the shoulder **173** and keep the sleeve **75** and guide pin correctly oriented in relation to the groove system **77**. Rotation of the mandrel **19** in a counterclockwise direction will only bring the guide pin **76** against the common wall of the grooves **83** and **86** which serves as a stop to prevent misalignment of the guide pin and groove system **77**.

The other stop shoulders **174–176** are similarly arranged at the same level of the transverse groove **81** to successively prevent re-entry of the guide pin **76** into either the groove **83** or groove **89** once the guide pin has entered the groove **87**, the groove **89** or the groove **88** or the groove **82** as the tool **10** is progressively operated. Thus, for example, once the guide pin **76** is in its position C (FIGURE 7), counterclockwise rotation of the mandrel **19** cannot reposition the guide pin into groove **83** since the shoulder **174** will engage the key **172** and hold the groove surface **168** above the pin so as to guide the pin to its position at D as the mandrel is lowered. Similarly, the shoulder **175** keeps the guide pin **76** from re-entering the groove **87** from the groove **89** and the shoulder **176** keeps the guide pin from re-entering the groove **89** from the groove **88**.

Accordingly, it will be appreciated that the present invention has provided a new and improved well tool adapted to control fluid communication between the pipe string and the well bore annulus above a packer as well as the well bore below a packer. By arranging the several valve means and their respective positioning means for selective operation only in response to particular movements of the pipe string, opening and closing of each of the valves is accomplished wholly independently of the operation of the others thereby eliminating the unwanted operation of any valve.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A well tool comprising: inner and outer relatively-rotatable tubular members telescoped together for movement relative to one another between longitudinally-spaced positions and including a first fluid passage between the interiors of said tubular members and a second fluid passage between the exterior of said tool and said first passage; first coengageable means on said tool for controlling fluid communication through one of said passages and selectively operable only upon a relative rotation between said tubular members and then longitudinal movement thereof to one of said spaced positions; and second coengageable means on said tool for controlling fluid communication through the other of said passages and selectively operable only upon longitudinal movement of said tubular members to another of said spaced positions and then relative rotation therebetween.

2. The well tool of claim **1** wherein said first-mentioned and said second-mentioned relative rotations are in the same rotative direction.

3. The well tool of claim **1** wherein said one passage is said first passage and further including: a third passage bypassing said first coengageable means; and third coengageable means on said tool controlling fluid communication through said third passage and selectively operable upon longitudinal movement of said tubular members between two of said spaced positions.

4. The well tool of claim **1** wherein said one passage is said first passage and said first and second coengageable means include first and second valve means that are selectively opened by said first and said second longitudinal movements and rotations respectively, and further including: means operable for closing said second valve means, if open, upon longitudinal movement of said tubular members toward said one spaced position.

5. The well tool of claim **4** further including: a third passage bypassing said first valve means and providing an alternate fluid communication path between spaced locations in said first passage; and third valve means controlling fluid communication through said third passage and selectively opened and closed upon alternate movements of said tubular members between a third one of said spaced positions and said other spaced position.

6. The well tool of claim **1** further including: clutch means co-rotatively securing said tubular members in a selected one of said spaced positions and selectively disengageable upon movement of said tubular members toward said one and said other positions.

7. The well tool of claim **6** further including: delay means for retarding movement of said tubular members toward said one and said other positions.

8. The well tool of claim **7** wherein said one passage is said first passage and further including: a third passage bypassing said first coengageable means; and third means controlling fluid communication through said third passage and selectively operable upon movement of said tubular members between a third one of said spaced positions and said other spaced position.

9. The well tool of claim **8** wherein said first, second and third means respectively include first, second and third valve means that are respectively opened and closed by said movements and rotations of said tubular members, and further including: means operable upon movement of said tubular members toward said one spaced position for closing said second valve means, if open; and means operable upon movement of said tubular members toward said one spaced position for closing said third valve means.

10. A well tool comprising: inner and outer relatively-rotatable tubular members telescoped together for movement relative to one another between selected longitudinally-spaced positions; a first passage between the interiors of said tubular members; a second passage between the interior and exterior of said tool; first means including first valve means between said tubular members for controlling fluid communication through said first passage and selectively opened and closed upon non-rotative longitudinal movement of said tubular members between first and second ones of said spaced positions; and second means including second valve means between said

tubular members for controlling fluid communication through said second passage and selectively opened only upon movement of said tubular members to a third one of said spaced positions and then relative rotation of said tubular members while remaining in said third position.

11. The well tool of claim **10** wherein said first means further include a third passage bypassing said first valve means and third valve means controlling fluid communication through said third passage and selectively operable upon relative longitudinal movement of said tubular members to a fourth one of said spaced positions, and further including: position-establishing means releasably co-engaged between said tubular members normally preventing movement of said tubular members to said fourth position and selectively operable in response to relative rotation of said tubular members for releasing said tubular members for movement to said fourth position.

12. The well tool of claim **11** wherein said first-mentioned and said second-mentioned relative rotations of said tubular members are in one rotative direction.

13. The well tool of claim **11** further including: second position-establishing means between said tubular members and responsive to successive longitudinal movements thereof for sequentially halting said tubular members at predetermined ones of said spaced positions.

14. The well tool of claim **11** further including: clutch means co-rotatively securing said tubular members in said first position and selectively disengageable upon movement of said tubular members away from said first position.

15. The well tool of claim **11** further including: clutch means co-rotatively securing said tubular members in said fourth position and selectively disengageable upon movement of said tubular members away from said fourth position.

16. The well tool of claim **11** further including: first clutch means co-rotatively securing said tubular members in said first position and selectively disengageable upon movement of said tubular members away from said position; and second clutch means co-rotatively securing said tubular members in said fourth position and selectively disengageable upon movement of said tubular members away from said fourth position.

17. A well tool comprising: inner and outer relatively-rotatable tubular members telescoped together for movement relative to one another between longitudinally-spaced positions and respectively having first and second lateral ports adapted to provide fluid communication between the exterior of said outer tubular member and the interior of said inner tubular member; valve means including a valve member movably disposed between said tubular members and adapted for movement relative thereto between a first position preventing fluid communication between said lateral ports and a second position opening fluid communication therebetween; and valve-actuating means for selectively moving said valve member from one of said valve positions to the other of said valve positions including first means releasably securing said valve member to one of said tubular members and releasable only upon rotation of said one tubular member relative to said valve member and the other of said tubular members, second means co-rotatively securing said valve member to said other tubular member in one of said spaced positions and releasable therefrom upon movement of said tubular members to others of said spaced positions, and means for moving said valve member to said other valve position upon release of said first valve-securing means.

18. The well tool of claim **17** further including: means operative only after movement of said valve member to said other valve position for returning said valve member to said one valve position upon longitudinal movement of said tubular members away from said one spaced position.

19. The well tool of claim **17** wherein said valve-moving means include a spring between said valve member and one of said tubular members.

20. The well tool of claim **19** wherein said one valve position is said first valve position and said valve-moving means further include means on said valve member responsive to a pressure differential between the exterior and interior of said tubular members for urging said valve member from said first valve position to said second valve position upon release of said first valve-securing means.

21. The well tool of claim **17** wherein said valve member is a sleeve adapted for longitudinal movement on said inner member and said valve means further include first and second sealing means between said sleeve and said inner member respectively above and below said first lateral port whenever said sleeve is in said first valve position.

22. The well tool of claim **21** wherein said first valve-securing means include external threads on said inner member, a radially-expansible internally-threaded member connected to said sleeve and threadedly engaged with said external threads whenever said sleeve is in said first valve position, and means co-rotatively securing said threaded member relative to said sleeve.

23. The well tool of claim **22** wherein said second valve-securing means are between said valve member and said outer member and include a longitudinal spline on one of said last-mentioned members and a longitudinal spline groove on the other of said last-mentioned members operatively located to receive said spline whenever said tubular members are in said one spaced position and to be longitudinally spaced from said spline whenever said tubular members are in said other spaced positions.

24. Well bore apparatus comprising: selectively operable well-packing means adapted for engagement in a well bore and including an axial passage through said well-packing means; a first tubular member connected at its lower end to said well-packing means; a second tubular member adapted for connection at its upper end to a pipe string and having its lower end telescopically arranged with said first tubular member for rotation as well as longitudinal movement between longitudinally-spaced positions relative thereto; means defining a first passage through said tubular members and adapted to provide fluid communication between said axial passage and a pipe string connected to said second tubular member; means defining a second passage through said tubular members and adapted to provide fluid communication between said first passage and a well bore exterior of said tubular members; first means including first valve means for selectively opening fluid communication through said first passage only upon rotation of said second tubular member and then longitudinal movement thereof to one of said spaced positions; and second means including second valve means for selectively opening fluid communication through said second passage only upon longitudinal movement of said second tubular member to another of said spaced positions and then rotation of said second tubular member while in said other spaced position.

25. The well bore apparatus of claim **24** further including: a first shoulder on one of said tubular members; a sleeve rotatably journalled on the other of said tubular members and having a second shoulder thereon adapted for abutment by said second shoulder only when said sleeve is in a selected angular position and said second tubular member is in said other spaced position for transmitting longitudinal forces from a tubing string connected to said second tubular member to said well-packing means; and indexing means on said one tubular member and said sleeve for rotating said sleeve to said selected angular position upon longitudinal movement of said second tubular member to said other spaced position and for rotating said sleeve away from said selected angular position upon longitudinal movement of said second tubular member away from said other spaced position.

26. The well bore apparatus of claim 25 wherein said first means include: position-establishing means releasably co-engaged between said tubular members for normally preventing movement of said second tubular member to said one spaced position and selectively releasable by said rotation to allow said second tubular member to be moved to said one spaced position.

27. The well bore apparatus of claim 24 wherein said first means include: position-establishing means releasably co-engaged between said tubular members for normally preventing movement of said second tubular member to said one spaced position and selectively releasable by said rotation to allow said second tubular member to be moved to said one spaced position.

28. The well bore apparatus of claim 27 further including: means defining a third passage through said tubular members and adapted to provide fluid communication between said axial passage and a pipe string connected to said second tubular member; and third means including third valve means for selectively opening fluid communication through said third passage upon longitudinal movement of said second tubular movement to a third one of said spaced positions.

29. The well bore apparatus of claim 28 further including: second position-establishing means between said tubular members and responsive to consecutive alternating longitudinal movements of said second tubular member for successively halting said second tubular member at said other and said third spaced positions.

30. A well tool comprising: inner and outer relatively-rotatable tubular members telescoped together for movement relative to one another between longitudinally-spaced positions and having a fluid passage establishing communication between the interior of said tubular members and a well bore exterior thereof; valve means on one of said tubular members and movable in relation thereto between a position closing said passage and a position opening said passage; first means releasably securing said valve means to said one tubular member for retaining said valve means in one of said valve positions and responsive only to rotation of said one tubular member in relation to said valve means for releasing said valve means for movement to the other of said valve positions; second means releasably securing said valve means to the other of said tubular members whenever said tubular members are in one of said spaced positions for preventing relative rotation between said valve means and said other tubular member, said second securing means being releasable upon movement of said tubular members to another of said spaced positions; and means for moving said valve means to said other valve position upon release of said first valve-securing means.

31. The well tool of claim 30 further including: second valve means on said inner member for blocking fluid communication through said interior of said tubular members when said tubular members are in said one spaced position and for establishing fluid communication through said interior of said tubular members when said tubular members are in said other spaced position.

32. The well tool of claim 31 further including: position-establishing means responsive to alternating longitudinal movements of said tubular members for successively positioning said tubular members in said spaced positions.

33. The well tool of claim 31 further including: position-establishing means releasably secured to said inner member for preventing movement of said tubular members to said other spaced position and responsive to relative rotation thereof when said tubular members are in a spaced position intermediate of said one and said other spaced positions to release said inner member and permit movement of said tubular members to said other spaced position.

34. The well tool of claim 33 further including: third valve means on said inner member for blocking fluid communication through said interior of said tubular members when said tubular members are in said one spaced position and for establishing fluid communication through said interior of said tubular members when said tubular members are in said intermediate spaced position.

35. The well tool of claim 33 further including: means responsive to movement of said tubular members away from said one spaced position for returning said first-mentioned valve means from said other valve position to said one valve position.

36. A well tool comprising: inner and outer relatively-rotatable tubular members telescoped together for movement relative to one another between longitudinally-spaced positions and defining a longitudinal flow passage through said tool; first means selectively operable for opening and closing communication through said longitudinal flow passage in response to relative movement of said tubular members between intermediate ones of said spaced positions and at least one other of said spaced positions; and second means including a lateral flow passage in said inner member providing communication between said longitudinal flow passage and a well bore exterior of said tool, a slidable sleeve member sealingly coengaged on said inner member for movement thereon between a position blocking communication through said lateral flow passage and a position opening communication therethrough, first means threadedly coupling said sleeve member to said inner member for retaining said sleeve member in its said flow-blocking position and releasable only upon relative rotation between said sleeve member and said inner member, second means co-rotatively coupling said sleeve member to said outer member when said tubular members are in one of said intermediate spaced positions for allowing relative rotation between said sleeve member and said inner member when said tubular members are in said one intermediate position, said second coupling means being disengaged when said tubular members are moved away from said one intermediate position for preventing relative rotation between said sleeve member and said inner member, and biasing means between said inner member and said sleeve member for moving said sleeve member to its said flow-opening position upon release of said first coupling means by relative rotation between said sleeve member and said inner member whenever said tubular members are in said one intermediate position.

37. The well tool of claim 36 wherein said first means include: an annular valve seat on said inner member, a rotatable valve member pivotally supported on said inner member engaged with said valve seat and rotatable in relation thereto between a position blocking communication through said longitudinal flow passage and a position opening communication therethrough, and means operatively arranged between said rotatable valve member and said outer member normally retaining said rotatable valve member in its said flow-blocking position and responsive only to relative movement of said tubular members from said intermediate ones of said spaced positions and toward a first one of said other spaced positions to rotate said rotatable valve member to its flow-permitting position.

38. The well tool of claim 36 wherein said first means include: a second lateral flow passage in said inner member, and passage-covering means on said outer member and sealing means between said passage-covering means and said inner member cooperatively arranged for closing fluid communication through said second lateral flow passage whenever said tubular members are in said intermediate spaced positions and for opening fluid communication through said second lateral flow passage whenever said tubular members are in a first one of said spaced positions.

39. The well tool of claim 36 wherein said first means include: an annular valve seat around said longitudinal flow passage, a rotatable valve member pivotally supported on said inner member engaged with said valve seat and rotatable in relation thereto between a position

blocking communication through said longitudinal flow passage and a position opening communication therethrough, and means operatively arranged between said rotatable valve member and said outer member normally retaining said rotatable valve member in its said flow-blocking position and responsive to relative movement of said tubular members from said intermediate ones of said spaced positions and toward a first one of said other spaced positions to rotate said rotatable valve member to its flow-permitting position; a second lateral flow passage in said inner member between said first lateral flow passage and said rotatable valve member, and passage-covering means on said outer member and sealing means between said passage-covering means and said inner member cooperatively arranged for closing fluid communication through said second lateral flow passage whenever said tubular members are in said intermediate spaced positions and for opening fluid communication through said second lateral flow passage whenever said tubular members are in a second one of said other spaced positions.

40. The well tool of claim **39** further including: means cooperatively arranged between said tubular members

normally preventing movement thereof to said first spaced position and releasable only upon relative rotation between said tubular members to permit their movement to said first spaced position.

41. The well tool of claim **40** further including: position-establishing means cooperatively arranged between said tubular members and responsive to alternating longitudinal movements thereof to successively position said tubular members in predetermined spaced positions.

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