Dec. 3, 1968 B. P. NUTTER 3,414,059

ACTUATING MEANS FOR WELL TOOLS

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Fig. 2A

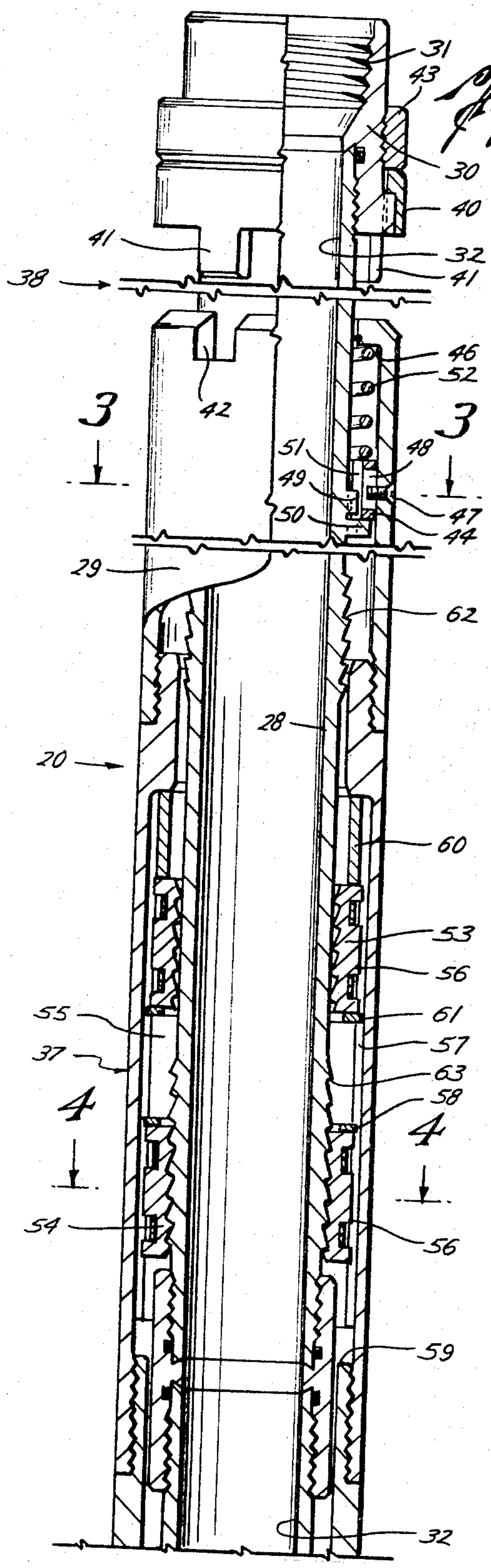

Fig. 1

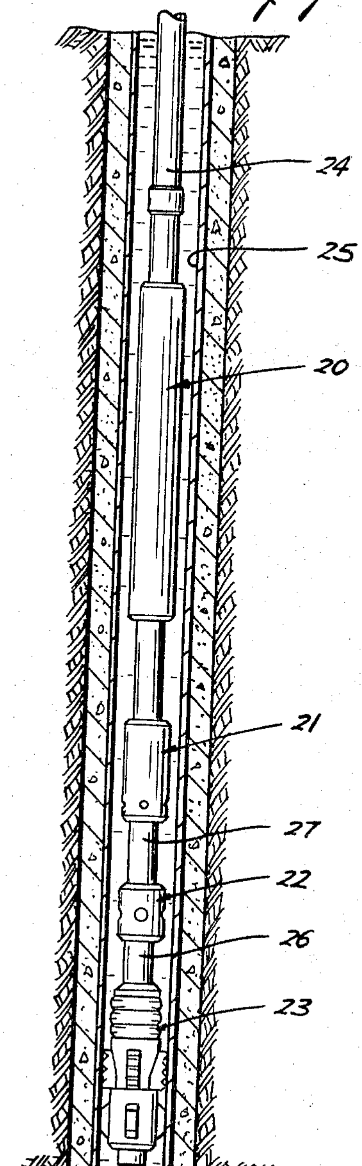

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Fig. 2B

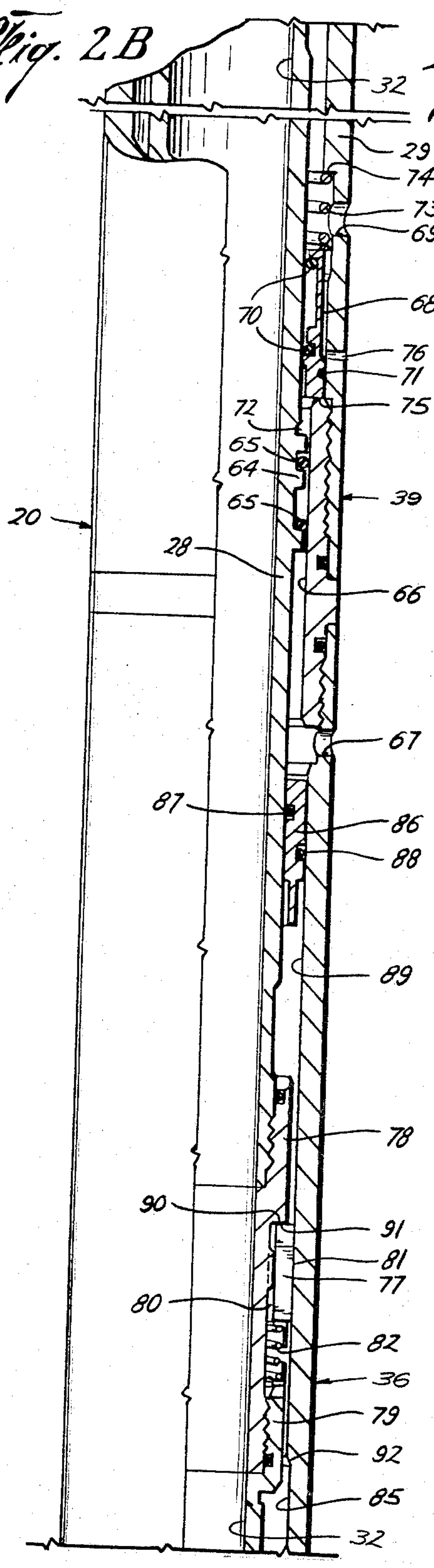

Fig. 2C

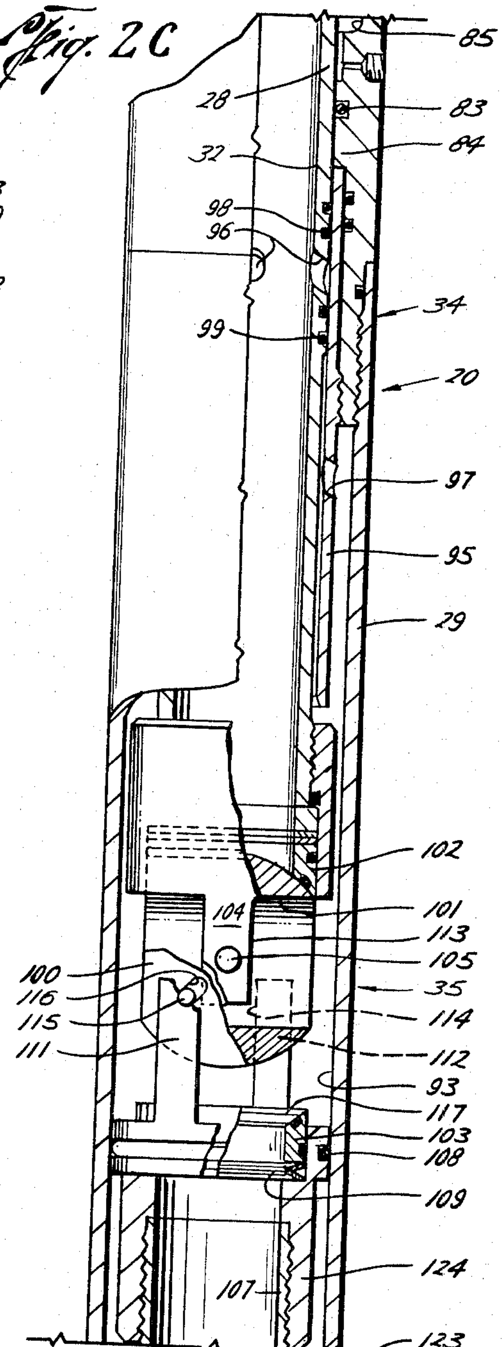

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Fig. 2D

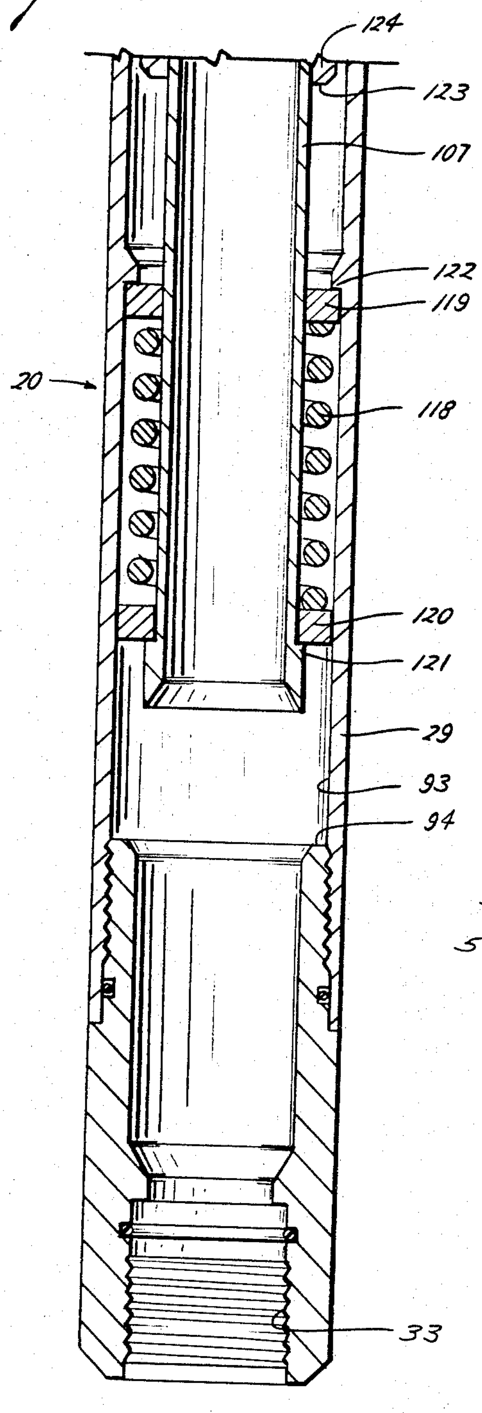


Fig. 3

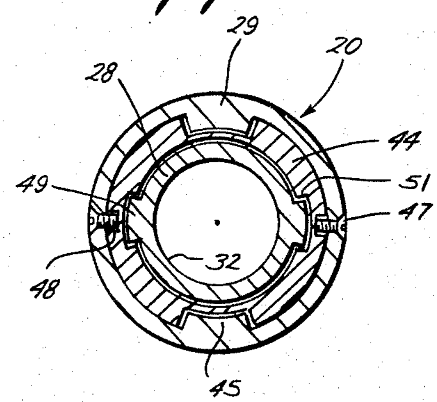
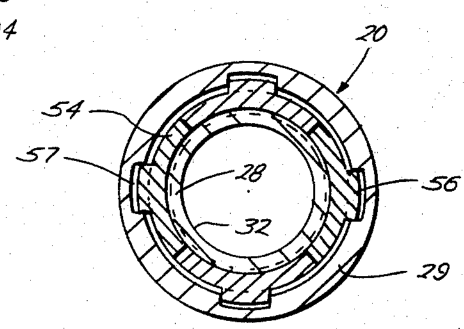


Fig. 4



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ACTUATING MEANS FOR WELL TOOLS

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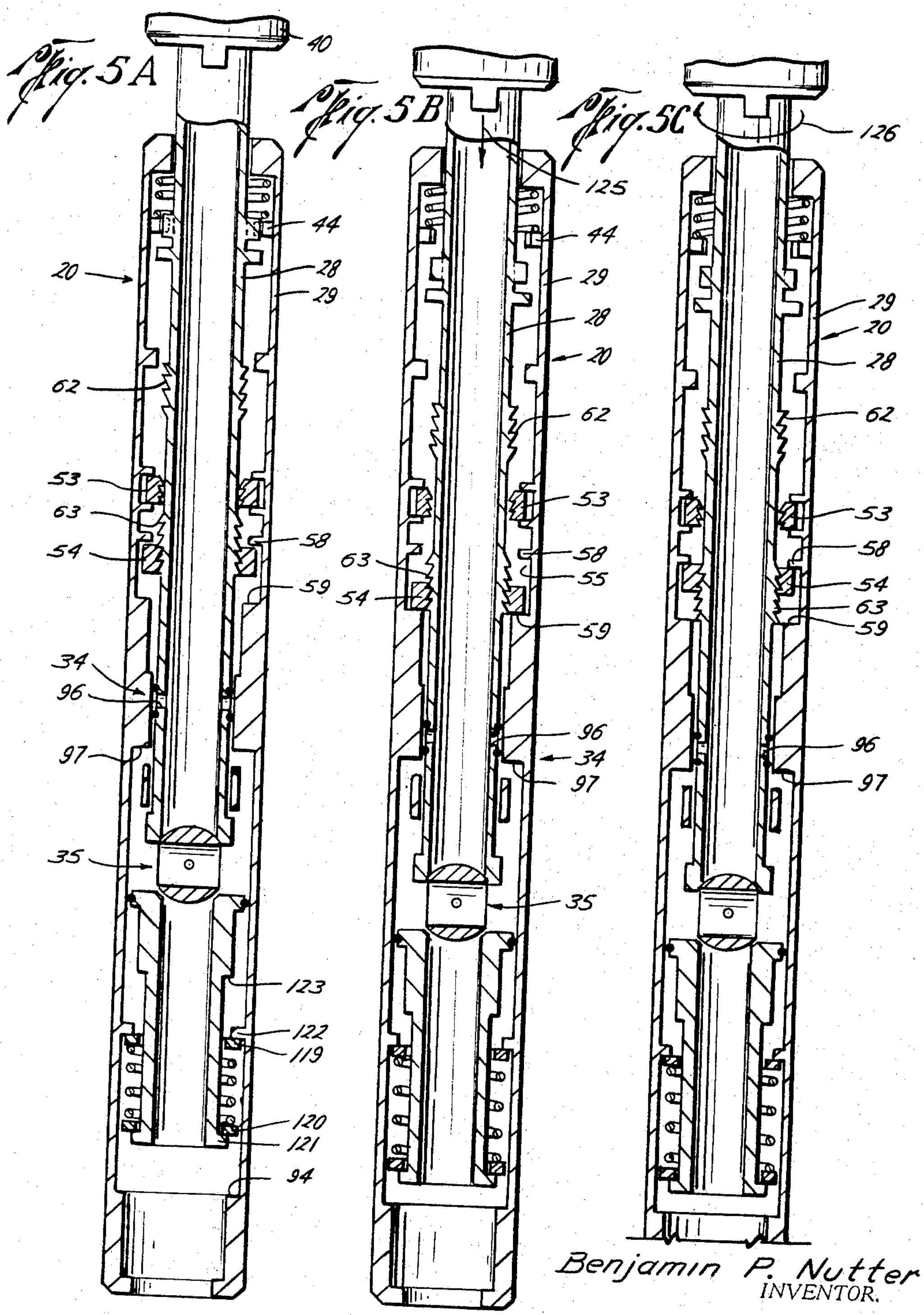

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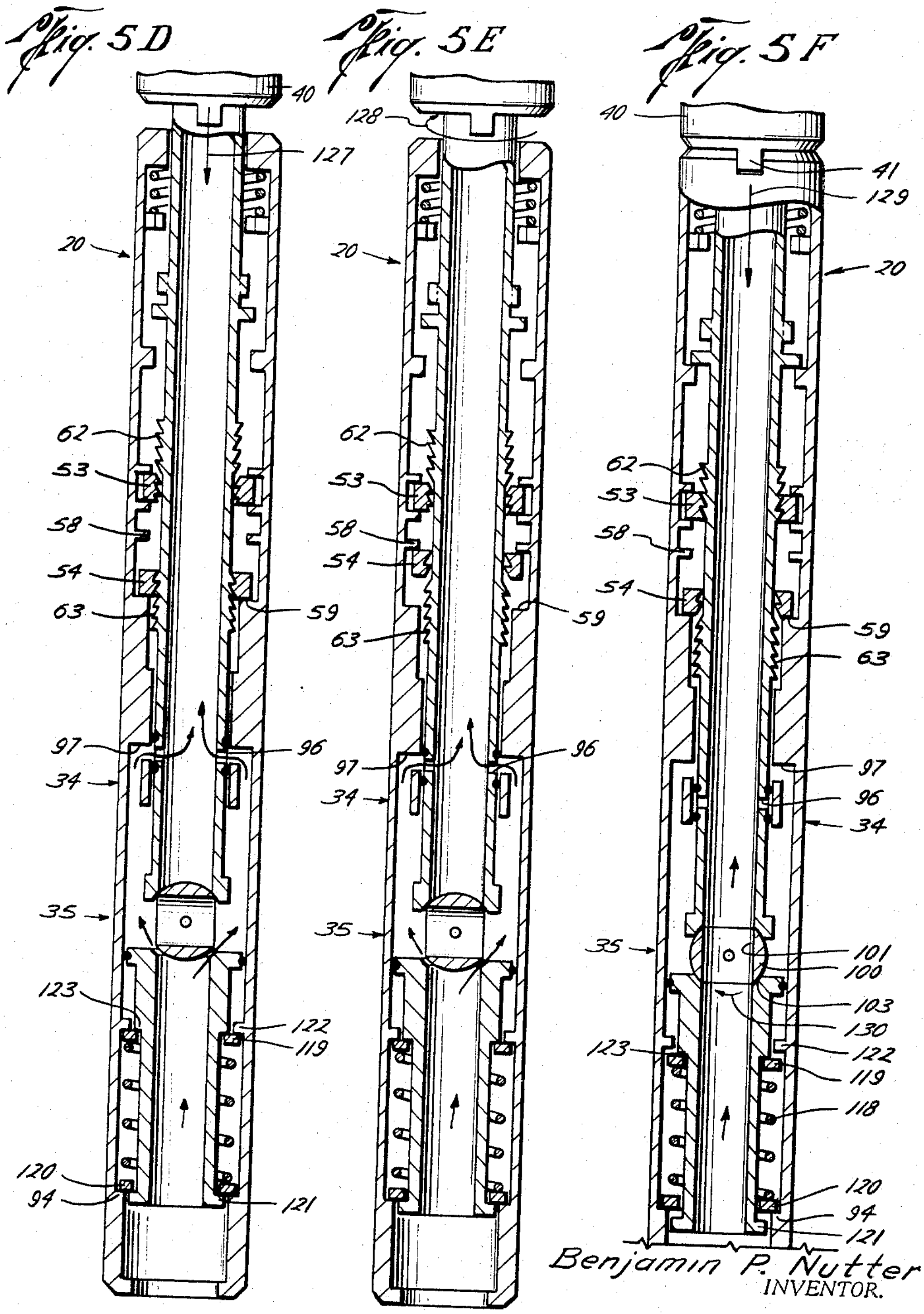

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Fig. 6

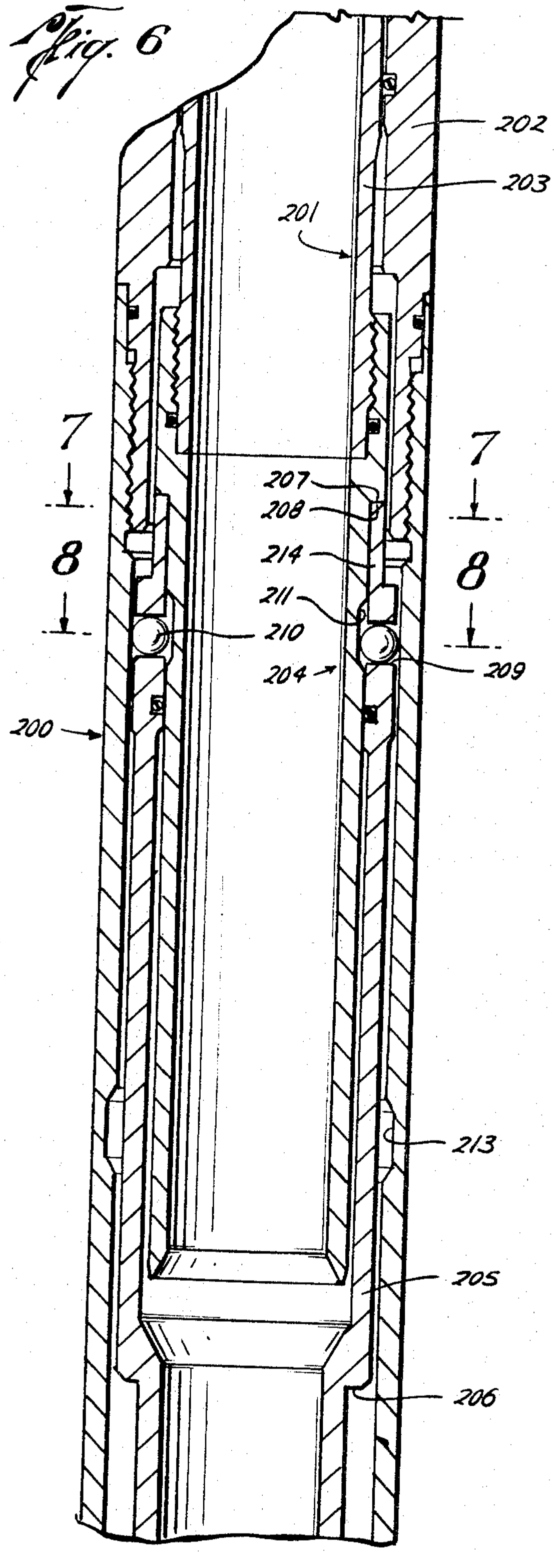


Fig. 7

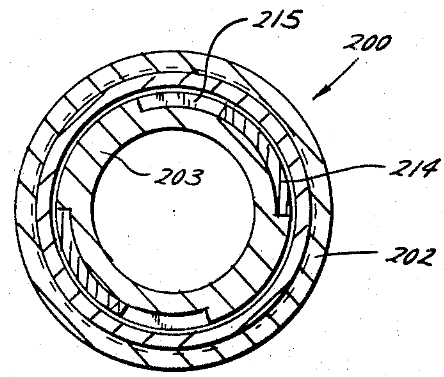
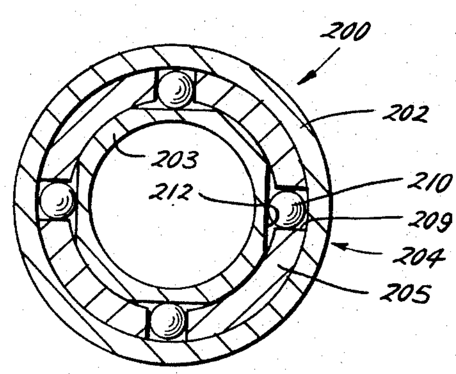


Fig. 8



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ACTUATING MEANS FOR WELL TOOLS

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Fig. 9

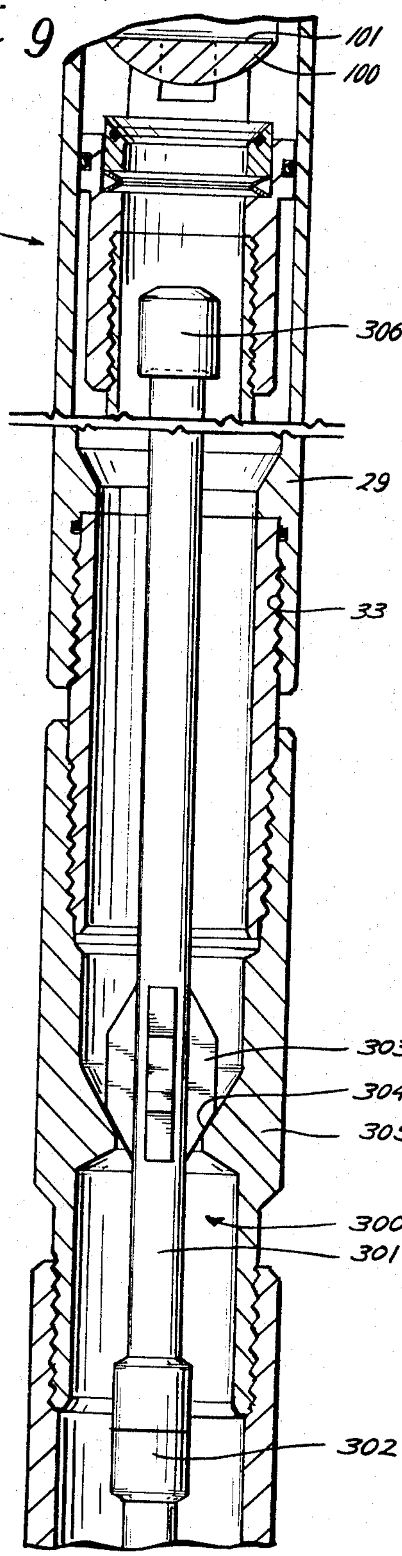

Fig. 10

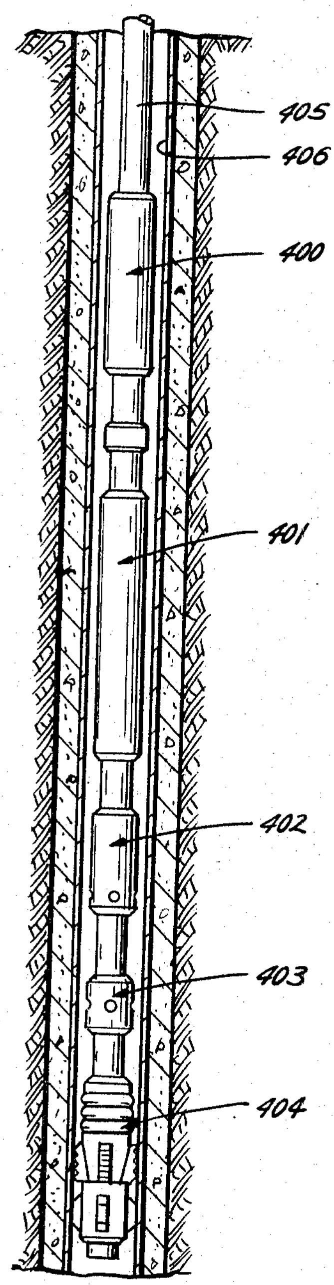

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Fig. 11A

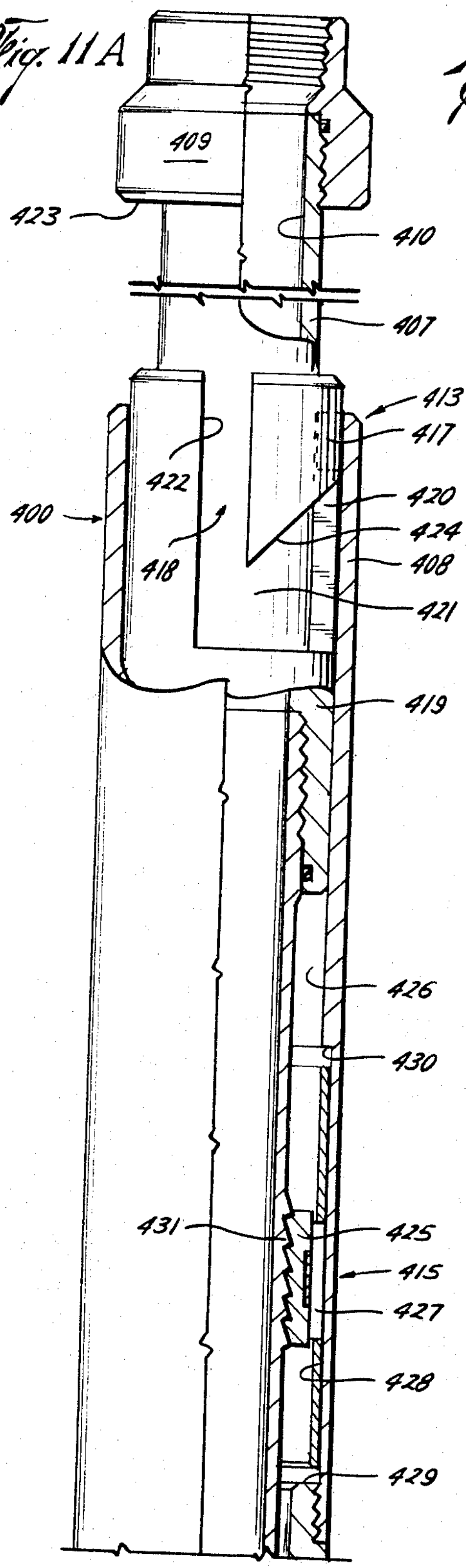

Fig. 11B

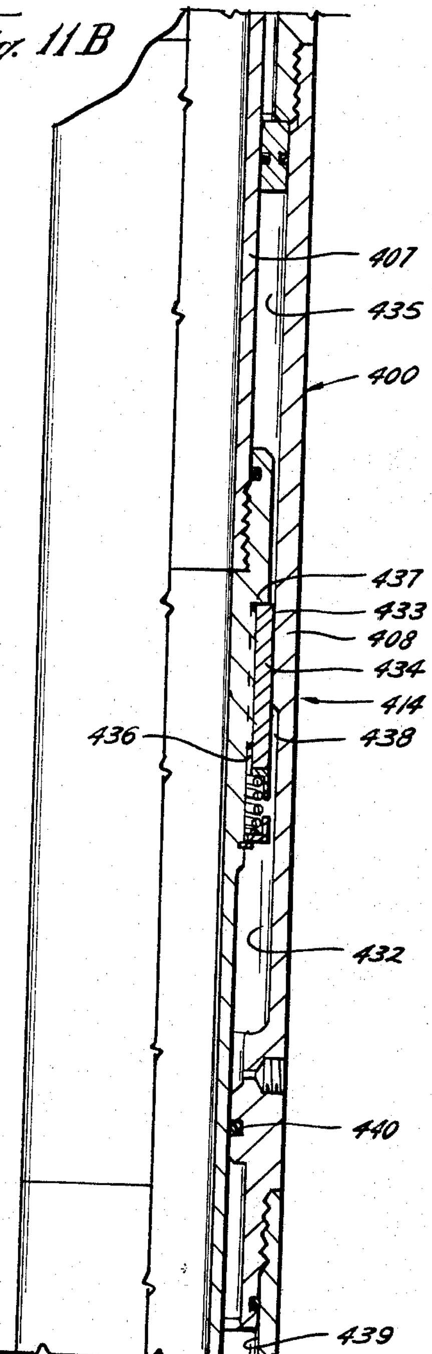

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Fig. 11C

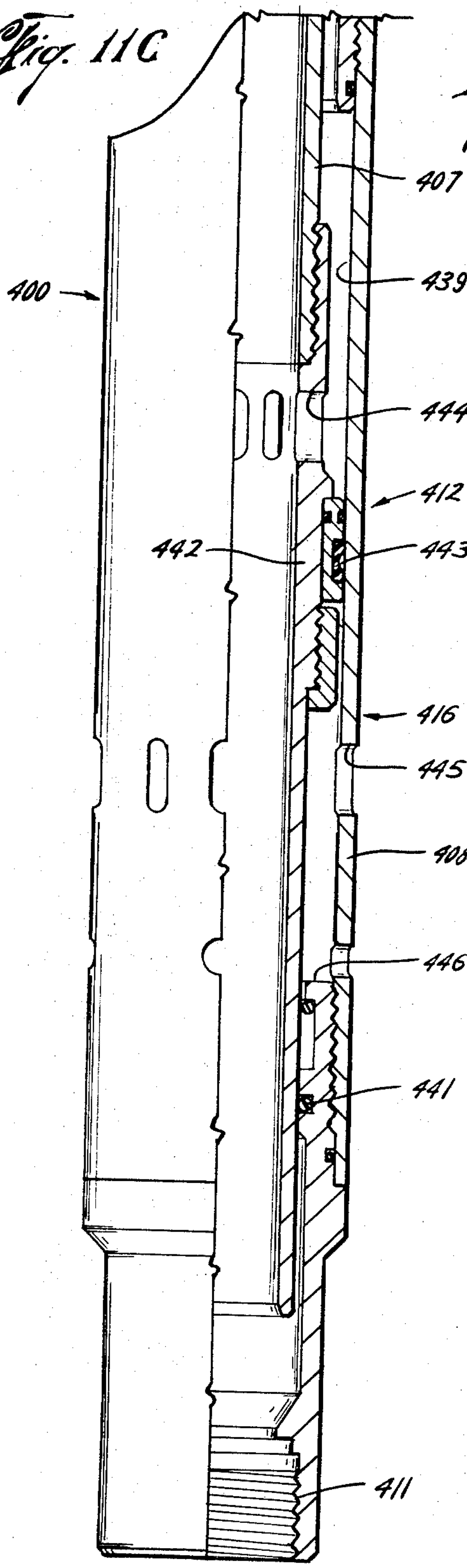
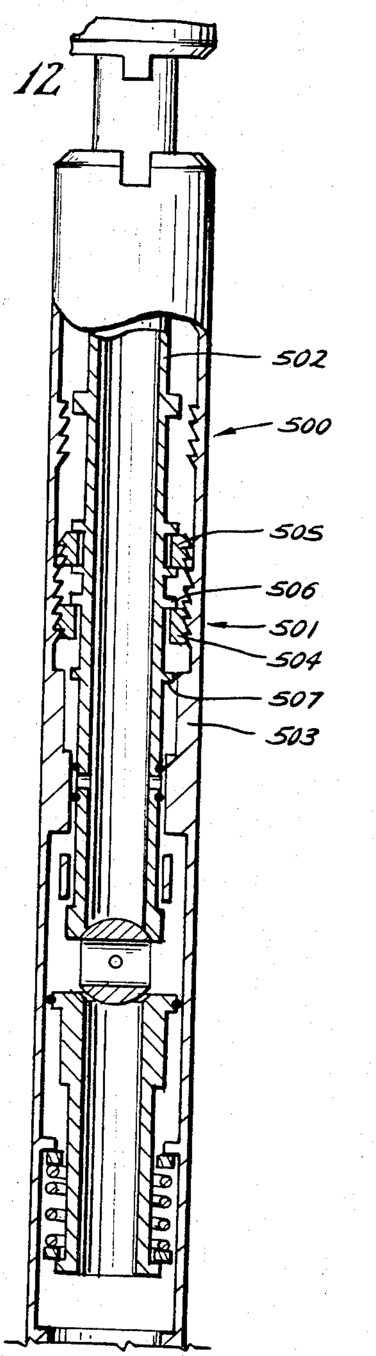


Fig. 12



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United States Patent Office

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3,414,059
ACTUATING MEANS FOR WELL TOOLS

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Filed Mar. 6, 1967, Ser. No. 620,943
54 Claims. (Cl. 166—150)

ABSTRACT OF THE DISCLOSURE

This disclosure describes actuating means for well tools having relatively rotatable inner and outer telescopically arranged members. A threaded member, such as a nut, is disposed in the annular space between the telescoped members between two spaced stops on one of the members such as, for example, the outer member. Threads on the other member, for example the inner member, are normally engaged with the threaded member. So long as the threaded member remains in its normal position relative to the threads, the other member cannot be moved over a longitudinal span any greater than allowed by the spaced stops. Means are provided for retarding longitudinal movement of the other member in a direction toward one of the stops. Thus, upon relative rotation of the telescoped members, the threaded member will be moved in the opposite direction along the threads until it engages the second stop. This will permit the telescoped members to then be moved in a different longitudinal span.

Accordingly, as will subsequently become apparent, this invention relates to well tools; and, more particularly, this invention pertains to new and improved actuating means for selectively placing well tools into a plurality of distinctive operating positions with only a minimum of different manipulations.

It is customary to employ a number of different full-bore tools coupled into one string for 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 a selectively operable valve for controlling communication into the lower end of the tubing string. 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 used to manipulate each of the tools into various relative positions.

It will be recognized, of course, that as the number of operations to be performed by a particular string of tools increases, a correspondingly increasing number of different manipulations of the tubing string are required to move the tools into their various operating positions. In general, the only basic manipulative movements are limited to either a longitudinal shifting in either vertical direction or else rotation in one or the other rotative direction.

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-

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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 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.

Thus, for these and other reasons, whenever several operating positions must be assumed by the tools, at least some manipulative movements must be duplicated and the operator must depend upon variations and degrees in these few movements to distinguish which operative positions the tools are in. Accordingly, many well tools of this nature are so arranged. that they 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 mandrels. Typical of such control arrangements is a so-called "J-slot" system in which a lateral pin projecting from one of the relatively movable members of a tool is received within a labyrinth arrangement of grooves formed on an adjacent surface of another member. By providing several longitudinally space branch portions in such J-slot grooves, a variety of distinct operating positions are obtained by shifting the well tool mandrel longitudinally in either direction either with or without an accompanying rotative movement.

Although such J-slot systems are widely used, they are nevertheless still recognized as having 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 tool.

Accordingly, is is an object of the present invention to provide new and improved well tools having control or actuating means which permit these tools to be selectively placed in a plurality of distinctive operating positions with only a minimum of different manipulations. This and other objects of the present invention are obtained by arranging an expansible gripping member between inner and outer telescoped members in such a fashion that the expansible gripping member will be securely engaged with one of the telescoped members and be free to move longitudinally relative to the other telescoped member between longitudinally spaced shoulders thereon. Motion-retarding means are preferably provided to delay longitudinal travel of the one telescoped member relative to the other for a period of time sufficient for the one member to be rotated relative to the expansible gripping member and bring a different portion of that one member into gripping engagement with the expansible member. In this manner, the one telescoped member is free to b shifted longitudinally relative to the other telescoped member through a plurality of longitudinal spans as determined by the relative length of the expansible member as well as the longitudinal spacing between the shoulders. These various positions are accomplished with only longitudinal movement and unidirectional rotation of the one telescoped member.

The novel features of the present invention are set forth with particularity in the appended claims. The operation, together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings, in which:

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

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

FIGS. 3 and 4 are cross-sectional views taken along the lines "3—3" and "4—4" respectively in FIG. 2A;

FIGS. 5A–5F are somewhat schematic views of the well tool shown in FIGS. 2A–2D and depict its successive operating positions;

FIG. 6 is an elevational view of a portion of another embodiment of a well tool that may employ the positioning means of the present invention;

FIGS. 7 and 8 are cross-sectional views taken along the lines "7" and "8" respectively in FIG. 6;

FIG. 9 is an elevational view of one embodiment of pressure-measuring apparatus that is releasably secured in either of the tools depicted in FIGS. 2A–2D or in FIG. 6;

FIG. 10 shows a typical string of well tools in a well bore including another embodiment of a well tool arranged in accordance with the present invention;

FIGS. 11A–11C are successive views showing in detail the well tool depicted in FIG. 10; and

FIG. 12 is a schematic view similar to FIG. 5A but showing still another embodiment of a well tool with positioning means in accordance with the present invention.

Turning now to FIG. 1, a number of full-bore well tools **20–23** are shown tandemly connected to one another and dependently coupled from the lower end of a string of pipe, such as a tubing string **24**, suspended in a cased well bore **25**. At the lower end of these tools, a conventional full-bore packer **23** is arranged for selectively packing-off the casing **25**. A typical hydraulic holddown **22** is coupled to the mandrel **26** of the packer **23** and arranged to engage the casing **25** to secure the mandrel against the upward movement whenever the packer is set and fluid pressure within the tubing string **24** exceeds the hydrostatic pressure of the well control fluids in the well annulus. A typical bypass valve **21**, coupled by a tubing sub **27** above the holddown **22**, is suitably arranged to open and facilitate shifting of the tools **20–23** within the fluid-filled casing **25** by diverting a substantial portion of the fluids through the central bore of the retracted packer **23**. Connected at the upper end of the string of tools **20–23** is a tool **20** incorporating the principles of the present invention. Although the tools **21–23** 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 a similar nature may be used in conjunction with the tool **20**.

Turning now to FIGS. 2A–2D, successive elevational views, with each being partially in cross-section, are shown of the tool **20**. The tool **20** includes a tubular mandrel **28** telescopically disposed within a tubular housing **29** and arranged in accordance with the present invention for selective longitudinal movement therein between an extended position as shown in FIGS. 2A–2D, one or more intermediate positions, and a fully telescoped position as subsequently described with reference to FIGS. 5A–5F. A threaded collar **30** (FIG. 2A) on the upper end of the mandrel **28** has threads **31** arranged for coupling to the tubing string **24** (FIG. 1), with the central bore **32** (FIGS. 2A–2D) of the mandrel having substantially the same internal diameter as that of the tubing string. Similarly, threads **33** (FIG. 2D) on the lower end of the housing **29** are arranged for coupling the tool **20** to the other well tools therebelow such as the bypass valve **21** shown in FIG. 1.

In general, the tool **20** includes first and second valve means **34** and **35** (FIG. 2C) of a suitable nature that are each selectively opened and closed by shifting the mandrel **28** between different longitudinal positions with respect to the housing **29**. The valve means **34** and **35** are preferably those shown in a copending application Ser. No. 620,841, filed by the applicant on the same day as the present application. For establishing these longitudinal positions, means, such as movement-retarding means **36** (FIG. 2B) and the selectively operable positioning means **37** (FIG. 2A) of the present invention, are provided. Clutch means **38** are also provided to permit selective application of torque from the mandrel **28** through the housing **29** to the other tools **21–23** when the mandrel is in certain ones of its positions. Biasing means **39** (FIG. 2B) are preferably provided to maintain a downward force on the housing **29** to assist in keeping the packer **23** seated while the mandrel **28** is being moved as well as to apply an upward force on the mandrel to keep the clutch means **38** engaged whenever the mandrel is in its uppermost extended position with respect to the housing.

Turning now to FIG. 2A, the uppermost portion of the tool **20** is shown. As seen there, the clutch means **38** are arranged to co-rotatively secure the mandrel **28** to the housing **29** when the mandrel is in either its lowermost or fully telescoped position or is in its uppermost or extended position relative to the housing. The clutch means **38** are comprised of an annular member **40** that is co-rotatively secured over the collar **30** on the upper end of the mandrel **28** and has one or more depending lugs **41** thereon adapted for reception in a corresponding number of upwardly facing longitudinal slots **42** in the upper end of the housing **29** whenever the mandrel is in its lowermost position relative thereto. A threaded ring **43** is threadedly secured to the collar **30** above the member **40** to retain the annular member in position as well as to facilitate its removal for disengaging the lugs **41** from the slots **42** after the tool **20** is removed from the well bore **25**.

The clutch means **38** are further comprised of an annular member **44** slidably mounted in the uppermost end of the housing **29** and co-rotatively secured thereto as by external longitudinal grooves adapted to receive complementary longitudinal splines **45** projecting inwardly from the internal wall of the housing. Stop means, such as an inwardly directed housing shoulder **46** above the annular member **44** and inwardly projecting screws **47** in the housing **29** that are received in longitudinal slots **48** in the annular member, are provided to limit the downward longitudinal travel of the annular member. External longitudinal splines **49** (FIG. 2A) on the mandrel **28** and immediately above an external shoulder **50** thereon are adapted for reception in complementary longitudinal spline grooves **51** (FIG. 3) in the internal wall of the annular member **44**.

Means, such as a spring **52** between the housing shoulder **46** and the upper end of the annular member **44**, are provided to normally urge the annular member downwardly against the lower stop **47** but permit it to retrogress should the mandrel splines **49** not be in registry with their complementary grooves **51** as the mandrel **28** is being moved upwardly. It will be understood, of course, that even though the mandrel splines **49** may not be initially in alignment with the spline grooves **51**, rotation of the mandrel **28** in either direction will quickly bring the splines into orientation with their grooves and the spring **52** will then urge the annular clutch member **44** downwardly over the splines.

Accordingly, it will be appreciated that so long as the mandrel **28** is in its extended position (as seen in FIGS. 2A–2D) with respect to the housing **29**, the mandrel is co-rotatively secured thereto by the clutch means **38**. Downward movement of the mandrel **28** into one of its intermediate positions with respect to the housing **29**, will, however, shift the mandrel splines **49** out of the spline grooves **51** and allow the mandrel to be rotated relative to the housing until the mandrel reaches its fully telescoped or lowermost position. The mandrel **28** will again be co-rotatively secured to the housing **29**, however, once it is moved to its lowermost position and the lugs **41** enter the slots **42**.

The position-establishing means **37** of the present invention are shown in FIG. 2A below the clutch means **38** as being comprised of radially expansible gripping means such as two segmented split-nuts **53** and **54** placed at longitudinally spaced positions in a housing recess or the annular clearance space **55** between the mandrel **28** and the housing **29**. As best seen in FIG. 4, means, such as longitudinal splines **56** on each of the segments of the nuts **53** and **54** and complementary interlocked in grooves **57** in the internal wall of the housing **29**, are provided to co-rotatively secure the split-nuts to the housing. As seen in FIG. 2A, to limit the longitudinal travel of the lower split-nut **54**, means, such as inwardly directed housing shoulders **58** and **59** above and below the nut, respectively, are provided. The upper split-nut **53** is held against longitudinal movement by an annular spacer **60** on top of the nut that is engaged with the housing **29** and an inwardly directed shoulder **61** below the nut.

Oppositely directed buttress threads **62** and **63** are appropriately spaced at longitudinal intervals around the mandrel **28** and respectively arranged for selective engagement with complementary threads in the nuts **53** and **54** in certain longitudinal positions of the mandrel. The upper mandrel threads **62** are faced upwardly and, in the tool **20** depicted in FIGS. 2A–2D, are preferably so-called "left-hand" threads arranged to threadedly engage the downwardly facing threads in the upper split-nut **53**. With this arrangement, downward longitudinal movement of the mandrel **28** will allow the upper mandrel threads **62** to be ratcheted freely into the upper split-nut **53** 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 **63** are faced downwardly and are so-called "right-hand" threads. To accommodate the lower mandrel threads **63**, the threads in the lower split-nut **54** are faced upwardly. Thus, release of the mandrel threads **63** from the lower split-nut **54** for downward movement of the mandrel **28** can be accomplished only by rotating the mandrel in a clockwise direction to unthread these members. It will be appreciated, of course, that by facing the mandrel threads **63** and those in the lower split-nut **54** in opposite directions, upward movement of the mandrel **28** 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 **63** are normally engaged with the lower split-nut **54** and the upper threads **62** are normally disengaged from the upper split-nut **53** and spaced a particular distance thereabove. Thus, with the lower mandrel threads **63** engaged with the lower split-nut **54** as shown in FIG. 2A, the mandrel **28** is free to travel longitudinally with respect to the housing **29** only so far as is permitted by the distance between the spaced housing shoulders **58** and **59** respectively above and below the lower split-nut. Similarly, as will also subsequently become apparent, whenever the upper mandrel threads **62** are threadedly engaged with the upper split-nut **53**, the mandrel **28** will be secured in its lowermost telescoped position and cannot be returned to its intermediate or extended positions since the upper split-nut is held by the spacer **60** and the co-engagement of the lugs **41** and slots **42** prevent further rotation of the mandrel with respect to the housing **29**. It will be recalled that the lugs **41** cannot be disengaged from the slots **42** until the tool **20** is returned to the surface and the threaded collar **43** is removed to permit disengagement of the clutch member **40**.

Turning now to FIG. 2B, the intermediate portion of the tool **20** is shown in which are located the pressure-biasing means **39** and the movement-retarding means **36**.

The pressure-biasing means **39** are comprised of an enlarged-diameter shoulder **64** on the mandrel **28** that is fluidly sealed, as by O-rings **65**, within a reduced-diameter portion **66** of the housing **29** above an external housing port **67** and an annular slidable piston member **68** that is around the mandrel above its enlarged-diameter shoulder **64** and below another external housing port **69**. O-rings **70** and **71**, respectively, inside and outside of the slidable piston **68** fluidly seal the piston to the mandrel **28** and housing **29** so as to provide a fluid-tight annular space **72** between the piston and the enlarged-diameter mandrel shoulder **64**, which space is normally at atmospheric pressure. A spring **73** between an inwardly directed housing shoulder **74** and the upper end of the piston **68** normally urges the piston downwardly against a shoulder **75** defined by the upper end of the reduced-diameter housing portion **66**.

It will be recognized that well control fluids will enter the ports **69** and **67** above the piston **68** and below the enlarged-diameter mandrel portion **64** as the tool **20** is being used. Inasmuch as the annular space **72** is normally at atmospheric pressure, the hydrostatic pressure of the well control fluids will therefore tend to lift the mandrel **28** 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 **64** itself. The cross-sectional area of the mandrel **28** itself will, of course, be subjected to both upwardly and downwardly acting pressure forces. Similarly, the piston **68** will be urged downwardly against the housing shoulder **75** by a force equal to the difference between the hydrostatic and atmospheric pressures multiplied by the annular cross-sectional area bounded by O-rings **65** and **71**.

Thus, it will be appreciated that since the mandrel **28** 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 **29**. Similarly, it will be appreciated that the downwardly acting pressure force on the piston **68** is effective through the housing shoulder **75** to impose a corresponding downwardly directed force thereon which will be transmitted through the housing to the mandrel **26** of the packer **23** (FIG. 1) to assist in keeping the packer seated.

Although the piston **68** could be made an integral portion of the housing **29**, it is preferred to make it a separate member as shown in FIG. 2B and to provide a small lateral port **76** in the housing immediately above the normal position of the external O-ring **71**. In this manner, should well control fluids leak into the enclosed annular space **72**, as the tool **20** is being removed from the well bore **25**, any excessive pressure in the enclosed space **72** will be vented through the port **76** whenever this trapped pressure is sufficient to lift the piston **68** against the restraint of the spring **73** a sufficient distance to move the O-ring **71** above the port **76**. This arrangement also insures that the mandrel **28** can be returned upwardly should fluids leak into the space **72** after the mandrel is lowered. Otherwise, the piston **68** could just as well be made an integral portion of the housing **29**.

The movement-retarding means **36** are comprised of a sleeve **77** loosely disposed between longitudinally spaced, enlarged-diameter portions **78** and **79** of the mandrel **28**, with only a limited annular clearance **80** being left between the mandrel and sleeve and a very minute annular clearance **81** being left between the sleeve and inner wall of the housing **29**. Means, such as a compression spring **82** between the sleeve **77** and the lower enlarged-diameter mandrel portion **79**, normally urge the sleeve upwardly against the upper enlarged-diameter mandrel portion **78**. An O-ring **83** (FIG. 2C) around the internal wall of an inwardly facing shoulder **84** in the housing **29** fluidly seals the mandrel **28** and housing relative to one another and defines a fluid-tight space **85** therebetween below the sleeve **77**. An annular piston **86** (FIG. 2B) having internal and external O-rings **87** and **88** is provided just below the housing port **67** to fluidly seal the housing **29** relative to the mandrel **28** and define a second fluid-tight space **89** therebetween above the sleeve **77**. In this manner, the separate fluid-tight spaces **85** and **89** are able to communicate with one another only by way of the annular clearance spaces **80** and **81** inside of and around the sleeve **77** respectively. A suitable hydraulic fluid, such as an oil or the like, fills the fluid-tight spaces **85** and **89**.

It will be appreciated that the hydrostatic pressure of the well control fluids will be effective through the port **67** against the piston **86** to maintain the oil in the spaces **85** and **89** at the same pressure. Accordingly, the speed of longitudinal movement of the mandrel **28** with respect to the housing **29** will be governed by the rate at which the oil can be displaced from one to the other of the fluid-tight spaces **85** and **89**. Downward movement of the mandrel **28** with respect to the housing **29** will, of course, maintain the lower face **90** of the upper enlarged-diameter mandrel portion **78** tightly engaged against the adjacent upper face **91** of the sleeve **77**. By appropriately machining the abutting surfaces **90** and **91** of the shoulder **78** and sleeve **77**, a metal-to-metal seat is effected to close the internal annular space **80** and make the minute external annular clearance space **81** the only flow path by which oil can be transferred from the lower space **85** to the upper space **89** as the mandrel **28** is moved downwardly. In this manner, the time required to move the mandrel **28** downwardly with respect to the housing **29** will be directly related to the dimensions of the external annular clearance space **81** and the viscosity of the oil in the fluid-tight spaces **85** and **89**. If it is desired, the lower space **85** may be slightly enlarged, as at **92**, so that whenever the mandrel **28** has moved downwardly at this controlled rate a predetermined distance with respect to the housing **29**, it can continue moving further downwardly with added relative freedom.

To permit fairly rapid upward movement of the mandrel **28** with respect to the housing **29**, the internal clearance space **80** between the sleeve **77** and mandrel is made somewhat larger than the external clearance space **81**. It will be understood, of course, that the spring **82** is not sufficiently strong to keep the sleeve end **91** abutted against its mating surface **90** on the shoulder **78** whenever the mandrel **28** is being moved upwardly. Thus, whenever the mandrel **28** is pulled upwardly with respect to the housing **29**, the sleeve **77** will shift slightly downwardly and move the seating surfaces **90** and **91** apart so as to allow oil from the upper space **89** to pass relatively free between these surfaces, through the larger annular clearance **80**, and on into the lower fluid-tight space **85**.

Turning now to FIGS. 2C and 2D, the lowermost portion of the tool **20** is shown in which are located the first and second valve means **34** and **35** (FIG. 2C). The internal diameter of this portion of the housing **29** is preferably increased to provide an enlarged bore, as at **93**, below the enclosed space **85** and above an upwardly directed housing shoulder **94** (FIG. 2D) near the lower end of the housing.

The first valve means **34** (FIG. 2C) are preferably arranged as a telescoping sleeve valve adapted to control fluid communication between the enlarged housing bore **93** and the internal bore **32** of the mandrel **28** so long as the second valve means **35** therebelow are closed. These first valve means **34** include a coaxially arranged tubular member **95** that is dependently secured within the housing **29** and extended downwardly into the enlarged housing bore **93**. Lateral ports **96** in the mandrel **28** are adapted to be moved into registry with corresponding lateral ports **97** in the coaxially arranged tubular member **95** whenever the mandrel is moved into one of its intermediate longitudinal positions with respect to the housing **29**. O-rings **98** and **99** respectively above and below the mandrel ports fluidly seal the mandrel **28** relative to the tubular member **95** to block flow through the ports **96** and **97** whenever they are not in registration in the other positions of the mandrel.

The second valve means **35** preferably include a spherical valve member **100** having an axial passageway **101** therethrough along one of its central axes that is sized to correspond at least approximately to the internal mandrel bore **32**. The ball member **100** is operatively disposed between a pair of opposed, longitudinally spaced, annular seats **102** and **103** having complementary spherical seating surfaces. One of the valve seats **102** is coaxially mounted in a complementary counterbore in the lowermost end of the mandrel **28** between a pair of depending longitudinal lugs **104** (only one seen) extending downwardly from the lower end of the mandrel **28** on opposite sides of the seat. The ball member **100** is pivotally supported between the free ends of these depending lugs **104** about another of its central axes by appropriately located transverse pivots **105** (only one seen) that are so positioned that the ball member will remain seated on the seat **102** as the ball moves between its open and closed positions. The axis of these pivots **105** is, of course, perpendicular to the central axis of the passageway **101** so that as the ball member **100** is pivoted, the passageway will move into and out of registration with the valve seat **102**.

The other valve seat **103** is coaxially mounted in an upwardly facing, complementary counterbore **106** in the upper end of an elongated tubular member **107** that is loosely disposed immediately below the ball member **100** in the enlarged housing bore **93** and fluidly sealed therein by an O-ring **108** around its upper end. The valve seat **103** is preferably supported in its receptive counterbore **106** by a spring **109** and fluidly sealed therein by an O-ring **110**.

A pair of upwardly extending lugs **111** and **112** (only one lug of each pair seen) are arranged on the upper end of the tubular member **107** opposite sides of the valve seat **103** to straddle the ball member **100**, with each of these lugs being laterally displaced from the central axis and extended upwardly alongside the opposite sides of the depending lugs **104**. Each associated set of the lugs **104**, **111** and **112** are so arranged that their opposed longitudinal edges, as at **113** and **114**, are in juxtaposition with one another. Inwardly projecting transverse pins **115** (only one seen) on the free ends of the lower lugs **111** are disposed parallel to the axis of the pivots **105** but longitudinally spaced therebelow and slightly offset to one side. The free ends of these pins **115** are each confined within fairly short, inclined grooves **116** (only one seen) formed in the adjacent external surfaces of the ball member **100**. It will be noted that the pivots **105** normally support the ball member **100** off of the lower seat **103** so as to leave an annular clearance, as at **117**, therebetween so long as the ball member is in its closed position as seen in FIG. 2C.

Accordingly, it will be appreciated that whenever the ball member **100** is moved toward the tubular member **107** and valve seat **103**, the ball will be pivoted by the pins **115** and slots **116** about its pivots **105** in a clockwise direction as seen in the drawings. It will be realized, of course, that the cooperative engagement of the juxtaposed edges **113** and **114** of the lugs **104**, **111** and **112** will prevent the mandrel **28** and the tubular member **107** from rotating relative to one another and limit their relative motion to rectilinear travel. The inclined grooves **116** must, of course, be of sufficient length to accommodate the transverse pins **115** whenever the ball member **100** has rotated midway between its fully-closed and its fully-open positions.

Biasing means are provided such as a compression spring **118** (FIG. 2D) that is disposed around the tubular member **107** between spaced, annular abutment members **119** and **120** slidably disposed thereon and supported by an external shoulder **121** on the lower end of the tubular member 107. An inwardly directed housing shoulder 122 is suitably located to normally engage the upper face of the upper abutment 119 whenever the tool 20 is in the position shown in FIGS. 2A–2D.

It will be noted that in this position of the tool 20, the lower face of the lower abutment 121 is spaced above the housing shoulder 94 a distance equal to the longitudinal spacing of the ports 96 and 97 when they are in the position shown in FIG. 2C. Similarly, this same longitudinal spacing is maintained between the upper face of the upper abutment 119 and the lower face 123 of an enlarged-diameter portion or shoulder 124 at the upper end of the tubular member 107. The shoulder 124 is, of course, suitably sized to pass freely through the annular housing shoulder 122. Moreover, for reasons that will subsequently become apparent, these longitudinal spacings are greater than and, preferably, about double the maximum longitudinal spacing between the upper face of the housing shoulder 59 and the lower face of the lower split-nut 54 (FIG. 2A) when this split-nut is engaged with the lower portion of the mandrel threads 63.

Accordingly, it will be appreciated that when the mandrel 28 is in its extended position with respect to the housing 29 as shown in FIGS. 2A–2D, both valve means 34 and 35 will be closed. However, by moving the mandrel 28 downwardly with respect to the housing 29 the above-mentioned longitudinal distance to one of its intermediate positions (to be subsequently described in greater detail), the first valve means 34 will be opened to provide fluid communication from the enlarged housing bore 93, through the clearance at 117 and the ports 96 and 97, and on into the central bore 32 of the mandrel 28. The second valve means 35 are, of course, still closed in this intermediate position of the mandrel 28. Similarly, as will be subsequently described with greater detail, further downward movement of the mandrel 28 (this same longitudinal distance) will reclose the first valve means 34 and open the second valve means 35 as the mandrel reaches its lowermost, telescoped position. In this latter position, a full-opening passage is provided through the tool 20 since the passageway 101 in the ball member 100 will have been rotated into alignment with the central mandrel bore 32.

Turning now to FIGS. 5A–5F, the tool 20 is schematically represented to illustrate each of its various positions during the course of a typical operating sequence. To facilitate the explanation of the positioning means 37 of the invention, the movement-retarding means 36 and biasing means 39 have not been shown in FIGS. 5A–5F. It will be understood, however, that downward travel of the mandrel 28 will be regulated by the movement-retarding means 36 until the top of the sleeve 77 has entered the enlarged space 92 (FIG. 2B). Similarly, it should be kept in mind that the biasing means 39 will be effective to provide an upwardly directed force on the mandrel 28 and to apply an equal, but downwardly directed, force on the housing 29 during the entire operation of the tool 20.

In FIG. 5A, the tool 20 is shown with the mandrel 28 being in its uppermost extended position with respect to the housing 29 as already described with reference to FIGS. 2A–2D. The first and second valve means 34 and 35 are closed to block fluid communication through the mandrel bore 32 as the tools 20–23 are moved into position in the cased well bore 25 (FIG. 1). It will also be noted from FIG. 5A that although the upper clutch member 40 is disengaged, the lower clutch member 44 is engaged to permit rotation to be applied from the tubing string 24, through the tool 20, and onto the other tools 21–23 therebelow. Accordingly, with the tool of the present invention secured in the position depicted in FIG. 5A, the tools 20–23 can be brought into position at any desired depth in the cased well bore 25.

Once the tools 20–23 have reached a desired position in the well bore 25, they are momentarily halted and the tubing string 24 is manipulated as required to set the packer 23 and close the bypass valve 21. Although other tools may utilize different movements for their operation, it is preferred to arrange the bypass valve 21 and packer 23 so that their respective 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 21 and 23 having cooperative J-slot systems arranged in this manner, the tubing string 24 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 24, the packer 23 will be set and the bypass valve 21 closed. It will be recalled that the mandrel 28 cannot move downwardly relative to the housing 29 until the upward force provided on the mandrel by the biasing means 39 is overcome.

Once the packer 23 is set, it will be appreciated that it is capable of supporting the full weight of the tools 20–22 and tubing string 24 thereabove. The housing 29 of the tool 20 will, of course, now be fixed relative to the casing 25 until the packer 23 is unseated. It will be recalled, moreover, that the biasing means 39 will also be effective to maintain a substantial downward force through the housing 29 to aid in holding the packer 23 seated. Thus, the mandrel 28 of the tool 20 will now be capable of being moved relative to the now-stationary housing 29 by corresponding motions of the tubing string 24 to bring the tool into its various operating positions.

Accordingly, as shown in FIG. 5B, application of weight to the mandrel 28 for setting the packer 23 will carry the mandrel a short distance downwardly (as shown by arrow 125) until the lower split-nut 54 engages the upwardly facing shoulder 59. This downward movement will, however, be retarded by the motion-retarding means 36 and furthermore will require sufficient weight on the mandrel 28 to at least overcome the upwardly directed force on the mandrel provided by the biasing means 39. It will be noted from FIG. 5B, however, that this initial downward travel of the mandrel 28 is not sufficient to open either of the valve means 34 and 35 and that the only significant change in the tool 20 will be to disengage the lower clutch member 44. Thus, by means of the positioning means 37 of the present invention, downward motion and rotation of the tubing string 24 in these first two operating positions of the tool 20 will be effective only to set the packer 23 and close the bypass valve 21 without introducing any risk whatsoever that either of the valve means 34 and 35 might be opened prematurely by overmovement of the mandrel 28.

It will also be appreciated from FIG. 5B that further downward travel of the mandrel 28 relative to the housing 29 is not possible so long as the lower nut 54 is abutted on the housing shoulder 59. On the other hand, upward travel of the mandrel 28 is unimpeded should, for example, it be necessary to re-engage the lower clutch member 44 to apply rotation from the tubing string 24 through the housing 29 to the tools 21–23.

Accordingly, in keeping with the principles of the present invention, to continue further downward travel of the mandrel 28, it is necessary to first unthread the lower mandrel threads 63 at least partway through the lower nut 54. It will be realized, of course, that unthreading rotation of the mandrel 28 would ordinarily tend to move the mandrel on downwardly and leave the lower split-nut 54 shouldered on its associated lower housing shoulder 59. It should be noted that, as a matter of operating technique, it is preferred to relieve some of the downward load on the mandrel 28 while rotating the tubing string 24. This is done by picking up the tubing string 24 somewhat but still leaving sufficient weight on the mandrel 28 to overcome the biasing means 39 which added weight will, of course, slowly overcome the movement-retarding means 36. Thus, a sufficient time is assured to allow the lower split-nut 54 to climb the mandrel threads **63** before the movement-retarding means **36** are overcome.

Accordingly, as best seen in FIG. 5C, rotation of the mandrel **28** in the appropriate direction (as shown by arrow **126**) in cooperation with the movement-retarding means **36** will instead cause the lower split-nut **54** of the present invention to climb the mandrel threads **63** and leave the mandrel in substantially the same longitudinal position as before. The nut **54** cannot, of course, rotate by virtue of the splines **56** (FIG. 4) but it will nevertheless climb the threads **63** as the mandrel **28** rotates relative to the split-nut.

Once the split-nut **54** reaches the upper limit of its travel as determined by the housing shoulder **58**, further rotation of the mandrel **28** will be ineffective and the lower split-nut will only alternately expand and contract within the recess **55** until the rotation is halted. It will be understood, of sourse, that the time delay provided by the movement-retarding means **36** should be sufficient to at least enable the lower nut **54** to climb the mandrel threads **63** to its next intended position thereon before significant downward travel of the mandrel **28** can occur. It will also be understood that to keep the lower nut **54** threadedly engaged, the height of this nut plus the effective length of the mandrel threads **63** must be at least equal to the spacing between the opposed housing shoulders **58** and **59**.

Once the lower nut **54** has engaged the upper shoulder **58**, the mandrel **28** will again be capable of traveling further downwardly to re-engage the split-nut on its associated lower shoulder **59**. The rate of this downward travel will, of course, still be governed by the movement-retarding means **36**. Thus, as best seen in FIG. 5D, once a sufficient length of time has elapsed, downward force (as shown by arrow **127**) on the mandrel **28** in excess of the opposing upward force of the biasing means **39** will serve to carry the mandrel downwardly until the lower split-nut **54** again engages the lower housing shoulder **59**. At this point, by appropriately spacing the ports **96** and **97** in relation to the vertical height of the nut **54** and the spacing between the opposed shoulders **58** and **59**, the ports of the first valve means **34** will be in registry whenever the lower nut **54** is shouldered on the lower shoulder **59** and is at its desired second position as, for example, at the top of the mandrel threads **63**.

It will be realized that the free clearance above and below the lower split-nut **54** between the housing shoulders **58** and **59** in relation to the length of the mandrel threads **63** will determine the number of discrete longitudinal positions that the mandrel **28** can be placed into with respect to the housing **29**. Thus, if desired, the mandrel threads **63** could be of sufficient length to require three, four, or even more distinct steps to move the mandrel **28** from its uppermost to its lowermost position. Similarly, the spacing between the shoulders **58** and **59** in relation to the height of the split-nut **54** will determine the incremental distance that the mandrel **28** moves downwardly during any given step. In this manner, as many discrete operating positions could be provided as circumstances might require so long as the split-nut **54** is engaged with the threads **63**. Moreover, positive surface indication is always assured inasmuch as the full weight of the tubing string **24** can be supported by resting the nut **54** on the shoulder **59** at the end of each incremental position change.

In any event, once the ports **96** and **97** are open, fluid communication will be established between the well bore **25** below the seated packer **23** and, by way of the intervening tools **21** and **22**, into the mandrel bore **32** and tubing string **24** thereabove. The ball valve means **35** will, however, remain closed. Thus, fluids may either be introduced from the tubing string **24**, through the ports **96** and **97** and the clearance **117**, and on into the well bore **25** below the packer **23** or received therefrom depending upon the nature of the completion or treating operation.

It should be realized that, if desired, the tubing string **24** can still be picked up a sufficient distance to first shoulder the lower nut **54** on its associated upper shoulder **58** (FIG. 5C) and then bring the mandrel **28** on up still further until the lower clutch member **44** is again reengaged (FIG. 5A). This latter movement is accomplished by ratcheting the mandrel threads **63** back through the lower nut **54**. It will be realized, however, that once the mandrel **28** is restored to its initial position (FIG. 5A), it cannot be returned to the position depicted in FIG. 5D without again going through the above-described intervening positions depicted in FIGS. 5B and 5C. Thus, the present invention further provides means for repetitively opening and closing of the first valve means **34** without inadvertently opening the second valve means **35**.

To open the second valve means **35**, it is, of course, necessary to move the mandrel **28** further downwardly than permitted by the engagement of the lower split-nut **54** (as now positioned on the threads **63**) with its associated lower shoulder **59** (FIG. 5D). Accordingly, as best seen in FIG. 5E, the mandrel is again rotated (as shown by arrow **128**), which rotation causes the lower split-nut **54** to climb still further up the mandrel threads **63** until it is completely disengaged therefrom. The movement-retarding means **36** will again serve to prevent corresponding downward travel of the mandrel **28** until at least sufficient time has elapsed for the lower nut **54** to disengage itself from the mandrel threads **63**. It will be understood, of course, that although the enlarged-diameter space **92** could be far enough up the housing **29** to deactivate the movement-retarding means **36** before the lower split-nut **54** is disengaged from the threads **63**, positioning this enlargement as shown in FIG. 2B will enable the lower split-nut to climb the lower mandrel threads without the co-engaging threads ever having to support the full weight of the tubing string **24**.

Once the lower mandrel threads **63** are freed from the lower split-nut **54**, the mandrel **28** is then free to travel on downwardly as permitted by the movement-retarding means **36**. Once the upper end of the sleeve **77** clears the enlarged-diameter housing portion **92**, the mandrel **28** will then move rapidly downwardly (as shown by arrow **129**) into the position depicted in FIG. 5F. This sudden movement will provide a substantial jar that is easily detected at the surface. As seen in FIG. 5F, movement of the mandrel **28** into this position will simultaneously co-engage the upper mandrel threads **62** with the upper split-nut **53**, move the mandrel ports **96** below the sleeve ports **97**, and pivot the ball member **100** (as shown by arrow **130**) into a position where its passageway **101** is coaxially aligned with the mandrel bore **32**. Then, if necessary, the tubing string **24** is rotated one or two rotations to insure engagement of the upper clutch member **40**. This will also provide a positive indication at the surface that the ball member **100** is open and that the mandrel **28** and housing **29** are co-rotatively secured.

It will be appreciated that to pivot the ball member **100** into its open position, the ball member must move downwardly relative to the tubular member **107** with sufficient force that the camming action of the transverse pins **115** in the slots **116** will rotate the ball member about its pivots **105**. This upward force is, of course, provided by the spring **118** which, as best seen in FIGS. 5D–5F, is progressively compressed until it develops a resisting force that is sufficient to rotate the ball member **100** against the frictional forces imposed by the upper valve seat **102**. Moreover, it will be realized that the spring **118** cannot develop an upwardly acting force until the lower abutment **120** has engaged the housing shoulder **94** as seen in FIGS. 5D and 5E. Then, as the mandrel **28** is moved further downwardly as seen in FIG. 5F, the spring **118** is progressively compressed to develop a correspondingly increasing upwardly directed bias through the upper abutment **119** to the shoulder **123** of the tubular member **107**.

Accordingly, as the downward force **129** on the mandrel

28 increases, downward movement of the tubular member 107 will be restrained by the force of the spring 118 as the shoulder 123 tends to move the abutment 119 below the housing shoulder 122. In some instances, the resulting force of the spring 118 will be sufficient to pivot the ball member 100 before the tubular member 107 moves downwardly far enough to shift the abutment 119 below the shoulder 122. However, to emphasize the function of the spring 118 in supplying the rotational bias to the ball member 100, the abutment 119 is shown slightly below the housing shoulder 122 in FIG. 5F. It will also be recognized that as the ball member 100 rotates, it will move slightly downwardly into seating engagement with the lower seat 103. Thus, once the ball member 100 is rotated, the seats 102 and 103 will be tightly seated around the opposite ends of the passage 101 to prevent entrance of fluids in the mandrel bore 32 into the enlarged space 93. It will also be noted that since the ports 96 and 97 are no longer in registration, solids or fluids in the mandrel bore 32 are similarly blocked from entering the enlarged space 93.

Once the tool 20 is in the position shown in FIG. 5F, the mandrel 28 will be prevented from traveling upwardly by the co-engagement of the upper mandrel threads 62 in the upper split-nut 53. Release of the threads 62 from the nut 53 could, of course, be accomplished by rotation of the mandrel 28 were it not for the engagement of the upper clutch member 40 which now prevents further rotation of the mandrel relative to the housing 29. Thus, once the mandrel 28 reaches its lowermost telescoped position shown in FIG. 5F, the tool 20 is locked in this position with the ball valve means 35 open and the sleeve valve means 34 closed. This will provide a substantially continuous and uninterrupted passage from the tubing string 24 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 20–23 must be retrieved to the surface in order to return the mandrel 28 to its original position. To do this, the upper clutch member 40 is quickly released by removing the threaded collar 43 and shifting the annular member upwardly to disengage the lugs 41 from the slots 42.

The annular spacer 60 is, of course, employed to prevent the mandrel 28 from being picked upwardly once the ball valve 100 is opened and the upper mandrel threads 62 have become engaged with the upper split-nut 53 as shown in FIG. 5F. It will be appreciated, therefore, that by omitting this spacer 60, the mandrel 28 could be moved upwardly a sufficient distance to disengage the lugs 41 from their receptive slots 42. This movement would, however, be insufficient to allow either the ball member 100 to be rotated back into its closed position or for the ports 96 and 97 to realign as shown in FIG. 5E so long as the mandrel 28 was not rotated. Yet, once the lugs 41 were free of their slots 42, the mandrel 28 could be rotated sufficiently to disengage the upper split-nut 53 from the mandrel threads 62 and permit the valve means 34 and 35 to be alternately opened and closed as many times as desired between the positions shown in FIGS. 5E and 5F. Moreover, with the spacer 60 omitted, once the mandrel 28 is rotated sufficiently to disengage the upper split-nut 53 from the upper mandrel threads 62, the mandrel could also be returned to any of the positions shown in FIGS. 5A–5D as well.

Omission of the spacer 60 is not too desirable, however, where the bypass valve 21 and packer 23 are of the types described above with reference to FIG. 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 24 by applying pressure to the well control fluids in the well annulus 25 and forcing these fluids up into the lower end of the tubing string and on upwardly therein. Access to the tubing string 24 is typically gained by either unseating the packer 23 or, as a last resort, opening the bypass valve 21 should the packer not be readily unseated. It will be realized, of course, that in either event, the ball valve means 35 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 24 usually must be at least partially rotated and then picked up with considerable force to either open the bypass valve 21 or unseat the packer 23. These motions could, therefore, serve to reclose the ball valve means 35 and prevent the desired flushing operation if either the packer 23 or bypass valve 21 were not completely free of foreign matter and readily movable. Thus, unless the packer 23 and bypass valve 21 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 60 so that the ball member 100 will unquestionably remain securely locked in its open position once the tool 20 is moved into the position depicted in FIG. 5F.

Turning now to FIG. 6, a partial view is shown of another tool 200 that is similar to the tool 20 in most respects and differs therefrom in only a few significant respects which differences are shown in the aforementioned copending application (22,429). As will subsequently become apparent, the tool 200 functions in substantially the same manner as the tool 20 except that the mandrel 201 in the tool 200 can be restored to its initial extended position relative to its associated housing 202 after a ball member therebelow (not shown in FIG. 6) similar to ball 100 in the tool 20 is opened and without reclosing the ball member.

To accomplish this, the tool 200 is not equipped with either an upper clutch member or an upper split-nut as are used with the tool 20. This, of course, will allow the mandrel 201 to be rotated relative to the housing 202 after the ball member (not shown) is opened. In addition, the mandrel 201 is somewhat longer than the mandrel 28 and is comprised of an upper section 203 that is releasably secured at its lower end by suitably arranged latch means 204 to the upper end of a lower mandrel section 205. As for the upper mandrel section 203, it is substantially like the mandrel 28 from its upper end down to a point just below that portion which engages O-ring 83 (FIG. 2C) when the mandrel 28 is in its elevated position. The other mandrel section 205 is substantially like the remainder of the mandrel 28 from a point just above the mandrel ports 96. Thus, in effect, the mandrel 201 can be considered like the mandrel 28 with the separated ends and latch means 204 being just above the mandrel ports 96. The housing 202 is substantially the same as housing 29 except that the housing 202 is somewhat longer to accommodate the latch means 204.

Generally speaking, the mandrel 201 functions in the same manner as the mandrel 28 to initially open the ports (corresponding to ports 96 and 97) which are not shown in FIG. 6 but are immediately below an O-ring (not shown but just below the shoulder 206) that fluidly seals the lower mandrel section 205 to the housing 202. Similarly, the ball member on below these ports is opened in the same manner as the ball member 100. Once the ball member is rotated to its open position, however, the latch means 204 are disengaged from the upper mandrel section 203 and now function to releasably receive the lower mandrel section 205 to the housing 202 so that the ball member will remain open and to allow the upper mandrel section 203 to be returned to its initial extended position. It will be realized that the lower split-nut (not shown in FIG. 6) and lower mandrel threads (not shown in FIG. 6) are arranged to permit the upper mandrel section 203 to be pulled upwardly without rotation.

Once the upper mandrel section is returned to its initial extended position, the lower clutch member (corresponding to member 44) re-engages the splines (corresponding to splines 49) to again co-rotatively secure the mandrel section 203 to the housing 202. In this manner, the tubing string 24 can again transmit torque through the tool 200 to operate the tools therebelow as, for example, would be necessary to reopen the bypass valve 21 and to unseat the packer 23 arranged as shown in FIG. 1. Once the tools 21–23 are operated as, for example, to reposition the tools and reset the packer, the mandrel section 203 can be reconnected by the latch means 204 to the lower mandrel section 205 to reclose the ball valve. It will be appreciated, of course, that the lower split-nut (corresponding to nut 54) will require the mandrel section 203 to be progressively lowered and rotated through the same sequence as previously described with reference to FIGS. 5A–5F before it can be relatched to the lower mandrel section 205.

The latch means 204 are arranged to accomplish the selective coupling of the lower mandrel section 205 to either the housing 202 or the upper mandrel section 203 as desired by telescopically fitting the lower portion of the upper mandrel section into the upper portion of the lower mandrel section. A shoulder or enlarged-diameter portion 207 on the upper mandrel section 203 abuts the upper end 208 of the lower mandrel section 205 so that when the mandrel sections are coupled together, downward loads can be transmitted to the lower section. The upper portion of the lower mandrel section 205 is provided with a number of circumferentially spaced lateral openings 209 which respectively receive a ball member 210. These ball members 210 are appropriately selected to have a diameter slightly greater than the wall thickness of that portion of the lower mandrel section 205 through which the lateral openings 209 are formed.

When the tool 200 is in the position shown in FIGS. 6–8, the immediately adjacent inner wall of the housing 202 is closely spaced from the outer surface of the lower mandrel section 205. Thus, each of the balls 210 will partially project radially inwardly toward the outer surface of the lower portion of the upper mandrel section 202 and each will be partially received in an adjacent recess 211 formed therein by a corresponding number of cords or flats 212 of limited height cut at circumferentially spaced intervals into the adjacent surface of the upper mandrel section.

Accordingly, as will be appreciated from FIGS. 6 and 8, the close fit of the mandrel sections 203 and 205 with one another and in the housing 202 will cause the balls 210 to latch the mandrel sections to one another so long as the flats 212 are opposite the openings 209 and prevent both relative rotation and longitudinal movement therebetween without hampering relative rotation or longitudinal movement of the mandrel 201 with respect to the housing. Thus, so long as the mandrel sections 203 and 205 are latched together, the mandrel 201 will operate as a unit in the same manner as mandrel 28. This will, of course, permit the mandrel 201 to be operated through the same sequence as the mandrel 28 as previously illustrated in FIGS. 5A–5E.

When the mandrel 201 is moved into the position corresponding to that shown for the mandrel 28 in FIG. 5F, the openings 209 and balls 210 are then adjacent to a circumferential groove 213 formed around the inner surface of the housing 202. Thus, by rotating the mandrel 201 clockwise, the upper mandrel section 203 will rotate relative to the lower mandrel section 205 and, as the full diameter of the upper mandrel section comes into registration with the openings 209, force the balls 210 radially outwardly and into partial reception in the circumferential groove 213. It will be appreciated that the upward force of the spring (as at 118) as well as the frictional restraint of the various O-rings on the lower mandrel section 205 with the housing 202 will be sufficient to permit the upper mandrel section 203 to be rotated relative thereto at this time. To limit their relative rotation, the abutting surfaces at 207 and 208 are cooperatively keyed to one another as by upwardly extending fingers 214 loosely received in much wider arcuate slots or recesses 215 (FIG. 7) in the shoulder 207. Thus, it will always be possible to recouple the mandrel sections 203 and 205 in the proper orientation to assure the proper cooperation of the flats 212 with the lateral openings 209.

Once the flats 212 are moved out of registration with the lateral openings 209, the lower mandrel section 205 will then be secured to the housing 202 by the balls 210. With the mandrel section 205 secured in this manner, the ball valve will be held open and the ports (neither shown in FIG. 6) will be closed (as in FIG. 5F) so that the upper mandrel section 203 can be returned to its initial elevated position. It will be appreciated that the upper mandrel section 203 is of an appropriate length that its lower portion that is telescoped into the lower section 205 will always be adjacent to the lateral openings 209 so as to hold the balls 210 outwardly and in place in the circumferential groove 213.

To recouple the mandrel sections 203 and 205, the upper mandrel section can be returned only by being manipulated through the same sequence as already described in relation to FIGS. 5A–5F. Once, however, the upper mandrel section 203 is again in its telescoped position, it is necessary only to rotate it in the reverse direction (counterclockwise) to re-engage the latch means 204, by bringing the flats 212 back into registration with the lateral openings 209 and balls 210. With the flats 212 again in position, upward movement of the upper mandrel section 203 will recouple it through the latch means 204 to the lower mandrel section 205 so that the ball valve can be reclosed and the mandrel 201 moved onto either its intermediate position or its upwardmost extended position.

Accordingly, it will be appreciated that the tool 200 can be operated through several sequences during a single trip into the well bore 25 rather than being limited to only a single sequence as is the case with the tool 20. This added flexibility provided by the latch means 204 will have primary utility where a given well bore requires a number of completion operations at different depths. It will be recognized, of course, that the tool 200 can be employed with any type of packer or bypass valve and is not limited in its operation as is the tool 20.

The tool 20 (either with or without the spacer 60) and the tool 200 as described to this point are capable of performing any completion or testing operation except for measuring so-called "downhole" or "bottom" pressures. Inasmuch as it is essential to have a full-opening bore through the tools, as at 32 in the tool 20, for most if not all completion operations, it is necessary to provide means for releasably securing pressure-measuring devices in or just below the tools 20 or 200 in such a manner that these devices can be selectively released and returned to the surface when a full-opening bore is needed. Heretofore, pressure-measuring devices have been releasably connected to full-opening tools as, for example, respectively shown on opposite sides of page 3057 of the aforementioned "Composite Catalog."

Although such tools as illustrated in the above-mentioned catalog have been successfully employed, there have been occasions where the releasable section (shown on the left of page 3057) is too long to freely pass through a "corkscrewed" tubing string. Similarly, the complexity of the releasing mechanism of this releasable section has been known to fail for one reason or another so that the entire tubing string and string of tools must be retrieved in order to release the center section.

Accordingly, selectively releasable barrier means, such as a pressure-measuring device 300, are shown in FIG. 9 which are free of the disadvantages mentioned above. Although the pressure-measuring device 300 is shown in position in the tool 20, it will be understood, of course, that this device could just as well be employed with the tool 200. These barrier means 300 are also fully described in the aforementioned copending application and are shown here only to illustrate another embodiment of a tool employing the position-establishing means **37** of the present invention.

As seen in FIG. 9, the pressure-measuring device **300** is comprised of a support body **301** connected to the upper end of one or more typical pressure recorders **302** therebelow. The pressure-measuring device **300** is supported below the ball member **100** by means such as two or more outwardly extending shoulders **303** on the body **301** that are adapted to rest on an upwardly facing tapered seat **304** formed in the internal bore of a tubular sub **305** appropriately connected to the threads **33** at the lower end of the housing **29**. It will be appreciated, of course, that the maximum transverse dimensions of the shoulders **303** must be at least slightly less than the internal diameter of either the ball member passage **101** or the mandrel bore **32** (FIGS. 2A–2C) to allow the pressure-measuring device **300** to pass freely therethrough as well as on through the tubing string **24**. Similarly, no portion of the pressure-measuring means **300** below the shoulders **303** can have a transverse dimension that would prevent its passage past the inwardly projecting seat **304**.

Accordingly, it will be appreciated that the pressure-measuring device **300** will be trapped between the ball member **100** and the seat **304** so long as the selectively operable blocking means or ball member is in its closed position. Inasmuch as the passage **101** is preferably the same diameter as the mandrel bore **32**, once the ball member **100** is in its open position, however, the pressure-measuring device **300** is no longer trapped below the ball member and can be returned to the surface, by, for example, applying pressure to the annulus fluids and "reverse circulating" them through the bypass valve **21** (or around the unseated packer **23**) and back up through the bottom of the tool **20**. Similarly, when either the spacer **60** (FIG. 2A) is not in the tool **20** or the tool **200** is employed, once the pressure-measuring device **300** is at the surface, it or other like devices could be returned through the tubing string **24** to the position shown in FIG. 9 and the ball member **100** reclosed to again trap the device.

It is preferred to extend the support body **301** upwardly and terminate it with suitable coupling means such as a fishing neck **306**. The upright body **301** is extended upwardly so that the fishing neck **306** will be near to but spaced just below the bottom surface of the ball member **100** when that member is in its lowermost position. This minimum separation limits the distance that the pressure-measuring device **300** can shift due to fluid flow so long as the ball member **100** is closed.

Accordingly, it will be appreciated that so long as the valve means **34** and **35** are closed, the pressure recorder or recorders **302** will be measuring the so-called "shut-in" pressure of the well. Moreover, whenever the ports **96** and **97** are opened (FIG. 5E), the recorder and recorders **302** will then measure the pressure of the well as it is flowing. Once the ball member **100** is opened, however, the pressure-measuring device **300** is free and can be returned to the surface through the ball passage **101** either by flowing well bore or formation fluids up through the tool **20** or by connecting suitable retrieving devices to the fishing neck **306** on the upright body member **301**. As already mentioned, it will be seen that once the pressure-measuring device **300** is removed from the tool **20** (or tool **200**), a continuous full-opening passage is provided to the well bore **15** below the packer **23** with the ball member **100** being opened to remove the only other barrier remaining therein.

Turning now to FIGS. 10 and 11A–11C, still another well tool **400** also employing the principles of the present invention is shown. This tool **400** is arranged to be employed as shown in FIG. 10 in conjunction with a string of full-bore tools **401–404** such as all of those shown on page 3057 of the aforementioned "Composite Catalog" to serve as a so-called "reverse-circulating valve." As is well known in the art, once a testing operation is com-

pleted, the tubing string, as at **405** in FIG. 10, will quite often contain inflammable formation fluids. To prevent spilling such fluids on the floor of the derrick or rig as the various portions or "stands" of the tubing string **405** are removed and thereby creating a possible fire hazard, it is usually preferred to flush these fluids out of the tubing string before the tubing string is retrieved. To accomplish this, the fluids in the well bore, as at **406**, are pressured and, by opening the tool **400** (or any other reverse-circulating valve), can be flowed back up through the tubing string **405** until all formation fluids are safely disposed of. Then, as the stands of the tubing string **405** are successively removed, whatever well bore fluids that are left in the tubing string will drain out of the still-open reverse-circulating valve and back into the well bore.

As already discussed, the number of manipulations required to operate some or all of the tools **401–404** may be so great that it is difficult to selectively operate others in the same string. It will be quite evident, for example, that it is not at all desirable to open the reverse-circulating valve **400** until after the tools **401–404** have performed a particular operation. Accordingly, the tool **400** of the present invention is so arranged that it cannot be inadvertently opened but yet does not require tedious manipulations to be opened when desired.

As seen in FIG. 10, the full-bore packer **404** is arranged at the lower end of the string of tools **400–403** for selectively packing-off the well bore **406**. The hydraulic holddown **403** and bypass valve **402** are also arranged in the same manner as their counterparts in FIG. 1. Connected at the upper end of the tools **402–404** is a testing tool **401** as shown on opposite sides of page 3057 of the 1960–61 "Composite Catalog of Field Equipment and Services." Although the tools **401–404** may be those shown in this catalog, other tools of a similar nature may, of course, be used in conjunction with the tool **400**.

Turning now to FIGS. 11A–11C, successive elevational views (partially in cross-section) are shown of the tool **400**. The tool **400** is comprised of a tubular mandrel **407** telescopically disposed within a tubular housing **408** and arranged for selective movement therein between an extended position as shown in FIGS. 11A–11C and a fully telescoped position. A coupling **409** on the upper end of the mandrel **407** is provided for coupling the tool **400** to the tubing string **405** (FIG. 10), with the central bore **410** (FIGS. 11A–11C) of the mandrel having substantially the same internal diameter as that of the tubing string. Similarly, threads **411** (FIG. 11C) on the lower end of the housing **408** are arranged for coupling the tool **400** to the other well tools **401–404** therebelow seen in FIG. 10.

In general, the tool **400** includes valve means **412** (FIG. 11C) that are selectively opened and closed by shifting the mandrel **407** between its two longitudinal positions with respect to the housing **408**. For establishing these longitudinal positions, clutch means **413** are associated with movement-retarding means **414** (FIG. 11B) and selectively operable positioning means **415** (FIG. 11A). Pressure-balancing means **416** (FIG. 11C) are provided to equalize pressure forces acting on the mandrel **407** and the housing **408**.

Turning now to FIG. 11A, the uppermost portion of the tool **400** is shown. As seen there, the clutch means **413** are arranged to permit free rotation of the mandrel **407** relative to the housing **408** when the mandrel is in its lowermost or telescoped position and to co-rotatively secure these two members when the mandrel is in its uppermost or extended position relative to the housing. The clutch means **413** are comprised of an inwardly projecting housing lug **417** that is confined in a slot **418** formed in the adjacent outer surface of an enlarged-diameter portion **419** of the mandrel **407** in a configuration that may be likened somewhat to a reversed "J." It will be appreciated, therefore, that with this configuration of the slot 418, the mandrel 407 will be secured in the position shown in FIGS. 11A–11C against downward movement relative to the housing 408 so long as the lug 417 is confined in the enclosed upper end of the shorter substantially vertical portion 420 of the J-slot. By picking up on the mandrel 407 sufficiently to bring the lower end of the shorter slot portions 420 up and into alignment with the stationary lug 417, the mandrel may then be turned counterclockwise through an arc sufficient to shift a short transverse or generally horizontal slot portion 421 across the housing lug and bring the lower end of a somewhat longer, substantially vertical portion 422 of the J-slot 418 into registration with the lug. Then, once the housing lug 417 is in the lower end of this longer portion 422 of the J-slot 418, the mandrel 407 is free to travel downwardly until it is halted by the engagement of the lug with a shoulder 423 such as that provided by the lower face of the coupling 409. It will be understood, of course, that the vertical distance between the upper end of the slot portion 420 and the shoulder 422 will be equal to the desired spacing between the two positions of the mandrel 407 in relation to the housing 408.

Although the various slot portions 420–422 may be substantially uniform in width, it is preferred to incline one side 424 of the slot portion 420 downwardly and toward the junction of the slot portions 421–422 in the manner depicted so that picking up of the mandrel 407 in conjunction with application of "left-hand" torque to the mandrel will quickly bring the lower end of the longer slot portion 422 over into alignment with the stationary housing lug 417. Similarly, when the mandrel 407 is being returned from its telescoped position to its extended position, the inclined surface 424 will be of assistance in assuring that the housing lug 417 enters the shorter enclosed slot portion 420.

It will be noted in FIG. 11A that the upper end of the longer slot portion 422 extends to the top of the enlarged mandrel portion 419 so that once the mandrel 407 reaches a position somewhat lower than its position shown in FIGS. 11A–11C, the housing lug 417 will no longer be confined within the J-slot 418. Thus, once the housing lug 417 is clear of the J-slot 418, the mandrel 407 can be freely rotated with respect to the housing 408 so long as it is in or near its fully telescoped position relative thereto.

Accordingly, it will be appreciated that so long as the mandrel 407 is in its extended position (as seen in FIGS. 11A–11C) in relation to the housing 408, the mandrel is co-rotatively secured thereto by the clutch means or J-slot arrangement 413. Downward movement of the mandrel 407 toward its telescoped position with respect to the housing 408 will, however, release the housing lug 417 from the J-slot 418 and allow the mandrel to be rotated relative to the housing.

The position-establishing means 415 shown in FIG. 11A are substantially similar to those previously described and are comprised of radially expansible gripping means such as a segmented split-nut 425 disposed in the annular clearance space 426 between the mandrel 407 and the housing 408. The split-nut 425 is co-rotatively secured to the housing 408 in the same manner as shown in FIG. 4 by external splines 427 on each of the segments that are slidably received in longitudinal grooves 428 formed in the internal wall of the housing. The grooves 428 extend from just above an inwardly directed housing shoulder 429 to a point somewhat below the housing lug 417. Accordingly, it will be appreciated that the split-nut 425 is free to travel longitudinally relative to the housing 408 between the shoulder 429 and the housing shoulder 430 as defined by the upper end of the spline grooves 428.

When the mandrel 407 is in its extended position as shown in FIGS. 11A–11C, downwardly facing buttress threads 431 on the mandrel are arranged to engage the upwardly directed threads in the split-nut 425 and support the nut a predetermined distance above the lower housing shoulder 429. Thus, so long as the split-nut 425 is threadedly engaged with the mandrel threads 431, the mandrel 407 can be moved longitudinally upwardly a distance equal to the spacing between the bottom of the housing lug 417 and the bottom of the grooves 420 and 421. Similarly, with the split-nut 425 in the position shown, the mandrel 407 can be moved downwardly a distance equal to the spacing between the bottom surface of the split-nut and the housing shoulder 429. It will be noted, however, that although the normal spacing between the split-nut 425 and the housing shoulder 429 is adequate to allow the mandrel 407 to move sufficiently to release the housing lug 417 from the J-slot 418, this spacing is not great enough to permit the mandrel shoulder 423 to move far enough downwardly to engage the top of the housing 408. Accordingly, the mandrel 407 cannot be moved to its fully telescoped position so long as the split-nut 425 is threadedly engaged with the mandrel threads 431.

For reasons that will subsequently become apparent, the mandrel threads 431 and the complementary threads in the split-nut 425 are preferably so-called "right-hand" threads so that clockwise rotation of the mandrel 407 (by way of the tubing string 405) will serve to unthread the mandrel threads on through the split-nut and release the mandrel therefrom. It should also be noted that although rotation is required to disengage the mandrel threads 431 from the split-nut 425, they can be readily re-engaged merely by picking the mandrel 407 straight upwardly to first shoulder the split-nut on the upper housing shoulder 430 and then allow the mandrel threads to ratchet freely back into the split-nut. It will be appreciated that at this time the housing lug 417 will be engaged with the bottom of the slot portion 421 to keep the mandrel threads 431 from ratcheting on through and out of threaded engagement with the split-nut 425.

So far as the tool 400 has been described, the mandrel 407 is substantially co-rotatively secured to the housing 407 until the mandrel is moved downwardly a sufficient distance to bring the housing lug 417 completely out of the J-slot 418. At this point, the mandrel 407 is free to rotate relative to the housing 408 but cannot move further downwardly to its fully telescoped position since the split-nut 425 is then engaged on the lower housing shoulder 429. Thus, once the mandrel 407 is in this intermediate position, it must be rotated sufficiently to disengage the mandrel threads 431 from the split-nut 425. Once the mandrel threads 431 are disengaged from the split-nut 425, however, the mandrel 407 is, of course, free to move on downwardly to its fully telescoped position in relation to the housing 408.

Turning now to FIG. 11B, the movement-retarding means 414 are seen. Inasmuch as the means 414 function in the same manner as those already described with respect to the tools 20 and 200, it is necessary only to point out that the speed of any downward travel of the mandrel 407 is regulated by the time required to displace a hydraulic fluid from the lower fluid-tight space 422 through the minute annular clearance 433 between a sleeve 434 and the housing 408 and into the upper fluid tight space 435 above the sleeve. As already explained with respect to the tools 20 and 200, flow through the slightly larger annular clearance 436 between the sleeve 434 and the mandrel 407 is blocked by the seating of the upper end of the sleeve with a seating surface provided by the lower face of a mandrel shoulder 437. Upward travel of the mandrel 407 is also not materially affected since the hydraulic fluid can return from the upper space 435 to the lower fluid-tight space 432 by way of both annular clearances 433 and 436. It should be noted that, if desired, the minute annular clearance 433 can be relieved by slightly enlarging the housing bore, as at 438, to speed the downward travel of the mandrel 407 once the nut **425** has been disengaged and the upper end of the sleeve **434** has reached the enlargement **438**.

Turning now to FIG. 11C, the lowermost portion of the tool **400** is shown in which are located the valve means **412** and the pressure-balancing means **416**. The internal diameter of this portion of the housing **408** is preferably increased to provide an enlarged bore, as at **439**, below the lower fluid-tight space **432**. O-rings **440** (FIG. 11B) and **441** (FIG. 11C) above and below the enlarged housing bore **439** fluidly seal the mandrel **407** in relation to the housing **408** and seal the opposite ends of the enlarged housing bore **439**.

The mandrel **407** is enlarged, as at **442**, and arranged to carry a suitable fluid seal **443** that is slidably engaged with the internal wall of the enlarged housing bore **439**. One or more lateral ports **444** are provided in the enlarged mandrel portion **442** just above the mandrel sealing member **443** to provide fluid communication between the mandrel bore **410** and that portion of the enlarged housing bore **439** between the sealing members **440** and **443**. Similarly, one or more lateral ports **445** are provided through the housing **408** at a point below the mandrel sealing member **443** and ports **444** when the mandrel **407** is in its normal extended position.

It will be appreciated that when the mandrel **407** is in its extended position as shown in FIGS. 11A–11C, the longitudinal spacing between the ports **444** and **445** is substantially equal to the longitudinal spacing between the closed upper end of the slot portion **420** and the shoulder **423** (FIG. 11A). Thus, whenever the mandrel 407, is in its normal extended position (as seen in FIGS. 11A–11C), the ports **444** and **445** are longitudinally spaced apart and the mandrel sealing member **443** blocks fluid communication between the ports to isolate the mandrel bore **410** from the exterior of the tool **400**. Similarly, the ports **444** and **445** are sufficiently spaced that so long as the split-nut **425** (FIG. 11A) is connected to the mandrel threads **431**, the engagement of the nut with the housing shoulder **429** will keep the sealing member **443** between the ports. Thus, the ports **444** and **445** cannot be placed into communication with one another until the mandrel threads **431** are disengaged from the split-nut **425** and the mandrel **407** is free to be moved into its fully telescoped position relative to the housing **408**.

Accordingly, it will be appreciated that with the tool **400** in the position depicted in FIGS. 11A–11C, fluid communication between the ports **444** and **445** is blocked by the sealing member **443**. Moreover, even though the mandrel **407** may be moved down to an intermediate position by the usual manipulations of the tubing string **405** during the course of actuating the tools **401–404**, the ports **444** and **445** are positively isolated from one another and cannot in any manner be placed into communication until the mandrel **407** is deliberately manipulated in a manner calculated to bring it into its fully telescoped position.

It will be realized, of course, from the preceding discussion that before the mandrel **407** can be moved into its fully telescoped position, it must first be manipulated to bring the housing lug **417** out of the J-slot **418**. Then, before the mandrel **407** can continue from this intermediate position (as determined by the shouldering of the split-nut **425** with the shoulder **429**) to its fully telescoped position, the mandrel must be rotated so as to release the mandrel threads **431** from the split-nut **425** and then lowered the remaining distance. However, even though the mandrel **407** can be freely rotated when it reaches this intermediate position, it cannot be moved further downwardly except as allowed by the movement-retarding means **414**. Thus, in the same manner as previously described with respect to the tools **20** and **200**, the movement-retarding means **414** will make it essential to maintain a downward force on the mandrel **407** for a predetermined time interval sufficient to overcome the movement-retarding means before the mandrel can reach its fully telescoped position.

Those skilled in the art will realize that unless the tool **400** is properly arranged, the mandrel **407** could be restrained, if not totally prevented, from moving relative to the housing **408** by unbalanced pressure forces imposed by the well bore fluids. Accordingly, to prevent this, the pressure-balancing means **416** are provided and include the O-ring **441** and the inwardly directed housing shoulder **446** carrying this sealing member. By making the annular cross-sectional area of this shoulder **446** equal to the external or full cross-sectional area of the mandrel **407**, it will be realized that when the mandrel is empty (as, for example, while the testing tool **401** is closed and the tools **400–404** are first being lowered into the well bore **406**), the forces from the hydrostatic pressure acting through the ports **445** on the shoulder **446** as well as those acting on the top and bottom of the housing **408** will be balanced with respect to one another. Thus, there is no unbalanced force that would otherwise tend to telescope the mandrel **407** or housing **408** or prevent their relative movement.

If particular details are desired of the arrangement of the tools shown in FIG. 10, a copending application Serial No. 423,021, filed January 4, 1965, now Patent No. 3,329,209, includes schematic drawings depicting the various J-slot arrangements of the tools **401**, **402** and **404**. The tool **401** may, of course, be similar to either that shown in the above-mentioned "Composite Catalog" or to that shown in the above-mentioned patent without affecting the operation of the tool **400** of the present invention. In either event, for the purpose of explaining the operation of the tool **400**, it will be assumed that the tools **401–404** are generally like those shown in the above-mentioned patent.

Accordingly, once the tools **400–404** are in position in the well bore **406**, the packer **404** is set and the bypass valve **402** closed by picking up slightly on the tubing string **405**, turning it slightly in a clockwise direction, and then slacking off the weight of the tubing string until the packer is fully set. Thereafter, the test valve (not shown in the present application) in the tool **401** may be opened and closed as desired by moving the tool **401** between its "testing" and "shut-in" positions shown in FIGS. 2 and 3 respectively of the above-mentioned patent. It will be appreciated that to this point, the tubing string **405** would not require a manipulation that could inadvertently unthread the split-nut **425** from the mandrel threads **431**. Thus, although the mandrel **407** may well be moved to its intermediate position as the tool **401** is moved from its "testing" position to its "shut-in" position, the tool **400** will not have been opened.

Once the tool **401** is in its "shut-in" position, it may be desired to open the tool **400** so as to "reverse-out" any formation fluids still in the tubing string **405**. To do this, the tubing string **405** is picked up, torqued to the left, and then lowered to free the housing lug **417** from the J-slot **418**. With this done, the mandrel **407** can now be rotated relative to the housing **408** which is now fixed relative to the well bore **406** by the seated packer **404**. Right-hand rotation of the tubing string **405** in concert with a downward force will maintain the testing tool **401** in its "shut-in" position and permit the mandrel **407** to be rotated. Inasmuch as the movement-retarding means **414** will slow downward travel of the mandrel **407**, the split-nut **425** will climb the mandrel threads **431** in the same fashion as in the tools **20** and **200**. Then, with the nut **425** free of the threads **431**, once the movement-retarding means **414** have been finally overcome, the mandrel **407** will move on into its fully telescoped position and the ports **444** and **445** will be in communication. If desired, the ports **444** and **445** can be reclosed merely by picking up on the tubing string **405** and returning the mandrel **407** to its initial extended position. In this event, the mandrel threads **431** will, of course, easily ratchet through the split-nut **425**.

Turning now to FIG. 12, a schematic representation similar to FIG. 5A is shown of a tool **500** that is arranged in the same way as the tool **20** but for the position-establishing means **501**. A comparison of FIGS. 5A and 12 will show that the position-establishing means **501** for the tool **500** are reversed from those shown for the tool **20** or **200**. As previously mentioned with respect to FIGS. 5A–5F, the movement-retarding means and biasing means are employed with the tool **500** but are not shown in FIG. 12.

As seen in FIG. 12, the tool **500** has a mandrel **502** that is disposed in a housing **503** for longitudinal movement between an extended position and a fully telescoped position as determined by the position-establishing means **501**. It will be seen, therefore, that except for the reversal of the elements comprising the position-establishing means **501**, the tool **500** is otherwise like the tool **20**.

The position-establishing means **501** include a pair of externally threaded members **504** and **505** that are secured at longitudinally spaced intervals around the mandrel **502**. The lower threaded member **504** is slidably mounted on the mandrel **502** for longitudinal movement thereon between spaced stop means such as outwardly directed, opposed shoulders **506** and **507**. Means such as splines and keyways (not shown in FIG. 12) are appropriately arranged to co-rotatively secure the threaded members **504** and **505** to the mandrel **502**. So that the threaded members **504** and **505** can expand into threaded engagement with longitudinally spaced internal threads **506** and **507** in the housing **503**, the threaded members are preferably segmented and provided with suitable biasing means (not shown in FIG. 12) to expand the threaded members normally outwardly.

Accordingly, it will be appreciated that the tool **500** will function in the same manner as the tool **20**. The position-establishing means **501** will require that the tool **500** be moved through the same sequence of operations shown in FIGS. 5A–5F for the tool **20**. Moreover, the same design criteria as presented in the explanation of the tool **20** and FIGS. 5A–5F will apply with equal significance to the tool **500**. Thus, it is not believed necessary to describe in detail the operation of the tool **500**.

Accordingly, it will be appreciated that the present invention has provided new and improved actuating means for selectively placing well tools into a plurality of distinctive operating positions with only a minimum number of different manipulations. By arranging the selectively operable gripping means on one of two relatively movable members of the tool in such a fashion that the one member can move between longitudinally spaced positions relative to the other, the two members can be placed into one or more positions relative to one another. Then, to move the members into still different longitudinally related positions, the motion-retarding means are provided to slow the movement of the one member until the gripping means are relocated with respect thereto. Thus, once the gripping means are relocated, the two members can now be moved relative to one another between one or more longitudinally spaced positions that differ from the other longitudinal positions by a degree proportional to the change in location of the gripping means.

As has been shown by the various embodiments above, the present invention will permit a tool to be positioned in any number of discrete operating positions, which positions may be used to open or close associated ports, move other members connected to the telescoped members, or release or reposition still other members releasably secured between the telescoped members.

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. In well bore apparatus: inner and outer telescoped members movable relative to one another in a first distinctive manner as well as movable in a second distinctive manner between spaced positions; means for gripping a first location on one of said members; stop means on the other of said members and cooperable with said gripping means when said members are in one of their said positions for preventing said members from moving therefrom in their said second manner to another of their said positions, said gripping means being movable from said first location to a second gripping location on said one member in response to movement of said members in their said first manner; and means for retarding movement of said members in their said second manner toward their said other position.

2. The apparatus of claim **1** further including: means operable by movement of said members into their said other spaced position.

3. The apparatus of claim **2** wherein said movement-operable means include selectively-operable valve means.

4. The apparatus of claim **3** further including: means for packing-off a well bore.

5. The apparatus of claim **2** wherein said gripping means are releasable from said second location in response to further movement of said members in their said first manner to permit said members to be moved from their said other position to a third position; and further including: means operable by movement of said members toward their said third position.

6. The apparatus of claim **5** wherein said inner member is tubular; and one of said movement-operable means are movable between a non-restricting position and a position restricting passage through said inner member; and further including: barrier means adapted for reception in said apparatus below said one movement-operable means and movable through said inner member after movement of said one movement-operable means to said non-restricting position.

7. The apparatus of claim **5** wherein said first and second-mentioned movement-operable means are respectively first and second valve means selectively operable by movement of said members in their said second distinctive manner, said first valve means being open in at least one of said first and second spaced positions, and said second valve means being open in at least one of said second and third spaced positions.

8. In well bore apparatus: inner and outer relatively-rotatable members movable relative to one another between longitudinally-spaced positions; means for releasably gripping one of said members at a first location; stop means on the other of said members adapted to engage said gripping means for preventing said members from moving from a first one of their said positions to a second one of their said positions, said gripping means being selectively movable to grip said one member at a second longitudinally-spaced location thereon in response to rotation of said members and retardation of longitudinal movement of said members from their said first position toward their said second position; and means for retarding longitudinal movement of said members toward their said second position.

9. The apparatus of claim **8** further including: valve means operable by longitudinal movement of said members into their said second spaced position.

10. The apparatus of claim **9** wherein said inner member is tubular; and further including: means on the upper end of one of said members adapted for connection to a tubing string; and packing means connected to the lower end of the other of said members and adapted for packing-off a well bore.

11. The apparatus of claim **10** wherein said packing means are adapted to pack-off a well bore before said members have reached their said second position; and said valve means are closed so long as said members are in their said first position and open whenever said members are in their said second position.

12. The apparatus of claim 9 wherein said gripping means are releasable from said second location on said one member in response to further rotation of said members to enable said members to move longitudinally to a third position; and further including: second valve means operable by said further longitudinal movement of said members toward their said third position.

13. The apparatus of claim 12 wherein said first-mentioned valve means are closed whenever said members are in one of their said first and second positions and open whenever said members are in the other of their said first and second position; and said second valve means are closed whenever said members are in one of their said three positions and open whenever said members are in one of the other of their said three positions.

14. The apparatus of claim 13 wherein said inner member is tubular; and further including: means on the upper end of one of said members adapted for connection to a tubing string; and packing means connected to the lower end of the other of said members and adapted for packing-off a well bore before either of said valve means are opened.

15. In well bore apparatus: a tubular housing; an inner member fluidly sealed in said housing, said inner member being rotatable relative to said housing and movable therein between longitudinally-spaced positions; position-establishing means including a plurality of threads on said inner member, a threaded nut between said housing and said inner member, means co-rotatively securing said nut to said housing without restricting longitudinal travel of said nut in relation thereto, said nut being threadedly engaged with a first portion of said threads whenever said inner member is in a first one of its said positions and movable along said threads to a second portion thereof in response to rotation of said inner member without significant longitudinal movement thereof in relation to said housing from its said first position toward a second one of its said positions, and stop means on said housing adapted for engagement with said nut and arranged for preventing said inner member from reaching its said second position until said nut has traveled to said second portion of said threads; and movement-retarding means between said inner member and said housing for delaying the longitudinal movement of said inner member toward its said second position until said nut has traveled to said second portion of said threads in response to rotation of said inner member.

16. The apparatus of claim 15 wherein said nut can be disengaged from said second portion of said threads after traveling thereto in response to further rotation of said inner member; and further including: second stop means on said housing adapted for engagement with said nut and arranged for preventing disengagement of said nut from said second portion of said threads once said nut has reached said second portion until said inner member is moved into its said second position and said nut is re-engaged with said first-mentioned stop means.

17. The apparatus of claim 16 further including: first means selectively operably by movement of said inner member to its said second position; and second means selectively operable by further longitudinal movement of said inner member to a third spaced position after said nut has been disengaged from said second portion of said threads by further rotation of said inner member while in its said second position.

18. In well bore apparatus: a tubular housing; an inner member fluidly sealed in said housing, said inner member being rotatable relative to said housing and movable therein between longitudinally-spaced positions; and position-establishing means including a plurality of threads around the inner bore of said outer member, an outwardly-expansible externally-threaded member between said housing and said inner member, means co-rotatively securing said threaded member to said inner member without restricting longitudinal travel of said threaded member in relation thereto, said threaded member being threadedly engaged with a first portion of said threads whenever said inner member is in a first one of its said positions and movable along said threads to a second portion thereof in response to rotation of said inner member without significant longitudinal movement of said inner member in relation to said housing from its said first position toward a second one of its said positions, and stop means on said inner member adapted for engagement with said threaded member and arranged for preventing said inner member from reaching its said second position until said threaded member has traveled to said second portion of said threads.

19. The apparatus of claim 18 further including: means selectively operable by movement of said inner member to its said second position.

20. The apparatus of claim 19 wherein said inner member is tubular and has a continuous bore therethrough adapted for communication with a string of pipe connected to its upper end; said selectively-operable means include valve means for controlling fluid communication into said continuous bore; and further including: packing means connected to the lower end of said housing and having means for providing fluid communication between said housing and the underside of said packing means, said packing means being adapted for packing-off a well bore upon movement of said inner member toward one of its said telescoped positions.

21. The apparatus of claim 20 wherein said valve means are closed until after said packing means are set; said threaded member can be disengaged from said second portion of said threads after traveling thereto in response to further rotation of said inner member; and further including: second stop means on said inner member adapted for engagement with said threaded member and arranged for preventing disengagement of said threaded member from said second portion of said threads once said threaded member has reached said second portion until said inner member is moved into its said second position and said threaded member is re-engaged with said first-mentioned stop means; and second valve means normally in one position whenever said inner member is in its said first and second position and selectively movable to another position by further longitudinal movement of said inner member to a third spaced position after said threaded member has been disengaged from said second portion of said threads by further rotation of said inner member while in its said second position.

22. The apparatus of claim 18 further including: movement-retarding means between said inner member and said housing for delaying the longitudinal movement of said inner member toward its said second position until said threaded member has traveled to said second portion of said threads in response to rotation of said inner member.

23. The apparatus of claim 22 wherein said threaded member can be disengaged from said second portion of said threads after traveling thereto in response to further rotation of said inner member; and further including: second stop means on said inner member adapted for engagement with said threaded member and arranged for preventing disengagement of said threaded member from said second portion of said threads once said threaded member has reached said second portion until said inner member is moved into its said second position and said threaded member is re-engaged with said first-mentioned stop means.

24. The apparatus of claim 23 further including: first means selectively operable by movement of said inner member to its said second position; and second means selectively operable by further longitudinal movement of said inner member to a third spaced position after said threaded member has been disengaged from said second portion of said threads by further rotation of said inner member while in its said second position.

25. A well tool adapted for connection to a string of pipe and comprising: inner and outer relatively-rotatable tubular members fluidly sealed together and longitudinally movable relative to one another between an extended position and progressively-telescoped positions; means for establishing the positions of said inner member with respect to said outer member including longitudinally-spaced opposed stop means in said outer member, a plurality of continuous external threads on said inner member, a nut threadedly engaged with said threads and confined between said opposed stop means, said nut having a longitudinal height that is less than the effective length of said threads, said opposed stop means being spaced apart a distance greater than said longitudinal height but less than the total of said effective thread length and said longitudinal height, and means co-rotatively securing said nut to said outer member without limiting longitudinal travel of said nut between said opposed stop means; means for retarding movement of said tubular members toward at least the first of their said telescoped positions without limiting their relative rotation; and valve means selectively operable by movement of said tubular members between their said first position and a second telescoped position.

26. The well tool of claim 25 wherein said valve means control fluid communication between the exterior of said outer member and the internal bore of said inner member.

27. The well tool of claim 25 wherein said valve means control fluid communication through the internal bore of said inner member.

28. The well tool of claim 25 wherein said effective thread length is less than said vertical spacing between said opposed stop means whereby movement of said inner member beyond its said second telescoped position is accomplished by disengaging said nut from said threads.

29. The well tool of claim 25 further including: barrier means releasably disposed in said tool and movable through said internal bore of said inner member; and means selectively operable between a position blocking such movement of said barrier means whenever said tubular members are in their said extended position and one of their said telescoped positions and another position not blocking movement of said barrier means through said inner member whenever said tubular members are in another of their said telescoped positions.

30. The well tool of claim 29 wherein said blocking means are in their said non-blocking position whenever said tubular members are beyond their said second telescoped position.

31. The well tool of claim 25 further including: second valve means selectively operable by movement of said tubular members between their said second telescoped position and a third telescoped position.

32. The well tool of claim 31 further including: packing means connected to the lower end of said outer member and having passage means for providing communication between said outer member and the lower end of said packing means, said packing means being adapted for packing-off a well bore upon movement of said tubular members toward their said first telescoped position and settable therewith before said retarding means have allowed said tubular members to reach their said first telescoped position.

33. The well tool of claim 31 wherein said first-mentioned valve means are open only when said tubular members are in their said second telescoped position; and said second valve means are open only when said tubular members are in their said third telescoped position.

34. The well tool of claim 33 wherein said first valve means include: a sleeve member having a first port therein and coaxially mounted within said outer member, said inner member having a second port therein movable into registration with said first port whenever said tubular members are in their said first telescoped position, and sealing means between said inner member and said sleeve member for blocking fluid communication between said ports whenever said ports are not in registration.

35. The well tool of claim 34 wherein said second valve means include: a ball member pivotally mounted on the lower end of said inner member and having a transverse passage therethrough, a valve seat coaxially mounted on said lower end of said inner member and receiving said ball member, and actuating means responsive to movement of said inner member toward its said second telescoped position for rotating said ball member on its said seat a flow-blocking position to a flow-communicating position where said transverse passage is aligned with the internal bore of said inner member.

36. The well tool of claim 35 further including: pressure-indicating means movable through said transverse passage in said ball member and said internal bore of said inner member normally disposed in said outer member below said ball member and removable therefrom whenever said ball member is in its said fluid-communicating position.

37. A well tool adapted for connection to a string of pipe and comprising: inner and outer relatively-rotatable tubular members fluidly sealed together and longitudinally movable relative to one another between an extended position and progressively-telescoped positions; means for establishing the position of said inner member with respect to said outer member including longitudinally-spaced opposed stop means on said inner member, a plurality of threads around the internal wall of said outer member, an outwardly-expansible externally-threaded member threadedly engaged with said threads and disposed around said inner member between said opposed stop means, said threaded member having a longitudinal height that is less than the effective length of said threads, said opposed stop means being spaced apart a distance greater than said longitudinal height but less than the total of said effective thread length and said longitudinal height, and means co-rotatively securing said threaded member to said inner member without limiting longitudinal travel of said threaded member between said opposed stop means; means for retarding movement of said tubular members towards at least the first of their said telescoped positions without limiting their relative rotation; and valve means selectively operable by movement of said tubular members between their said first position and a second telescoped position.

38. The well tool of claim 37 wherein said valve means control fluid communication through the internal bore of said inner member.

39. The well tool of claim 37 wherein said effective thread length is less than said vertical spacing between said opposed stop means whereby movement of said inner member beyond its said second telescoped position is accomplished by disengaging said threaded member from said threads.

40. The well tool of claim 37 further including: second valve means selectively operable by movement of said tubular members between their said second telescoped position and a third telescoped position.

41. The well tool of claim 40 wherein said first valve means include: a sleeve member having a first port therein and coaxially mounted within said outer member, said inner member having a second port therein movable into registration with said first port whenever said tubular members are in their said first telescoped position, and sealing means between said inner member and said sleeve member for blocking fluid communication between said ports whenever said ports are not in registration.

42. The well tool of claim 41 wherein said second valve means include: a ball member pivotally mounted on the lower end of said inner member and having a transverse passage therethrough, a valve seat coaxially mounted on said lower end of said inner member and receiving said ball member, and actuating means responsive to movement of said inner member toward its said second tele-

scoped position for rotating said ball member on its said seat from a flow-blocking position to a flow-communicating position where said transverse passage is aligned with the internal bore of said inner member.

43. Well bore apparatus comprising: a first member adapted for connection at its upper end to a string of pipe; a second member telescopically arranged at its upper end with the lower end of said first member, said first member being movable relative to said second member between longitudinally-spaced positions in response to corresponding movements of a string of pipe; first means selectively operable in response to longitudinal movement of said first member in one direction from one of its said spaced positions to another of its said spaced positions; a third member telescopicaly arranged at its upper end with the lower end of said second member, said second member being movable relative to said third member between longitudinally-spaced positions in response to corresponding movements of said second member; second means selectively operable in response to longitudinal movement of said second member in said one direction from one of its said spaced positions to another of its said spaced positions; anchoring means connected to said third member for securing said third member against movement in said one direction relative to a well bore; first position-establishing means between said first and second members selectively operable between one position for co-rotatively securing said first and second members to one another and another position for preventing longitudinal movement of said first member in said one direction to its said other spaced position; second position-establishing means between said second and third members selectively operable between one position for co-rotatively securing said second and third members to one another and another position for preventing longitudinal movement of said second member in said one direction to its said other spaced position; one of said position-establishing means including a plurality of threads on the inner one of those two said telescopically-arranged members, a threaded nut between said inner member and the outer one of those two said telescopically-arranged members, means co-rotatively securing said nut to said outer member without restricting longitudinal travel of said nut in relation thereto, said nut being threadedly engaged with a first portion of said threads whenever said inner member is in its said one spaced position and movable along said threads to a second portion thereof, stop means on said outer member adapted for engagement with said nut and arranged for preventing said inner member from reaching its said other spaced position until said nut has traveled to said second portion of said threads, and movement-retarding means between said inner and outer members for delaying the movement of said inner member in its said one direction toward its said other position until said nut has traveled to said second portion of said threads in response to rotation of said inner member.

44. Well bore apparatus comprising: a first member adapted for connection at its upper end to a string of pipe; a second member telescopically arranged at its upper end with the lower end of said first member, said first member being movable relative to said second member between longitudinally-spaced positions in response to corresponding movements of a string of pipe; first means selectively operable in response to longitudinal movement of said first member in one direction from one of its said spaced positions to another of its said spaced positions; a third member telescopically arranged at its upper end with the lower end of said second member, said second member being movable relative to said third member between longitudinally-spaced positions in response to corresponding movements of said second member; second means selectively operable in response to longitudinal movement of said second member in said one direction from one of its said spaced positions to another of its said spaced positions; anchoring means connected to said third member for securing said third member against movement in said one direction relative to a well bore; first position-estabishing means between said first and second members selectively operable between one position for co-rotatively securing said first and second members to one another and another position for preventing longitudinal movement of said first member in said one direction to its said other spaced position; second position-establishing means between said second and third members selectively operable between one position for co-rotatively securing said second and third members to one another and another position for preventing longitudinal movement of said second member in said one direction to its said other spaced position; one of said position-establishing means including a plurality of threads around the inner bore of the outer one of those two said telescopically-arranged members, an outward-expansible externally-threaded member between said outer member and the inner one of those two said telescopically-arranged members, means co-rotatively securing said threaded member to said inner member without restricting longitudinal travel of said threaded member in relation thereto, said threaded member being threadedly engaged with a first portion of said threads whenever said inner member is in a first one of its said positions and movable along said threads to a second portion thereof in response to rotation of said inner member, stop means on said inner member adapted for engagement with said threaded member and arranged for preventing said inner member from reaching its said second position until said threaded member has traveled to said second portion of said threads, and movement-retarding means between said inner and outer members for delaying the movement of said inner member in its said one direction toward its said other position until said threaded member has traveled to said second portion of said threads in response to rotation of said inner member.

45. A well tool comprising: inner and outer telescoped members arranged for relative movement; position-establishing means including threaded means for selectively coupling said telescoped members to one another in a first relative longitudinal position, said threaded coupling means being movable longitudinally upon multiple relative rotations between said telescoped members whereby said telescoped members are released for movement to a second relative longitudinal position; and means for retarding movement of said telescoped members toward their said second relative longitudinal position.

46. The well tool of claim **50** wherein said position-establishing means include: a threaded member having a longitudinal height and between said telescoped members; means co-rotatively securing said threaded member to one of said telescoped members without restricting longitudinal travel of said threaded member; threads on the other of said telescoped members threadedly engaged by said threaded member; and opposed first and second shoulders on said one telescoped member spaced apart a distance greater than said longitudinal height but less than the total of the effective length of said threads and said longitudinal height.

47. Well bore apparatus comprising: inner and outer relatively-rotatable members telescoped together and adapted for relative non-rotative movement between first, second and third longitudinally-spaced positions; selectively-operable means on said telescoped members inoperable by movement thereof between their said first and second positions and operable by movement thereof between their said second and third positions; position-establishing means including fixed stop means on said outer member, threads on said inner member, threaded stop means releasably coupled to said inner member by said threads and adapted to be carried thereby into engagement with said fixed stop means upon non-rotative movement of said telescoped members from their said first position to their said second position for preventing further movement thereof toward their said third position so long as said inner member is threadedly coupled to said threaded stop means, and means co-rotatively securing said threaded stop means to said outer member without limiting longitudinal travel relative thereto so that upon relative rotation between said telescoped members said threaded stop means will be selectively uncoupled from said threads to free said telescoped members for further movement from their said second position to their said third position; and movement-retarding means between said telescoped members for delaying significant longitudinal movement thereof from their said second position toward their said third position until said threaded stop means have been uncoupled from said threads by said rotation of said telescoped members.

48. The apparatus of claim **52** wherein said telescoped members are tubular members respectively having axial bores therethrough; said selectively-operable means including valve means operatively arranged on said inner member closing fluid communication between said axial bores so long as said telescoped members are in their said first and second positions and selectively-operable for opening such fluid communication upon said movement of said telescoped members from their said second position toward their said third position.

49. Well bore apparatus comprising: inner and outer relatively-rotatable members telescoped together and adapted for relative non-rotative movement between first, second and third longitudinally-spaced positions; first and second selectively-operable means on said telescoped members and respectively operated by non-rotative movements thereof between their said first and second positions and between their said second and third positions; position-establishing means including threads on said inner member, threaded stop means releasably carried on said inner member by said threads, fixed stop means on said outer member and engageable by said threaded stop means to prevent further movement of said telescoped members upon reaching their said second position toward their said third position so long as said inner member is threadedly coupled to said threaded stop means, and means co-rotatively securing said threaded stop means to said outer member without limiting longitudinal travel relative thereto so that only upon relative rotation between said telescoped members will said threaded stop means be selectively released from said threads to free said telescoped members for further movement from their said second position to their said third position; and movement-retarding means between said telescoped members for delaying significant longitudinal movement thereof from their said second position toward their said third position until said threaded stop means have been released from said threads by said rotation of said telescoped members.

50. The apparatus of claim **49** further including: first and second fluid passage means in said telescoped members; and wherein said selectively-operable means are first and second valve means operatively arranged for controlling fluid communication through said first and second passage means respectively in response to movements of said telescoped members between their said first and second spaced positions and between their said second and third spaced positions.

51. The apparatus of claim **50** further including second fixed stop means on said outer member and spatially disposed from said first-mentioned fixed stop means and engageable by said threaded stop means to halt said telescoped members in their said first position thereby defining a fixed span of movement of said telescoped members between their said first and second positions; and wherein said threaded stop means are radially-expansible and adapted for ratcheting back onto said threads upon longitudinal non-rotative relative movement of said telescoped members from their said third position to their said first position.

52. The apparatus of claim **49** wherein said telescoped members are tubular members respectively having axial bores therethrough; one of said selectively-operable means including first valve means movably on said inner member and responsive to longitudinal movements of said telescoped members between their said second position and one of their said first and third positions for selectively opening and closing fluid communication between their said axial bores; and the other of said selectively-operable means including passage means in said inner member for bypassing said first valve means, and second valve means responsive to movements of said telescoped members between their said second position and the other of their said first and third positions for selectively controlling fluid communication through said passage means.

53. The apparatus of claim **52** further including: means adapted for movement through said axial bore of said inner member and adapted to be releasably positioned in said apparatus below said first valve means and blocked from upward movement through said inner member so long as said first valve means are closed, said first valve means being adapted upon opening thereof for movement of said testing means through said axial bore of said inner member.

54. The apparatus of claim **52** wherein one of said telescoped members is adapted for connection at its upper end to a string of pipe disposed in a well bore; and further including well-packing means connected to the lower end of the other of said telescoped members and adapted for selectively packing-off a well bore in response to movement of said telescoped members.

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