

Oct. 15, 1968

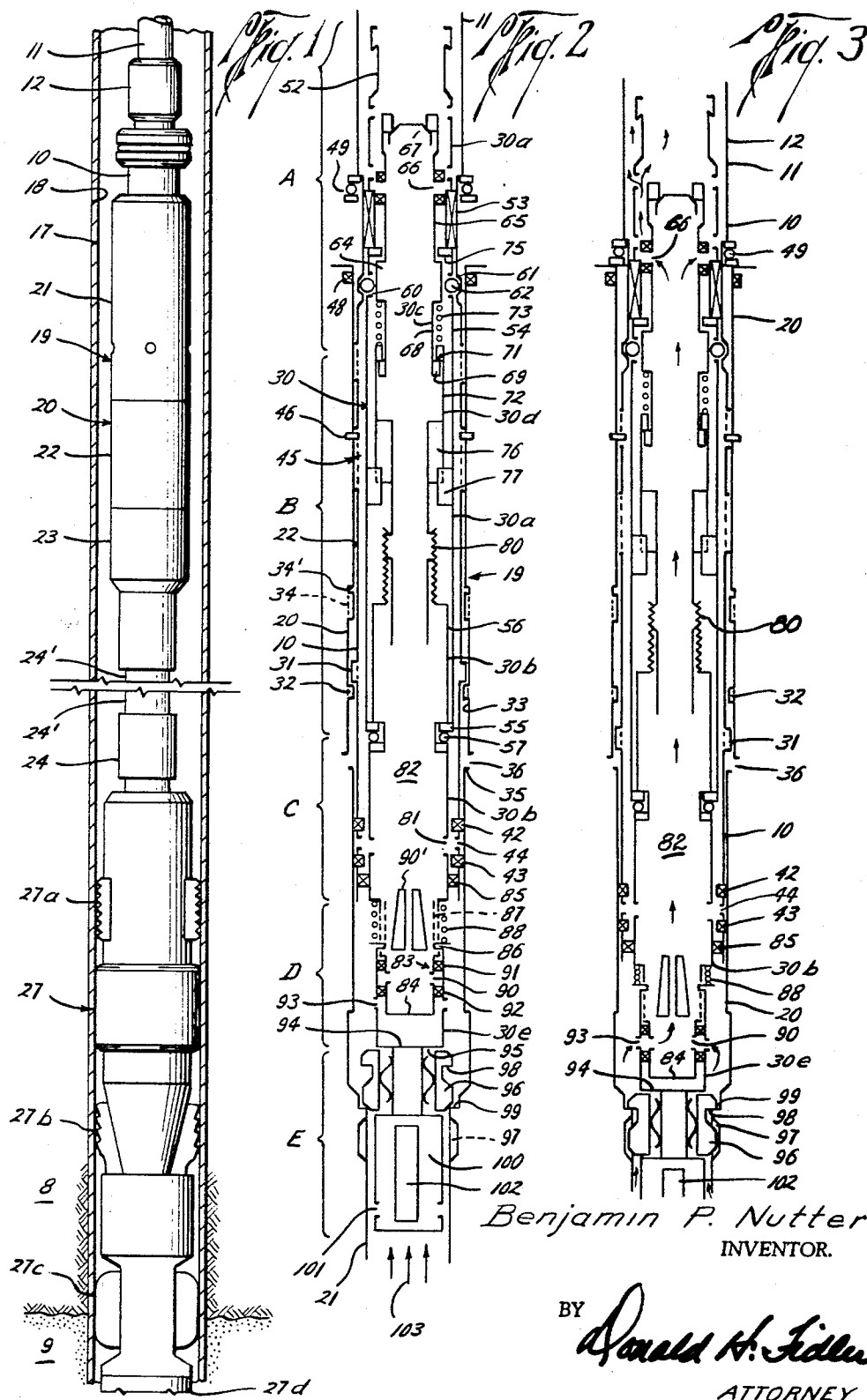
B. P. NUTTER

3,405,764

MULTIPLE PURPOSE WELL TOOLS

Original Filed Nov. 19, 1958

8 Sheets-Sheet 1



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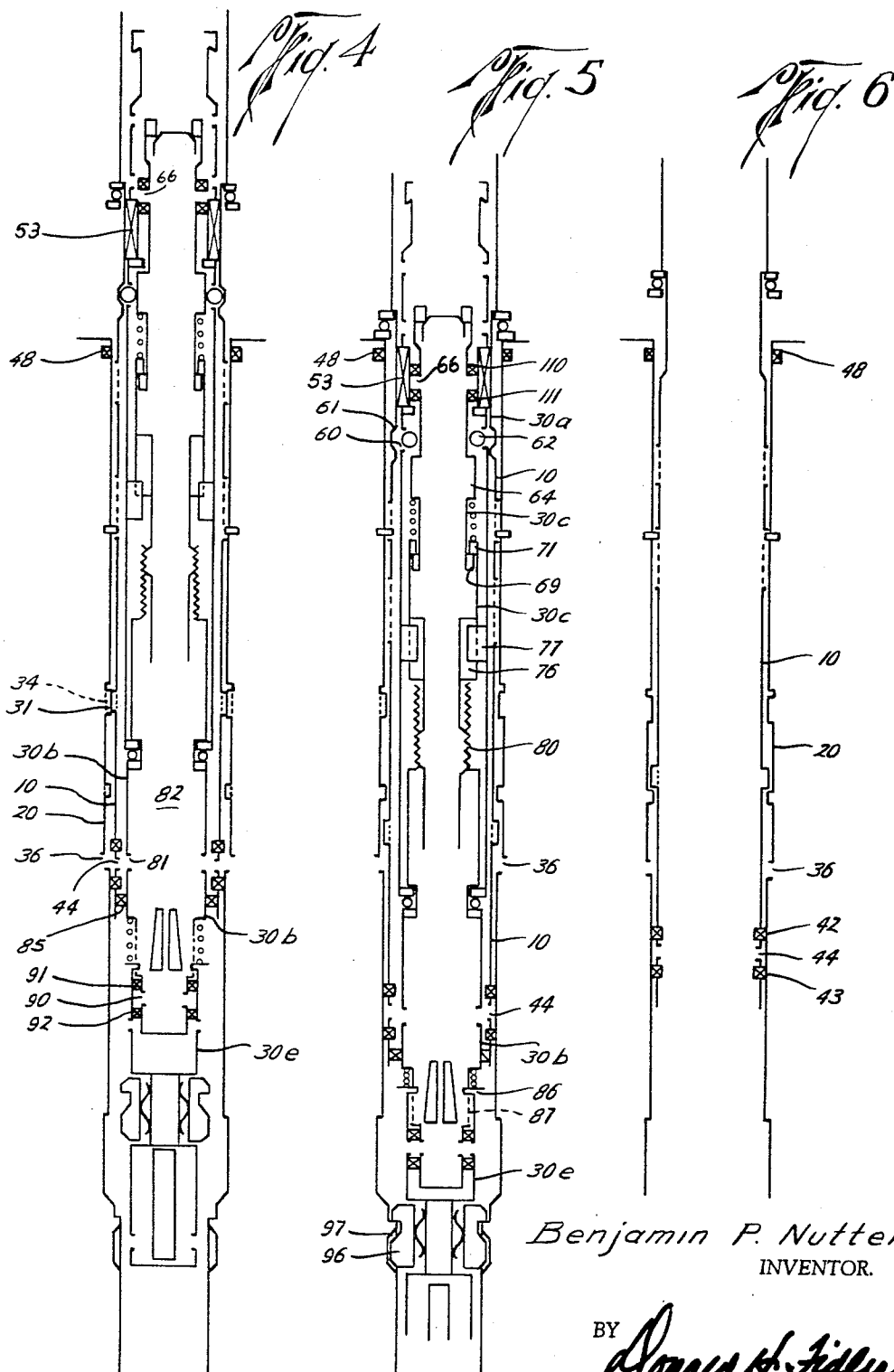
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8 Sheets-Sheet 2



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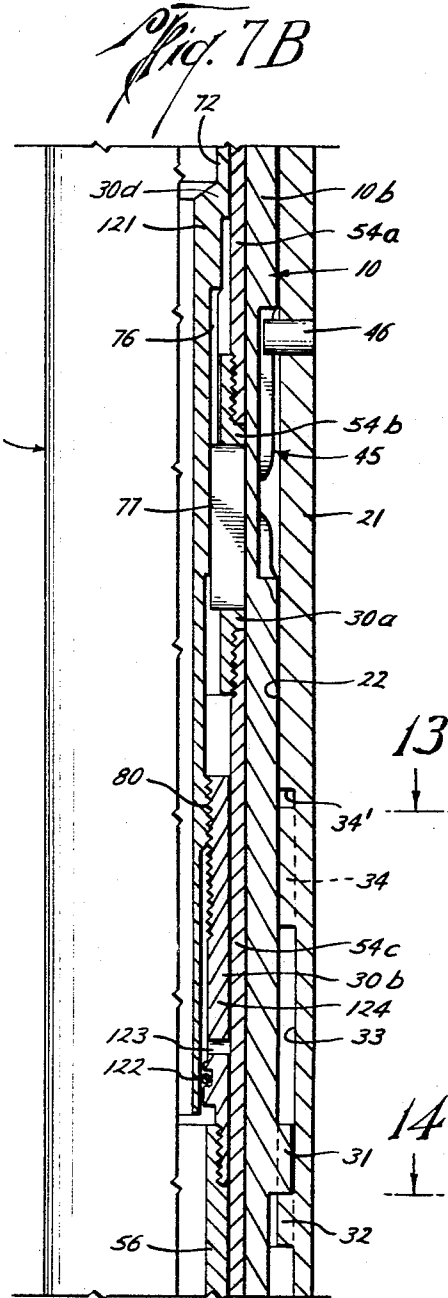
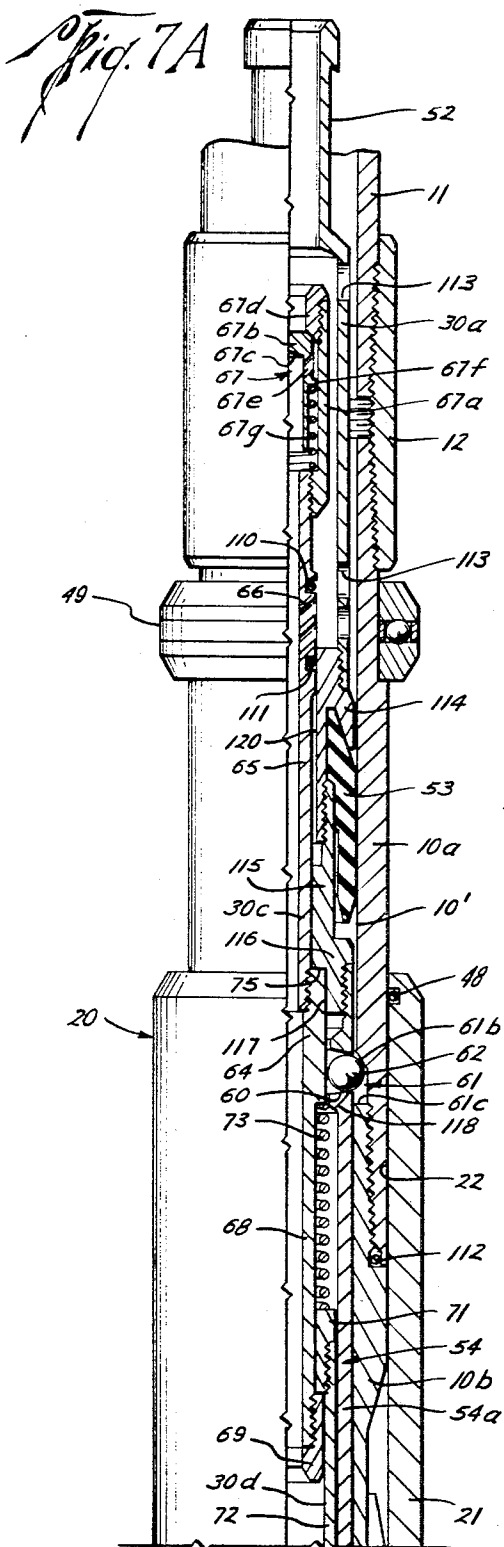
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MULTIPLE PURPOSE WELL TOOLS

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8 Sheets-Sheet 3



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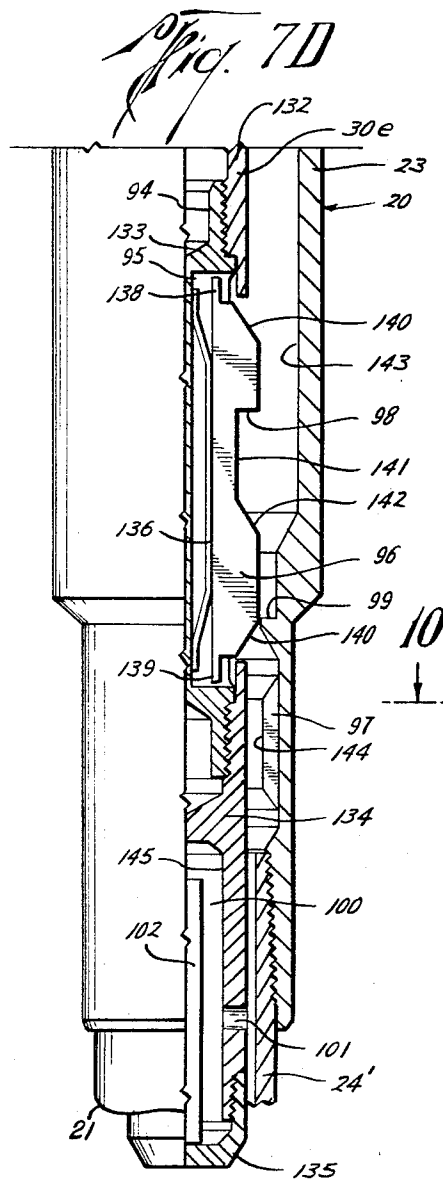
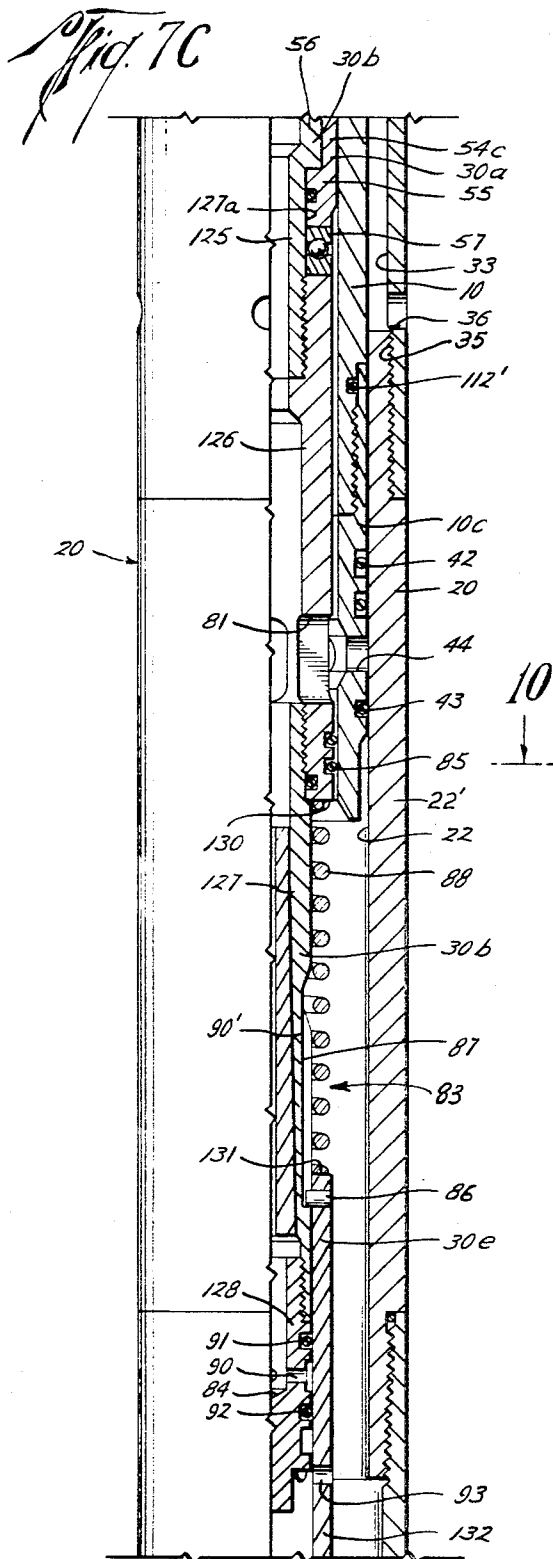
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8 Sheets-Sheet 4



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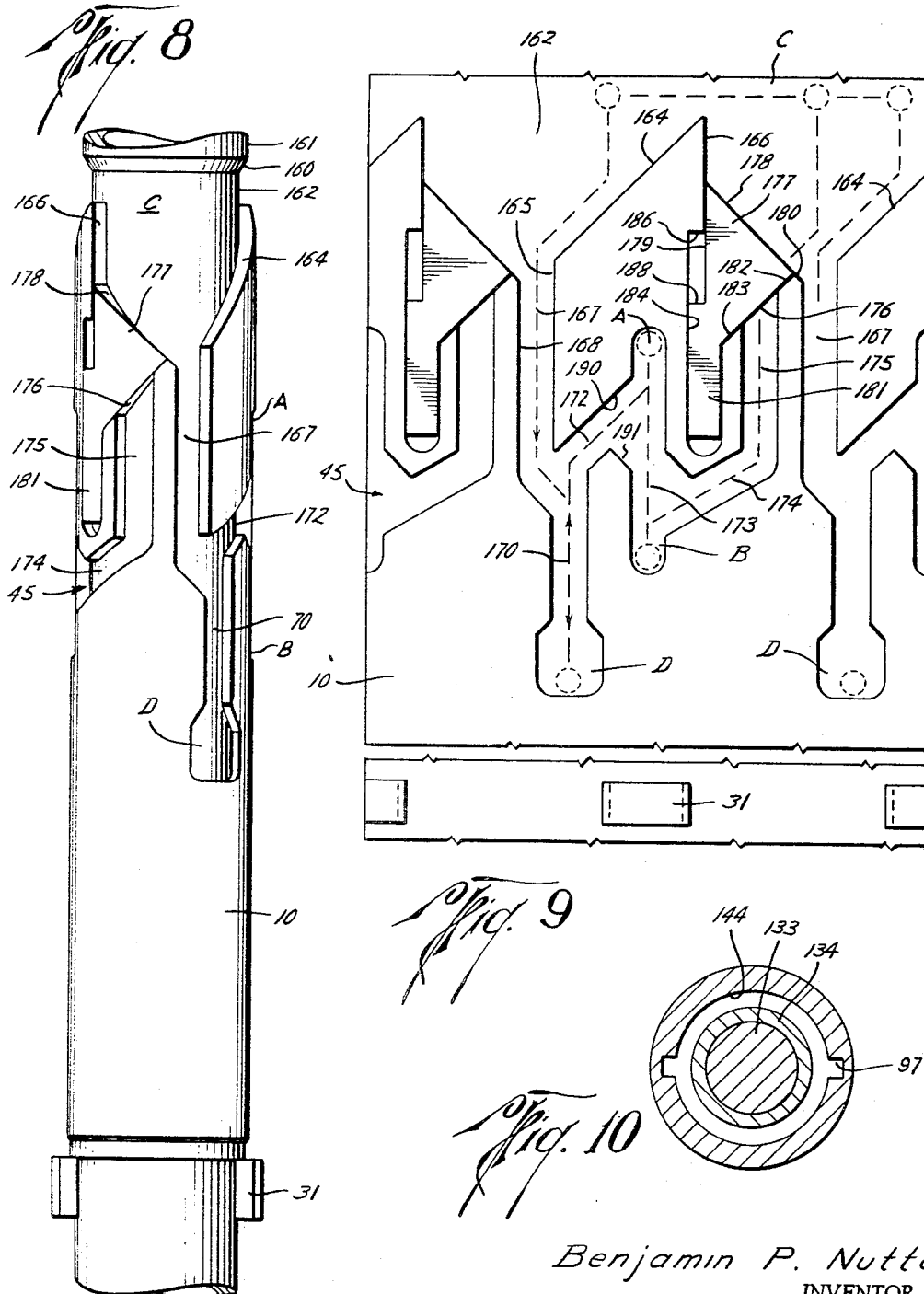
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MULTIPLE PURPOSE WELL TOOLS

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8 Sheets-Sheet 5



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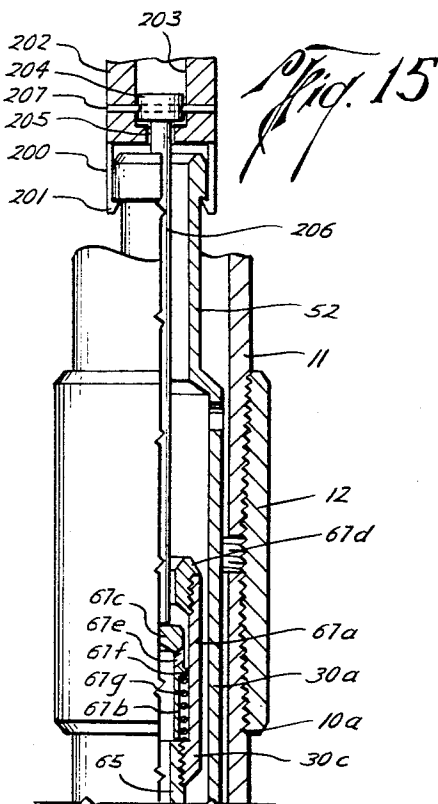
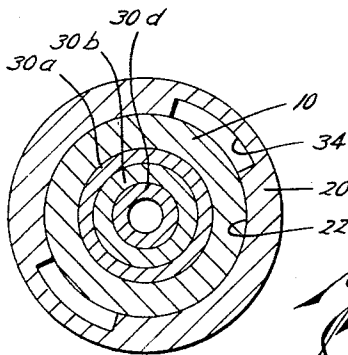
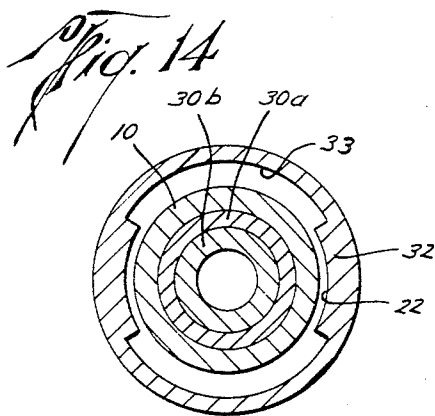
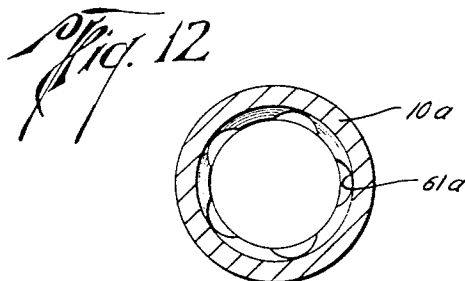
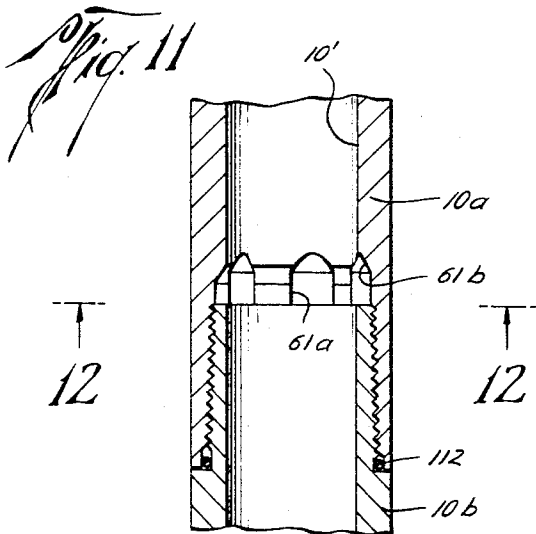
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MULTIPLE PURPOSE WELL TOOLS

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8 Sheets-Sheet 6



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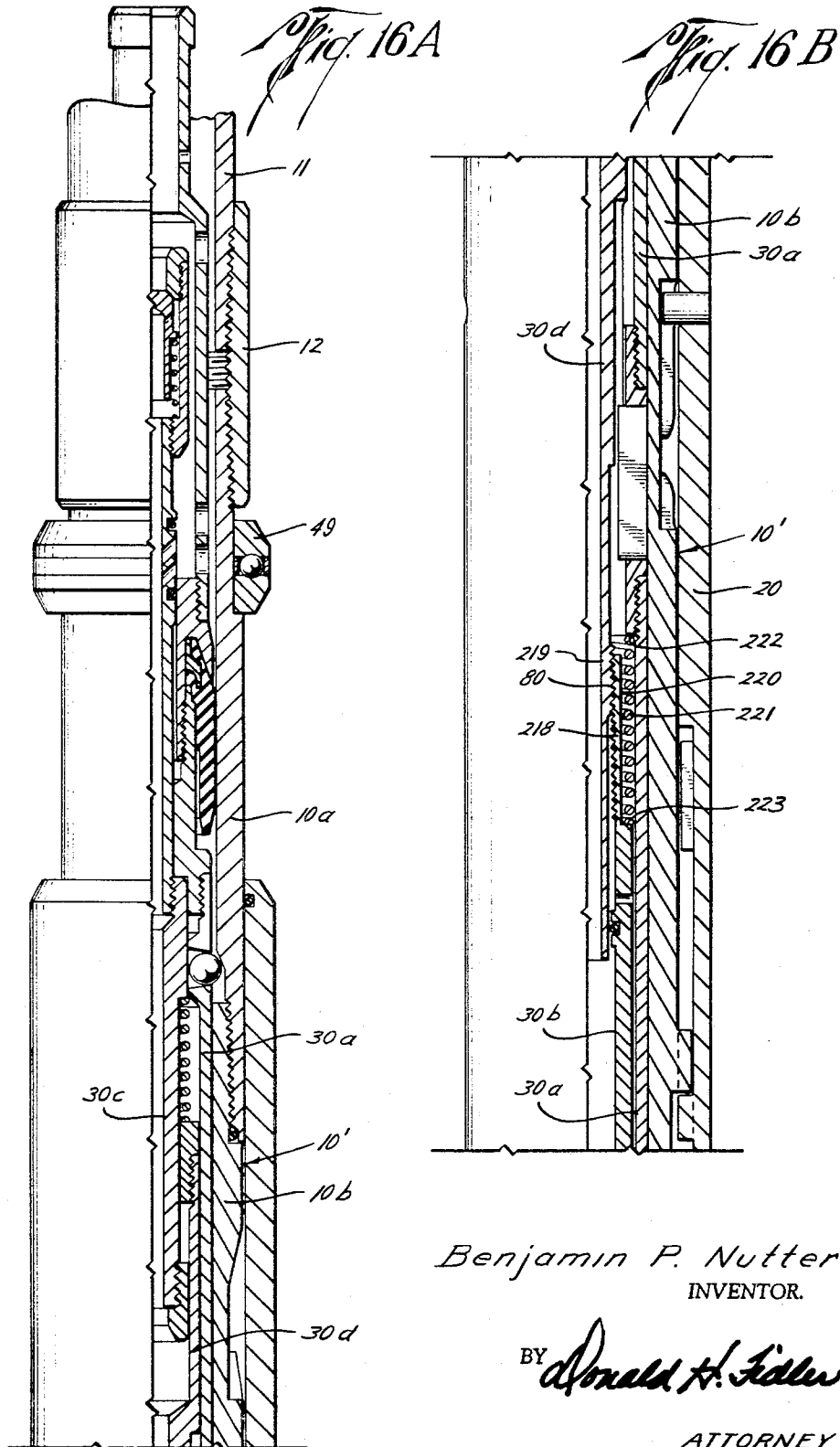
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MULTIPLE PURPOSE WELL TOOLS

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8 Sheets-Sheet 7



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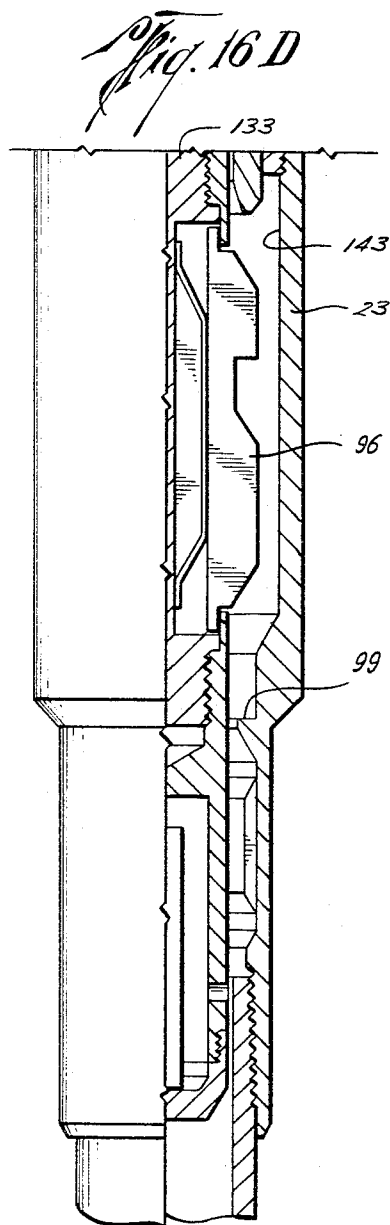
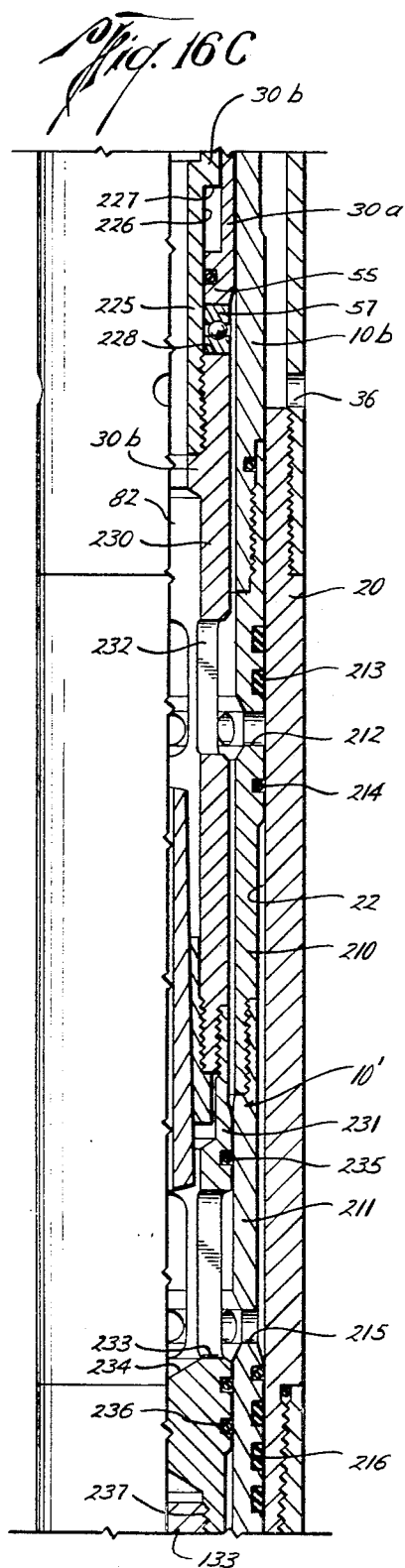
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MULTIPLE PURPOSE WELL TOOLS

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8 Sheets-Sheet 8



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1

3,405,764

MULTIPLE PURPOSE WELL TOOLS

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Continuation of application Ser. No. 775,002, Nov. 19, 1958. This application July 18, 1962, Ser. No. 213,565
39 Claims. (Cl. 166-145)

The present invention relates to well tools and, more particularly, to a multiple purpose well tool for performing a plurality of operations with only one insertion of the string of tubing which carries the tool into the well and which can remain in place when the well is put on production.

This application is a continuation of the applicant's copending application Ser. No. 775,002 filed Nov. 19, 1958, for "Multiple Purpose Well Tools," now abandoned.

It has heretofore been customary in performing various operations to employ a number of different tools, such as tools for perforating well casing, testing a formation under flowing or static conditions, squeeze cementing, acidizing, or fluid fracturing. To go from one operation to another, the drill stem or tubing string is generally removed from the well to permit a change of tools, and then the string is reinserted in the well. As the depth of drilled boreholes is increased, the number of round trips, that is, the number of times a well string is removed and reinserted in a borehole, becomes significant by virtue of the increased time required for making round trips. Hence, various individual operations necessary in testing, completion and remedial work result in increased costs.

It has therefore become increasingly desirable to perform multiple operations, where applicable, with a minimum number of round trips and preferably with only one trip into the borehole.

A multiple purpose well tool has been disclosed by J. L. Johnston et al. in Patent No. 2,760,581, issued Aug. 20, 1956. While the tool therein disclosed is quite satisfactory for many applications, it is often desirable to provide a variety of services and operations not readily available.

Exemplary services and operations which may be accomplished by a tool embodying the present invention are briefly outlined hereinafter. In a drill stem test: the tool may be inserted in a borehole containing fluid or in one without fluid; a packer below the tool is set and a pressure recorder in the tool obtains the initial shut-in pressure; the tool may then be opened to permit the well to produce and thereby to obtain a flow test; the tool may then be closed to obtain final shut-in pressure recording, and reverse circulation of well fluid may be accomplished either simultaneously with the obtaining of shut-in pressure or following the obtaining of shut-in pressure.

It will be seen from the above summary that all bottom hole pressures may be recorded. That is, the pressure chart will show the initial mud pressure, the initial shut-in pressure, flowing pressures, the final shut-in pressure and the final mud pressure.

After the drill stem testing operation, the pressure recorders, the bottom hole choke and central mandrel may be removed from the tool by wire line equipment, reverse circulation or flowing of well fluid. Removal of the central mandrel provides a full opening through the tool. Thus, a perforating gun may be lowered through the tool to perforate the casing. After perforation, hydraulic fracturing or acidizing may be accomplished through the full-opening tool. If it is desired, cement may be squeezed into the formation via the full-opening tool.

2

It will be apparent from the foregoing that a single tool allows testing, treating and squeezing operations.

Accordingly, an object of this invention is to provide a well tool whereby any or all of the above-enumerated operations may be carried out with only one insertion of a tubing string into the well.

Another object of this invention is to provide a multiple purpose well tool having a broader range of operations than heretofore possible.

Yet another object of this invention is to provide an improved multiple purpose tool in which circulation ports are included.

A further object of this invention is to provide an improved multiple purpose tool which is full-opening to permit lowering a gun perforator or other operational devices through the tool.

A still further object of this invention is to provide a multiple purpose well tool particularly suited for a sequence of test-treat-squeeze operations with only one insertion of a tubing string into the well.

These and other objects are obtained by a well tool including a tubular housing adapted to be connected to a packer which is set in a desired location in the well. An outer tubular mandrel assembly is slidably received within the housing for limited longitudinal movement therealong and is adapted to be connected to the lower end of a tubing string for movement therewith. An inner mandrel assembly including a fluid-tight plug portion is releasably locked within the outer mandrel assembly and when unlocked may be retrieved through the tubing string. In a first longitudinal position of the locked inner and outer mandrel assemblies relative to said housing, a fluid passage is provided to permit flow of test fluid from the formation through the interior of the housing below the inner mandrel assembly plug portion and through the interior of the mandrel assemblies to the tubing string thus permitting the well fluid to be sampled. In a second longitudinal position of the locked inner and outer mandrel assemblies relative to said housing, the fluid passage is closed preventing the flow of test fluid to the tubing string, thus shutting off fluid flow from the well. In a third longitudinal position of the locked inner and outer mandrel assemblies relative to said housing, a fluid passage is provided between the exterior of said housing above the plug portion of the outer mandrel assembly to the tubing string thus permitting reverse circulation of fluid in the tubing. The retrievable mandrel assembly may be unlocked and removed by wire line equipment leaving the housing and outer mandrel which may be manipulated so that a fluid passage therebetween provides a circulating valve to facilitate the handling of treating substances, and when the circulating valve is closed, to provide a fluid-tight passage for applying pressure to the substances. With the inner mandrel assembly removed, other tools, for example, a gun perforator may be passed through the body of the tool. The retrievable mandrel assembly may also be unlocked by rotation of the drill string which permits the assemblies to be removed by well fluid or by reverse circulation.

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

FIG. 1 is an elevational view of a multiple purpose tool embodying the present invention shown disposed together with a packer in a portion of a borehole;

FIG. 2 is a simplified schematic line representation of

the tool of FIG. 1 drawn to a reduced scale and arranged in a condition to obtain a shut-in pressure reading;

FIG. 3 is similar to FIG. 2 illustrating the arrangement of the tool in a testing condition;

FIG. 4 is similar to FIG. 2 illustrating the arrangement of the tool in a reverse circulating condition;

FIG. 5 is similar to FIG. 2 illustrating the arrangement of the tool prior to removal of the center mandrel assembly;

FIG. 6 is similar to FIG. 2 illustrating the arrangement of the tool with the center mandrel assembly removed;

FIGS. 7A, 7B, 7C and 7D are elevational views partly in longitudinal cross sections of successive portions of a well tool constructed in accordance with the principles of the present invention and arranged for insertion in a well bore;

FIG. 8 is a view of a portion of the outer mandrel assembly section of the tool shown in FIGS. 7A-7D;

FIG. 9 is a developed view of the index slot system in the outer mandrel assembly of FIG. 8;

FIG. 10 is a cross-sectional view taken along lines 10-10 of FIG. 7D in the direction of the arrows;

FIG. 11 is an elevational view in cross section of a portion of the tool housing illustrated in FIGS. 7A-7D;

FIG. 12 is a cross-sectional view taken along lines 12-12 of FIG. 11 in the direction of the arrows;

FIG. 13 is a cross-sectional view taken along lines 13-13 of FIG. 7B in the direction of the arrows;

FIG. 14 is a cross-sectional view taken along lines 14-14 of FIG. 7B in the direction of the arrows;

FIG. 15 is an elevational view of the upper end of the tool shown in FIGS. 7A-7D together with a retrieving device for the center mandrel assembly; and

FIGS. 16A-16D are elevational views partly in longitudinal cross sections of successive portions of a well tool featuring another embodiment of the present invention.

Referring now to the drawings, in FIG. 1, a well bore or borehole 18 having a conventional casing 17 is shown to traverse earth formations 8, 9. It is assumed in the following description that the formation 9 is the one to be tested.

A well tool 19 is suspended in the borehole at the lower end of a string of tubing 11 and connected to the lower end of the tool is a packer 27 which is arranged to seal off the annulus between the casing and the tool 19 while permitting fluid from formation 9 below the packer to enter the interior of the tubing string 11.

Tool 19 generally includes an outer mandrel 10 connected at its upper end to the string of pipe 11 telescopically arranged for limited longitudinal movement within a tubular housing 20 while the lower end of the housing 20 is arranged for connection with packer 27 by suitable couplings 24 and tubing extensions 24'.

The packer 27 does not form any part of the present invention; however, a full-opening packer, for example, of the type described in the copending application of B. P. Nutter, Ser. No. 774,910, filed Nov. 19, 1958, now Patent No. 3,020,959, and assigned to the same assignee as the present invention, is suitable for use with the tool. The packer described therein is provided with a full-opening central fluid passage with bypass valve means (not shown) to facilitate insertion in a well by passage of drilling fluid therethrough and is set by rotation of the string of tubing. Upper and lower slips 27a, 27b permit setting and holding of the packer in either direction against pressure differentials and conventional friction means 27c enables setting of the slips in the casing in a well-known manner. The lower end of the packer may be connected to perforated anchor tubing 27d which extends to the formation to be tested. In "going in" the borehole, well fluid or mud passes through the bypass ports in the well packer 27; however, at the desired testing level, the bypass ports are closed and packer 27 is expanded to seal off the annulus in the vicinity of the packer between the well tool and the wall of the casing 17.

Referring now to FIG. 2, well tool 19 is diagrammatically illustrated in the "closed" or "going in" position. Tubular housing 20 has a lower end 21 extending downward toward the packer 27 while the outer tubular mandrel 10 slidably received within the central bore 22 of housing 20 is connected at its upper end to the lower end of a string of tubing 11. A retrievable inner mandrel assembly 30 is releasably locked within bore 22 of outer mandrel 10 so that mandrel 10 and mandrel assembly 30 effectively operate as a unit until such time as the inner mandrel assembly 30 is released from outer mandrel 10.

Before describing the basic structure, it will be pointed out that the outer mandrel 10 has three basic manipulative positions relative to the housing assembly 20. These positions include: an intermediate or closed position (FIG. 2) where fluid is prevented from entering the interior of the tool and string of tubing 11; the lowermost or "testing" position (FIG. 3) where only the well fluid from the formation below the packer is permitted to flow into the housing interior at the lower end 21 to the interior of the tool and string of tubing 11; and the uppermost or "reverse circulation" position (FIG. 4) where only the fluid external of the housing above the packer is permitted to flow into the interior of the tool and the tubing 11. The lowermost or "testing" position (FIG. 3) also permits unlocking of the inner mandrel assembly 30 from the outer mandrel 10 by rotation of the outer mandrel (FIG. 5) which will hereinafter become more apparent.

Outer mandrel 10 is supported in the intermediate position (FIG. 2) by the abutment of external mandrel lugs or splines 31 with internal housing lugs or splines 32 (Section B). An enlarged bore 33 intermediate the length of the housing 20 provides a suitable recess to receive the outwardly extending splines 31 on mandrel 10 while housing splines 32 extend inwardly of the bore 33 to the diameter of the central bore 22 so as to slidably receive the mandrel 10 (FIG. 14). Above the upper end of enlarged bore 33 a pair of oppositely disposed spline grooves 34 (FIG. 13) extend longitudinally beyond the transverse end wall joining bores 22 and 33 to receive and rotatively lock mandrel splines 31 in the uppermost position of the mandrel. A downwardly facing shoulder 34' (FIG. 7B) at one end of grooves 34 engages splines 31 to limit upward movement thereof. Housing spline grooves 34 are angularly displaced approximately 30 degrees relative to housing splines 32 for reasons which will hereinafter become more apparent. The lower end surface 35 of enlarged bore 33 extends below lateral circulation ports 36 (FIG. 7C) which permit fluid ingress and egress between the exterior and interior of the housing. Thrust bearings 49 are secured to the upper end of the outer mandrel to engage the housing thereby to limit downward movement of the mandrel 10 and rotatively mount the mandrel relative to the housing.

To facilitate the positioning of the mandrel between the upper, lower and intermediate positions and to provide for the appropriate rotative orientation, mandrel splines 31, an indexing slot system 45 and index pins 46 are provided on the mandrel and housing, respectively. Index pins 46 are oppositely disposed in the housing 20 above grooves 34 and extend inwardly from the central bore 22 into the grooved indexing slot system 45 disposed circumferentially about the mandrel 10. The indexing system will be explained more completely with respect to FIGS. 8, 9 hereinafter.

Outer mandrel 10 has circulation ports 44 (FIG. 7C) arranged to be fluidly sealed when within central bore 22 by seals 42, 43 spaced above and below the ports while an upper sealing means 48, such as an O ring, is located between the central bore 22 near the top of the housing 20 and the outer surface of mandrel 10 to provide a fluid seal therebetween.

Turning now to the retrievable inner mandrel assembly 30 within outer mandrel 10, the assembly may be conveniently considered as comprising a locking section at A,

an unlocking section at B, a reverse circulation section at C, a testing section at D, and a keying section at E which also includes means for recording pressure.

The locking section at A includes a first tubular sub-assembly 30a having, in descending order, an upper tubular fishing head 52, an annular swab packer 53 and an upper tubular sleeve member 54 extending downwardly to a lowermost inwardly-directed flanged end 55. The lower portion of tubular member 54 above the flanged end 55 is rotatably received over the upper end 56 of a second tubular sub-assembly 30b (Section B). Ball bearing means 57 between sub-assemblies 30a and 30b rotatably secure the sub-assemblies relative to one another.

Locking means to lock sub-assembly 30a to the outer mandrel 10 include lateral frusto-conical openings 60 in member 54, internal circumferentially-spaced recesses 61 in outer mandrel 10 and ball members 62 received within openings 60 and sized so as to extend into internal recesses 61. Ball members 62 are retained in the recesses 61 by an enlarged portion 64 of a third tubular sub-assembly 30c slidably received within sub-assembly 30a. Above the enlarged portion 64 of sub-assembly 30c is a reduced diameter valve mandrel 65 having fluid ports 66 and a one-way check valve 67 while below the enlarged portion 64 is a reduced diameter locking sleeve 68 terminated by an enlarged outwardly-extending flange member 69. Slidably received on the lower locking sleeve 68 of sub-assembly 30c above the flanged member 69 is an inwardly-extending annular flange member 71 secured to the upper end 72 of a fourth tubular sub-assembly 30d in the form of a jackscrew mandrel. A compression spring 73 surrounds the lower locking sleeve 68 and is contained between the enlarged portion 64 and flanged member 71 to resiliently bias the enlarged portion 64 into abutment with a downwardly-facing shoulder 75 on tubular member 54 thereby to secure the balls 62 in the openings 60 and to hold sub-assemblies 30c and 30d in an extended position.

Sub-assembly 30d (Section B) has longitudinally-extending keyways 76 below the upper end 72 which receive keys 77 extending inwardly from and secured to tubular member 54. Sub-assemblies 30d and 30a therefore are co-rotatively secured together yet relative longitudinal movement therebetween is permitted whereby movement of interconnected sub-assemblies 30d and 30c in a downward direction can occur. The lower end of sub-assembly 30d is threadedly connected by a connection 80 within the upper end 56 of jackscrew housing sub-assembly 30b. Sub-assembly 30b is adapted to be secured against rotation in the lowermost position of the outer mandrel 10 so that upon rotation of sub-assemblies 30a and 30d relative to sub-assembly 30b, the sub-assembly 30d can be moved by the thread action of connection 80.

In Section C, the portion of sub-assembly 30b below the bearings 57 includes lateral inner circulation ports 81 aligned with outer ports 44 in mandrel 10 so that fluid may enter the interior 82 of the tool when ports 44, 81 are disposed adjacent to housing circulation ports 36 in an uppermost position of the mandrel. In Section D, sub-assembly 30b has a lower portion 83 of reduced diameter and a closed end 84. A seal means 85 such as an O ring fluidly seals sub-assembly 30b with respect to outer mandrel 10 below circulation ports 44, 81. The upper tubular end of a fifth sub-assembly 30e is telescopically received over the reduced tubular portion 83 and has inwardly-extending pins 86 which are slidably and co-rotatively received within longitudinally-extending grooves 87 in the portion 83. Pins 86 are resiliently biased to the lower closed ends of the grooves 87 by means of a compression spring 88 retained between oppositely-faced shouldered portions of sub-assemblies 30d and 30e. Below the grooves 87 in portion 83 of the sub-assembly 30b are lateral inner test ports 90 with O rings 91, 92, spaced above and below the ports 90 suitably sealing the sub-assembly 30b relative to the inner wall of sub-

assembly 30e. Below the O-ring seal 92, the sub-assembly 30e has outer test ports 93 and a hollow-ended portion 94 which is adapted to receive the lower closed end 84 of sub-assembly 30d when sub-assemblies 30b and 30e are telescoped together thereby placing inner ports 90 of sub-assembly 30b in fluid communication with outer ports 93 of sub-assembly 30e. Flow is then permitted through a choke bean 90' taper-fitted in sub-assembly 30b.

In the outer walls of sub-assembly 30e below the hollow-ended portion 94 are elongated rectangular recesses 95 which receive spring-biased flat-sided keys 96. Keys 95 are arranged to be received in elongated slots 97 in the housing 20 (FIG. 10) thereby preventing rotation of sub-assembly 30e when the mandrel 10 is in a lowermost position. Downward movement of the keys 96 is limited by engagement of a square shoulder 98 formed by a recess in the key with an inwardly-extending square shoulder 99 on the housing. Below keys 96 in sub-assembly 30e is a hollow chamber 100 having fluid access ports 101 and containing a conventional pressure recorder 102.

It will readily be apparent that in the position shown, the well fluid as indicated by the arrows 103 in the lower end 21 of the housing will enter ports 101 of chamber 100 to permit recording of hydrostatic pressure by means of the pressure recorder 102. Fluid bypassing the chamber 100 is prevented from flowing upwardly through the tool or to the interior 82 thereof by means of seals 92, 85, 43. Well fluid entering circulation port 36 is prevented from entering the interior 82 of the tool by seal 42 and from flowing between the housing 20 and outer mandrel 10.

To manipulate the outer mandrel 10 from the intermediate position of FIG. 2 to the lower testing position as shown in FIG. 3, the tubing 11 and mandrel 10 are raised, rotated and lowered which causes splines 31 on mandrel 10 to mesh with housing splines 32 and the mandrel to be lowered until thrust bearings 49 on the mandrel abut the upper end of the housing. Before the bearing 49 seats on the housing, the locking keys 96 at the lower end of member 30e enter slots 97 in the housing and the respective shoulders 98, 99 securing sub-assembly 30e against further downward movement so that the closed end 84 of sub-assembly 30b telescopes into the hollow-ended portion 94 of sub-assembly 30e placing test ports 90, 93 in alignment. Fluid flow may now pass through the aligned ports 90, 93 to the interior 82 of the mandrel and through ports 66 in sub-assembly 30c to the interior of the tubing 11. Seals 42, 43 and 85 fluidly seal the mandrel 10 and sub-assembly 30b thereby preventing any fluid flow externally of the housing to the interior 82 through housing ports 36.

After the flow test as shown in FIG. 3 has been taken, the mandrel 10 may be returned to the position shown in FIG. 2 to take a final shut-in pressure. As the mandrel 10 is moved upwardly the compression spring 88 between sub-assemblies 30b and 30e returns the sub-assemblies to their original position sealing inner test port 90 within sub-assembly 30e by seals 91, 92. The housing ports 36 remain sealed off by seal 42, while seals 43 and 85 seal off the interior 82 of the tool.

To reverse circulate the fluid sample collected in the tubing 11 to the surface of the earth, the outer mandrel 10 is raised to its uppermost position (FIG. 4) which causes mandrel splines 31 to mesh within the housing grooves 34. In the uppermost position the circulation ports 36, 44 and 81 are aligned to permit the fluid external of the housing 20 to be pumped through the ports to the interior 82 of the tool to the tubing 11. Seals 85 and 43 seal off the ports 81, 44 and 36 from fluid within the housing below the seals while inner test ports 90 in sub-assembly 30b are sealed off by seal means 91, 92 between sub-assemblies 30b and 30e. It will also be apparent that the shut-in pressure may be taken in this position simultaneously with the reverse circulation of the tool.

In one manner of release of the mandrel assembly 30

from mandrel 10, the mandrel is placed in its lowermost position in the housing 20 (FIG. 5) and rotated. The selector keys 96 in keyways 97 of the lower end of housing 20 secure sub-assembly 30e against rotation while pins 86 of sub-assembly 30e in grooves 87 of sub-assembly 30b secure sub-assembly 30b against rotation. The upper threaded end of sub-assembly 30b at 80 is therefore secured against rotation. Outer mandrel 10 and sub-assembly 30a are locked together by ball members 62 (FIG. 2) while sub-assembly 30a is co-rotatively secured to sub-assembly 30d by keys 77 and keyways 76 so that sub-assembly 30d at the threaded connection 80 may be rotated causing the sub-assembly 30c to be moved downwardly. Flanges 71 on sub-assembly 30d cooperate with flanges 69 on sub-assembly 30c to move the sub-assembly 30c downwardly. Seals 110, 111 above and below ports 66 of sub-assembly 30b are fluidly sealed within swab packer 47 upon downward movement. The enlarged portion 64 of sub-assembly 30c moves by openings 60 thereby releasing ball members 62 from the recesses 61. Release of the ball member 62 unlocks the sub-assembly 30a of assembly 30 from outer mandrel 10. Manipulation of the mandrel 10 to its uppermost position permits fluid to be pumped under pressure through circulation ports 36 of the housing 20 to act upon swab packer 53 thereby urging the inner mandrel assembly 30 upward through the tubing 11.

Alternatively, the inner mandrel assembly 30 may be removed by unlocking the ball members 62 as above described and permitting the well fluid 103 to act on the swab packer 53 to raise the center assembly 30 through the tubing 11.

Another alternative removal procedure for the mandrel assembly 30 may include the use of a fishing tool lowered through tubing 11 to grasp fishing head 52 and remove the center assembly 30 by means of the wire line. The fishing tool also can have a member arranged to move sub-assembly 30c downward to unlock the balls 62 without requiring rotation of the sub-assemblies as will be more apparent hereinafter.

After the inner mandrel assembly 30 has been removed the outer mandrel 10 and housing provide a circulation valve with ports 36, 44 which may be opened or closed to permit reverse circulation of fluid or fluid materials through the tubing in any of the desired well completion techniques of acidizing, cementing or the like.

The construction of the apparatus just described is shown in detail in FIGS. 7A-7D. As seen in FIG. 7A, outer mandrel 10 has a connection through a threaded coupling 12 to the string of tubing 11. Housing 20 includes a top sub 21 (FIGS. 7A-7C), an intermediate sub 22' (FIG. 7C) and a locking sub 23 (FIGS. 7C-7D) threadedly connected together with the locking sub 23 threadedly connected to the upper end of a tubing extension 24'. Mandrel 10 extends through the inner bore 22 of housing 20 to a distance intermediate the length of the housing (FIGS. 7A-7C) and includes a plurality of threadedly-connected members, namely, an upper tubular seating member 10a, an intermediate tubular indexing member 10b (FIGS. 7A, 7B) and a lower circulation port member 10c (FIG. 7C). The threaded connection between members 10a, 10b (FIG. 7A) and members 10b, 10c (FIG. 7C) is fluidly sealed by means of O rings 112, 112' so that the members are effectively a fluid-tight, unitary mandrel. The thrust bearings 49 are secured to an upper reduced portion of seating member 10a below the coupling 12.

The locking recesses 61 in the outer mandrel 10 are formed by circumferentially-spaced grooves 61a (FIGS. 11, 12) in the inner bore 10', near the lowermost box end of member 10a and are preferably five in number although the member may be varied as desired. The grooves 61a have downwardly-facing, inclined shoulder 61b (FIG. 7A) formed at the upper end thereof while

the lower end is defined by the upwardly-facing end 61c on the pin end of member 10b.

Sub-assembly 30a of the inner mandrel assembly 30 includes the upper tubular fishing head 52 shaped in a conventional manner and having longitudinally-spaced fluid ports 113 therein and a lower box end threadedly secured to the upper pin end of a swab packer retainer 114. The swab packer 53 is a conventional elastomer packing element having an upper end secured to the retainer 114 by, for example, bonding and a lower open end sealingly received within the inner bore 10' of outer mandrel 10. The lower end of retainer 114 is threadedly connected to a retainer mandrel 115 which has a lower, outwardly-flanged portion 116 externally threaded to receive the upper box end of tubular member 54. An inner recessed bore 117 forms the downwardly-facing shoulder 75. Member 54 includes a thin-walled tubular member 54a having an upper enlarged portion 118 with lateral openings 60 therein and a lower box end (FIG. 7B) threadedly connected to the upper end of a key sub 54b. Openings 60 (FIG. 7A) in tubular member 54a are frusto-conically shaped to prevent the balls from escaping from the member 54. Key sub 54b has a pair of longitudinally-extending flat keys 77 (FIG. 7B) received in slots therein (not shown) and a lower pin end threadedly received in the upper end of a lower thin-walled tubular member 54c. The lower end of the tubular members 54c (FIG. 7C) has an inwardly-extending flange 55 which is rotatably mounted in a recess of sub-assembly 30b by bearing means 57.

Sub-assembly 30c (FIG. 7A) of inner mandrel assembly 30 which serves to lock balls 62 in recesses 63 includes the check valve 67, the valve mandrel 65, the enlarged locking portion 64 on the locking sleeve 68 and the lower flanged member 69. Tubular member 65 is slidably disposed in the central bore 120 of retainer 114 and has fluid ports 66 therein spaced above the upper end of retainer 114 in the uppermost position of the assembly. Seals 110 and 111 above and below ports 66 effectively seal off the ports when valve mandrel 65 is moved downwardly within the central bore 120 of retainer 114.

The upper end of valve mandrel 65 is externally threaded to receive the lower end of the check valve body 67a. Received within the body 67a is a check valve member 67b having an upper closed end 67c which is resiliently held in abutment with an enlarged check valve seat 67d of the body 67a. Valve member 67b has lateral ports 67e spaced between its upper closed end 67c and an outwardly-extending flange 67f. A spring 67g surrounding the valve member 67b and contained between the flange 67f and the upper end of tubular member 65 holds the valve member 67b tightly against the valve seat 67d preventing flow of fluid in an upward direction but permitting downward flow when the valve member 67b is displaced downwardly from the valve seat 67b.

The lower pin end of valve mandrel 65 is threadedly received in the upper internally-threaded end in the enlarged portion 64 of locking sleeve 68 so that the upper end of enlarged portion 64 forms an upwardly-facing shoulder in complementary engagement with downwardly-facing shoulder 75. The enlarged portion 64 extends downwardly beyond the openings 60 in member 54a to secure balls 62 in the recesses 61. A compression spring 73 surrounds the locking sleeve 68 and is contained between the enlarged portion 64 and the upper end of upper flange member 71. Lower flanged member 69 is threadedly received on external threads on the lower pin end of sleeve 68 while flange member 71 is threadedly received on internal threads on the upper end of the tubular member 72.

Member 72 has an upper thin-walled section which permits sliding movement relative to lower flange 69 and has a lower inwardly offset portion 121 (FIG. 7B). The

offset portion 121 has longitudinally-extending keyways 76 in its outer walls to slidably receive keys 77 of sub-assembly 30a. Below the keyways 76 is a thin-walled section having an intermediate portion externally threaded at 80 which receives the upper internally-threaded end of a sub-assembly 30b. An O ring 122 in sub-assembly 30b fluidly seals the lower end portion of the thin-walled section relative to the sub-assembly 30b while a lateral port 123 in sub-assembly 30b above the seal 122 prevents a fluid lock between the threaded portions.

Sub-assembly 30b includes upper sub 124 internally threaded at 80 and having a lower end internally threaded to receive the upper threaded end of member 56. The lower end of the member 56 is offset inwardly at section 125 (FIG. 7C) and externally threaded to receive the upper end of an inner circulation port member 126 thereby forming a recess 127a which contains the flange 55 of sub-assembly 30a and bearings 57. Circulation port member 126 has ports 81 aligned with ports 44 of mandrel 10 in the position shown with lower seals 85 fluidly sealing port member 126 within outer mandrel 10. The lowermost end of port member 126 is internally threaded to receive the upper end of a keying member 127. Key member 127, in turn, threadedly receives a testing plug 128 having test ports 90 and closed end 84.

The upper end of sub-assembly 30e is slidably received over the plug 128 and keying member 127, and inwardly-extending pin 86 received in longitudinal slot 87 of member 127 nonrotatively but slidably secures the sub-assembly 30e to sub-assembly 30b. The sub-assembly 30e and pin 86 therein are forced downwardly to a lowermost position by means of a compression spring 88 about member 127 and contained between a downwardly-facing shoulder 140 of member 126 and an upwardly-facing shoulder 131 on sub-assembly 30e.

Sub-assembly 30e generally includes an upper testing sub 132, a selector key sub 133 (FIG. 7D), a recorder sub 134 and a bottom cap 135 threadedly connected together. Testing sub 132 has lateral testing ports 93 therein arranged to align with test ports 90 of testing plug 128 when plug 128 is moved downwardly relative to test sub 132. Selector key sub 133 has longitudinally-extending rectangular recesses 95 therein which receive selector keys 96 and springs 136 which urge keys 96 outwardly of the sub. Keys 96 have upper and lower tab ends 138, 139 which are arranged to abut overlapping ends of subs 132 and 134 to limit outward movement of the keys. The keys have upper and lower outwardly-tapered surfaces 140 to facilitate passage through the tubing and housing 20. Intermediate the length of the keys is a recess forming the downwardly facing shoulder 98 and including a bottom wall 141 and outwardly-tapering wall 142. Housing 20 has an upper enlarged bore 143 to facilitate expansion of the keys 96 and a lower reduced bore 144. The different diametered bores 143, 144 form the upwardly-facing shoulder 99 to limit downward movement of subassembly 30e. A pair of square-shaped keyways 97 extend inwardly of bore 144 to receive keys 96 and thereby secure subassembly 30e against rotation (FIG. 10). Recorder sub 134 has a blind bore 145 and together with cap 135 forms a chamber 100. A conventional pressure recorder 102 is suitably disposed within chamber 100 and permitted access to fluid pressures by lateral openings 101 in the sub 134.

Referring now more particularly to FIGS. 8 and 9, the indexing slot system 45 comprised of recessed slots and portions of the mandrel has intermediate pockets A and B for receipt of index pin 46 in the "going-in" or closed position of the tool. The slot system also has an upper portion "C" for the testing position and release of the center assembly 30. For the reverse circulation position there is a lower pocket D. The full circumference of the mandrel 10 is shown in the developed view of FIG. 9 and illustrates a duplicate slot tracking arrangement for each side

of the mandrel. Therefore, the discussion of one tracking arrangement will suffice for the other.

The slot system 45 is generally comprised of an upper recessed portion 162 in the mandrel 10 spaced radially-inwardly from the outer diameter 161 of the mandrel and extending circumferentially around the mandrel to permit free rotative movement of the pins 46 in the lowermost position of the mandrel (see FIGS. 3, 5) i.e., in position C. Spaced downwardly from the upper tapered surface 160 of the recess 162 is an edge surface 164 inclined in a first direction relative to the central axis of the mandrel and having ends adjoining parallel longitudinally-extending edge surfaces 165, 166. A longitudinal slot 167 is formed between the one-edge surface 165 and another longitudinally-extending edge surface 168 spaced therefrom. The lower end of slot 167 is inclined in a second direction opposite to the first direction and opens into a downwardly-extending longitudinally slot 170 which is offset slightly in a circumferential direction with respect to slot 167. The lower end of slot 170 terminates in enlarged pocket D while the upper end forms a generally Y-shaped arrangement with slot 167 and with another slot 172 that is inclined in the same direction as surface 164. Slot 172 opens into the upper end of a longitudinal slot 173 at a point below pocket A. Slot 173 extends longitudinally downwardly to pocket B. Another inclined slot 174 has a lower end opening into slot 173 above pocket B, is inclined in the same direction as edge surface 164 and extends upwardly to the lower end of another longitudinal slot 175. Slot 175 extends upwardly and is closed at its upper end by a downwardly-facing surface 176 of a gating member 177. The downwardly-facing surface 176 and an upwardly-facing surface 178 of gating member 177 are arranged at right angles to one another and together with a longitudinally-extending surface 179 form a generally triangular-shaped head. Surface 179 mates with longitudinally-extending surface 166 while inclined surface 176 mates with correspondingly-inclined upper edges 182, 183 of the elements which define slot 175. A tang 181 extends downwardly from the head of gating member 177 and is received by a vertical guide slot 184 which is offset from surface 166. The offset of the slot 184 forms a downwardly-facing shoulder 186 arranged to limit the upward movement of the gating member 177 by engagement with an upwardly-facing shoulder 188 formed by the offset portion of tang 181 while the engagement of surface 176 with surfaces 182, 183 limits downward movement of the gating member 177.

It will be observed from the layout of the slot system 45 that the pin 46 can only travel from pocket D to pocket A due to the extension of an upper surface 190 of slot 172 over slot 170 while a lower inclined surface 191 between slots 172 and 173 limits the travel of pin 46 from pocket A to B only. The upper surface 178 of gating member 177 and the inclined surface 164 of the recess provide a generally V-shaped throat to channel the pin 46 from a position at C into slot 167 to pocket D. It will therefore be appreciated that pin 46 will remain in slot 173 in either pocket A or B until rotation to the right and downward movement of the mandrel 10 guides pin 46 through slots 174, 175 and the one-way gating member 177. Once in the testing position C, the pin 46 can only go to pocket D upon raising the mandrel; and, upon further raising, from pocket D the pin 46 can only return to the pocket A. Hence, the slot system is semidirectional in operation in that a right-hand torque and longitudinal movement initiate a prescribed sequence of the various positions of pin 46 in the system.

Turning now to FIG. 15, the upper end of the mandrel section 10a is shown in conjunction with a fishing tool 200 which permits insertion or removal of the retrievable center assembly 30. The fishing tool 200 is adapted to fit over and engage the downwardly-facing fishing recesses at the upper end of fishing head 52. Its body 202

has a central bore 203 to slidably receive a piston-like member 204 and a bore 205 of reduced diameter to receive a downwardly-extending stem 206 secured to the piston member 204. Piston member 204 is secured in body 202 by a pin 207 so that when fingers 201 engage fishing head 52 of sub-assembly 30a the stem 206 displaces sub-assembly 30c downwardly therefrom. This is accomplished by the lower end of stem 206 engaging closed end 67c of the check valve 67 (FIG. 7A) so that spring 67g is compressed permitting check valve member 67 to bear downwardly on the valve mandrel 65. Displacing sub-assembly 30c downward relative to sub-assembly 30a permits enlarged portion 64 to be disposed below openings 60 in sub-assembly 30a (FIG. 7A) to permit balls 62 to be retracted within the outer walls of member 54 to insert or remove the inner mandrel assembly 30.

To insert the inner mandrel assembly 30 in the outer mandrel 10, the fishing tool 200 is connected to the mandrel assembly 30 and lowered through the tubing by means of wire line equipment until the selector keys 96 (FIG. 7D) on the sub-assembly 30e engage housing shoulders 99 limiting downward movement of the assembly. The pin 207, which in this case is designed to be easily sheared, thereafter is sheared permitting spring 73 (FIG. 7A) to urge the enlarged portion upwardly and position balls 62 in recesses 61.

In removing the device, another fishing tool similar to tool 200 is employed with the exception that pin 207 is not designed to shear. Therefore, the stem 206 engages and moves enlarged portion 64 below openings 60 so that balls 62 are unlocked from the recesses 61 and thus permits removal of the assembly.

The over-all operation of the above-described well tool has been previously explained with respect to FIGS. 2-6; however, a brief description of the combined function of the various elements of the tool at this point may serve to highlight the above description.

The tool is assembled, as shown in FIGS. 7A-7D, connected to a packer assembly, as shown in FIG. 1, and lowered into the well to the desired level of testing by a string of pipe. In the "going-in" position, as shown in FIG. 2, mandrel splines 31 bear against housing splines 32 while pin 46 is in pocket A (FIG. 9) of the slot system 45. Mandrel assembly 30 is locked by balls 62 within mandrel 10 and test port 90 is sealed by seals 91, 92 while circulation ports 44, 81 are sealed by seals 42, 43 and 85 so that no fluid can enter the interior 82 of the tool. After the packer has been set in position in the well, the tubing 11 and mandrel 10 are raised and torqued to the right permitting pin 46 to follow slots 173, 174 of the slot system to the bottom of slot 175. At this point mandrel splines 31 have been rotated relative to housing splines 32 so that downward movement of mandrel 10 and tubing 11 causes the splines to mesh. The pin 46 traveling in slot 175 engages lower surface 176 of gating member 177 causing the member to be lifted upwardly in slot 184 so that pin 46 enters the recess 162 at position C. The engagement of thrust bearings 49 on mandrel 10 with housing 20 limits the downward movement of mandrel 10 and permits the pin 46 to rotate 360° in the recess 162. During the rotative and downward movement of mandrel 10, the selector keys 96 on sub-assembly 30e are received in the slots 97 and limit downward movement of the sub-assembly 30e by engaging shoulders 98, 99 on the keys and housing. Sub-assembly 30b also telescopes into sub-assembly 30e placing test ports 90, 93 in fluid communication as shown in FIG. 3 so that the well fluid 103 can flow to the interior 82 of the tool. The pressure of the flowing fluid is, of course, measured by the recorder 102.

After a sufficient period of time for the fluid test, the mandrel 10 and tubing 11 are raised so that pin 46 is guided into slot 167 which aligns mandrel splines 31 to mesh with housing splines 32. The spring 88 between sub-assemblies 30b and 30e closes the ports 90 within the

sub-assembly 30e by seals 91, 92. Pin 46 follows slot 167 to slot 170 and the slight rotation between the slots align mandrel splines 31 to mesh with housing grooves 34 to limit the upward movement of mandrel 10 and align mandrel circulation ports 44, 81 with the housing circulation ports 36 as shown in FIG. 4. Well fluid external of the housing may then force the sample collected in tubing 11 to the surface of the ground. Thereafter, raising the mandrel 10 causes pin 46 to be guided from slot 170 to slots 172, 173 which rotates mandrel splines 31 into abutment position with housing splines 32 and closes the circulation ports 44, 81 within the housing 20. During the reverse circulation the shut-in pressure is recorded. In the event it is desired to obtain a shut-in pressure prior to reverse circulation the tool is immediately raised from pocket D to pocket A instead of reverse circulated. Thereafter, the mandrel can be recycled through the slot system to pocket D to reverse circulate.

From the foregoing it will be appreciated that both the circulation ports 81, 44 and test ports 90 may permit fluid communication with tubing 11 through the interior 82 of the tool respectively from above and below the closed end plug 84. In an intermediate position of the mandrel relative to the housing the ports 81, 44 and 90 are fluidly sealed to prevent fluid flow to the interior 82 of the tool. In an uppermost position of the mandrel, circulation ports 81, 44 are opened to the interior 82 to permit fluid flow while test ports 90 remained closed. In a lowermost position of the mandrel, test ports 90 are opened to the interior to permit fluid flow while circulation ports 81, 44 are closed. It will also be apparent that the tool can be recycled indefinitely between the various positions by longitudinal movement accompanied by a slight right-hand torque to the string of pipe.

After the above drill stem test, the mandrel assembly 30 may be unlocked and removed in a number of ways. The various combinations of removal and unlocking procedures available will be evident from the following discussion.

First of all, a wire line tool as disclosed in FIG. 15 may be employed to unlock balls 62 from recesses 61 by movement of enlarged portion 64 relative to the sub-assembly 30a. Thereafter, a conventional fishing tool on a wire line can retrieve the assembly 30. In another aspect, a fishing tool may be dropped through the tubing 11 as a "go-devil" to unlock the assembly 30 and the well fluid 103 acting on the assembly may drive it upwardly to the surface of the ground or should the well pressure be too low, the mandrel 10 can be manipulated to the circulation position and the well fluid pressured to pump the assembly 30 upwardly.

In another manner, the tubing 11 and the outer mandrel 10 can be lowered to the lowermost position wherein rotation serves to actuate a mechanism to unlock the balls 62 from the recesses 61. In this position sub-assembly 30e and 30b are co-rotatively locked to the housing 20 while sub-assemblies 30a and 30d are co-rotatively secured together and rotated relative to subassemblies 30e and 30b. The threaded connection at 80 between the sub-assemblies 30b and 30d causes sub-assemblies 30d and interlinked sub-assembly 30c to move downwardly to unlock the balls 62 from recesses 61. Thereafter, well fluid, reverse circulation or a wire line can be employed to return the assembly 30 to the surface of the ground.

Once the center assembly 30 has been removed there is a full opening through the tool and a reverse circulation valve remaining between mandrel 10 and housing 20. In this connection the term "full opening" is intended to mean a passage having an internal diameter substantially as great as the drift of clearance diameter of the well tubing by which the tool is supported. It will be appreciated that cementing or acidizing can be accomplished through the full-opening tool with the circulation valve permitting removal of acid or cement at the completion of the operation. Thereafter, of course, a perforating

apparatus could be lowered through the tool to perforate the casing to complete the well for production. Hence, with a one-tool arrangement, a complete set of well completion techniques can be employed.

From the foregoing it will be appreciated that a well tool constructed in accordance with the present invention permits a full range of test-treat-squeeze operations. The indexing system permits the testing valve to be opened and closed as many times as desired thus allowing multiple zone testing with only one insertion of the tubing string in the borehole. The circulating valve similarly can be repeatedly opened and closed at will and also permits a perforating apparatus or other devices to be passed through its full-opening arrangement. At the same time the operator can always determine the operating condition of the tool.

Another embodiment of the present invention is found in the tool illustrated in FIGS. 16A-16D wherein elements which correspond to like elements of the tool shown in FIGS. 7A-7D are similarly designated. In this embodiment the housing 20 slidably and rotatably receives a modified outer mandrel 10' which includes the upper tubular member 10a (FIG. 16A), the intermediate tubular member 10b (FIGS. 16A-16C), a tubular circulation port member 210 (FIG. 16C) and a tubular testing port member 211 (FIG. 16C), each of the members being threadedly connected together in an end-to-end relationship. Circulation port member 210 has lateral test ports 212 with seals 213, 214 spaced above and below ports 212 to seal the ports within the central bore 22 of housing 20. Testing port member 211 similarly has lateral test ports 215 with seals 216 spaced below ports 215 to seal the lower end of the mandrel with respect to the bore 22.

Releasably locked within mandrel 10' is a modified inner mandrel assembly 30' which includes sub-assemblies 30a (FIGS. 16A-16C), 30c (FIG. 16A), 30d (FIGS. 16A, 16B) and a modified sub-assembly 30b (FIGS. 16B-16D). Sub-assemblies 30a, 30c and 30d are assembled and arranged within mandrel 10' in a manner similar to the tool described in FIGS. 7A-7D. Sub-assembly 30b is modified mainly by the substitution of an elongated tubular circulation port member 230 (FIG. 16C) and a closed end test port member 231 for the sub-assembly 30e. The circulation port member 230 has lateral ports 232 aligned with ports 212 of the outer mandrel 10' while test port member 231 has test ports 233 aligned with test ports 215 of the outer mandrel. The lower end of the test member 231 is closed at wall 234 below ports 233.

At its upper end 218 (FIG. 16B), sub-assembly 30b has a threaded coupling 80 completing a connection with lower end 219 of sub-assembly 30d. The end 218 also has an outer portion 220 of reduced diameter surrounded by a tension spring 221. Spring 221 is contained between opposed shoulders 222, 223 on sub-assemblies 30a and 30b, respectively, to insure engagement of the keys 96 with stop shoulders 99 (FIG. 16D) in the lowermost position of the mandrel and to insure contact of flanges 69, 71 (FIG. 7A) in the uppermost position of the mandrel. The lower end 225 (FIG. 16C) of sub-assembly 30b is of reduced diameter to form an elongated annular recess 226 between a shoulder 227 and the upwardly-facing end 228 of circulation port member 230. Bearings 57 and the lower flanged end 55 of sub-assembly 30a are slidably received in recess 226 for limited longitudinal movement of sub-assembly 30a relative to sub-assembly 30b.

Intermediate the ends of circulation port member 230 are seals 235, 236 spaced above and below test ports 233 to seal the inner mandrel assembly relative to the bore of the outer mandrel 10'. A blind bore 237 in the lower end of test member 231 below wall 234 receives the threaded end of the key sub 133.

In operation, the apparatus of FIGS. 16A-16D has similar upper, intermediate and lower operational positions of mandrel 10' relative to housing 20. In the intermediate position shown test ports 215, 233 are fluidly sealed by

seals 214, 216, 235, 236 while circulation port 212 is fluidly sealed by seals 213, 214.

The mandrel assemblies 10', 30' are manipulated to a lower position in a manner similar to the operation above described for FIGS. 7A-7D. In moving downward, selector keys 96 engage shoulders 99 of the housing to limit downward movement of sub-assembly 30b. Spring 221 between sub-assemblies 30b and 30a urges subassembly 30b downward to insure register of keys 96 with shoulders 99 and keys 96 lock within the slots 97 in the housing 20. In the lowermost position inner and outer test ports 215, 233 extend into the enlarged bore 143 of housing 20 permitting fluid flow to the interior of the tubing. Also, in this position, mandrel 10' can be rotated which causes the threads at 80 to move sub-assemblies 30d, 30c downward to unlock balls 62.

To move from the lower position to the uppermost position the mandrel 10' is raised and test ports 215, 233 are again sealed within the housing 20 by seals 214, 216 while circulation ports 212, 232 are positioned adjacent housing circulation ports 36 to permit fluid external of the housing access to the interior.

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

What is claimed is:

1. A well tool comprising: a tubular housing having a lower end arranged for connection with packing means; a tubular full-opening outer mandrel telescopically received within said housing and having a plurality of circumferentially-spaced recesses in its inner wall; means to rotatably mount said outer mandrel relative to said housing; a retrievable inner mandrel assembly disposed within said outer mandrel, said assembly including an upper sleeve having openings therein, a locking sleeve telescopically received within said upper sleeve, and a lower jackscrew housing; means to releasably lock said inner mandrel assembly to said outer mandrel including a plurality of detent members received in said sleeve openings and held in said spaced recesses by a portion of said locking sleeve; means for threadedly connecting said locking sleeve to said lower jackscrew housing; means to co-rotatively secure said last-mentioned means to said upper sleeve; means to secure said upper sleeve and said lower jackscrew housing to one another in a longitudinally fixed relation while permitting relative rotation therebetween; and means to co-rotatively secure said jackscrew housing and said tubular housing to one another whereby rotation of said outer mandrel displaces the locking portion of said locking sleeve from said openings permitting the release of said detent members from the spaced recesses in the outer mandrel.

2. A well tool comprising: a tubular housing having a lower end arranged for connection with a packing means; a tubular full-opening outer mandrel telescopically received within said housing and having an upper end arranged for connection with a string of tubing, said outer mandrel having a plurality of circumferentially-spaced recesses in its inner wall; a retrievable inner mandrel assembly disposed within said outer mandrel, said assembly including an upper sleeve having openings therein, a locking sleeve with a locking portion telescopically received within said upper sleeve, and a lower jackscrew housing; means to releasably lock said inner mandrel assembly to said outer mandrel including a plurality of detent means received in said upper sleeve openings and held in said spaced recesses by said locking portion of said locking sleeve, said releasable locking means further including a tubular jackscrew mandrel telescopically received by said locking sleeve, said jackscrew mandrel and said locking sleeve being longitudinal-

ly movable relative to one another between an extended position where said detent means are retained in said recesses and a collapsed position permitting release of said detent means from said recesses; resilient means engaging portions of said jackscrew mandrel and said locking sleeve to bias said jackscrew mandrel and said locking sleeve in said extended position; means to co-rotatively secure said jackscrew mandrel and said upper sleeve to one another; means to secure said upper sleeve and said lower jackscrew housing to one another in a longitudinally fixed relation while permitting relative rotation therebetween; a threaded connection between said jackscrew housing and said jackscrew mandrel; and means to co-rotatively secure said jackscrew housing and said tubular housing to one another whereby rotation of said outer mandrel displaces the locking portion of said locking sleeve from said openings permitting the release of said detent means from the spaced recesses in the outer mandrel.

3. A well tool comprising: a tubular housing having circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening outer mandrel telescopically received within said tubular housing and having an upper end arranged for connection with a string of tubing, said outer mandrel having a plurality of circumferentially-spaced recesses in its inner wall and having circulation ports spaced intermediate of its ends adapted to be placed in fluid communication with said housing circulation ports in one longitudinal position of said outer mandrel relative to said housing, sealing means between said tubular housing and said outer mandrel adapted to close off fluid communication to the interior of said outer mandrel ports when said outer mandrel is displaced to another longitudinal position; means to rotatably mount said outer mandrel relative to said tubular housing; a retrievable inner mandrel assembly disposed within said outer mandrel and having a lower closed end portion below said outer mandrel ports, said inner mandrel assembly including an upper sleeve having openings therein, a locking sleeve having a locking portion telescopically received within said upper sleeve, and a lower jackscrew housing; means to releasably lock said inner mandrel assembly to said outer mandrel including a plurality of detent means received in said upper sleeve openings and held in said spaced recesses by said locking portion of said locking sleeve; said retrievable inner mandrel assembly further including a tubular jackscrew mandrel telescopically received on said locking sleeve, said jackscrew mandrel and said locking sleeve being longitudinally movable relative to one another between an extended position where said detent means are retained in said recesses and a collapsed position permitting release of said detent means from said recesses, resilient means engaging portions of said jackscrew mandrel and said locking sleeve to bias said jackscrew mandrel and said locking sleeve in said extended position, means to co-rotatively secure said jackscrew mandrel and said upper sleeve to one another, means to rotatively secure said upper sleeve and said lower jackscrew housing to one another in a longitudinally fixed relation while permitting relative rotation therebetween, a threaded connection between said jackscrew housing and said jackscrew mandrel, and means to co-rotatively secure said jackscrew housing and said tubular housing to one another whereby rotation of said outer mandrel displaces the locking portion of said locking sleeve from said upper sleeve openings permitting the release of said detent means from the spaced recesses in the outer mandrel.

4. The apparatus as defined in claim 3 and further including a packer element disposed between said upper sleeve and said outer mandrel above said circulation ports.

5. A well tool comprising: a tubular housing having lateral circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing

means; a tubular full-opening mandrel slidably received within said housing and arranged for limited movement between a plurality of longitudinal positions relative to said tubular housing, said full-opening mandrel having an upper end arranged for connection with a string of tubing and having lateral circulation ports spaced intermediate of its ends; a tubular inner mandrel assembly releasably locked within said full-opening mandrel and including a normally closed test valve at the lower end thereof adapted to place the interior of said inner mandrel assembly into open and closed conditions of fluid communication relative to the interior of the tubular housing below said test valve; and indexing means operably connected between said full-opening mandrel and said tubular housing to permit manipulation of said full-opening mandrel between a position in which said circulation ports are effectively closed by said tubular housing, a position wherein the circulation ports are in fluid communication with the lateral ports of said tubular housing, and a position wherein said test valve is opened.

6. A well tool comprising: a tubular housing having lateral circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening mandrel slidably received within said housing and arranged for limited longitudinal movement between first, second and third positions relative to said housing, said mandrel having an upper end arranged for connection with a string of tubing and having lateral circulation ports spaced intermediate of its ends said circulation ports being sealingly received within said housing in one of said longitudinal positions; a test valve at the lower end of said mandrel comprised of telescopically-arranged members each having a test port therein, the test port in one of said members normally being out of fluid communication with the test port in the other of said members, said test ports being adapted to be placed in fluid communication with one another in response to relative longitudinal movement of said members; means to releasably bias said members in relative positions wherein said fluid communication between said test ports is prevented; means on said mandrel and said housing adapted to co-operate with said telescopic members to permit fluid communication between said test ports in response to relative longitudinal movement between said mandrel and said housing; means on said mandrel and housing selectively operative to limit longitudinal movement of said mandrel in one direction in said first, second and third positions, but adapted to permit longitudinal movements of said mandrel through one of said positions when said housing and said mandrel are in a predetermined rotational orientation relative to one another; and indexing means including a guide system on one of said housing and said mandrel, a follower co-operating with said guide system and secured to the other of said mandrel and said housing, said guide system being constructed and arranged to selectively position said housing and said mandrel in said predetermined rotational orientation in response to relative longitudinal movement between said mandrel and said housing.

7. A well tool comprising: a tubular outer housing having lateral circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; an outer tubular full-opening mandrel slidably received within said outer housing and arranged for limited movement therein between a plurality of longitudinal positions relative to said outer housing, said full-opening mandrel having an upper end arranged for connection with a string of tubing and having lateral circulation ports spaced intermediate of its ends said circulation ports being sealingly received within said outer housing in at least one position of said full-opening mandrel relative to said outer housing; said full-opening mandrel further having circumferentially-spaced recesses about its inner wall; a tubular inner mandrel assembly disposed within said full-opening mandrel including an upper sleeve telescopically

received within said full-opening mandrel and having openings therein, a locking sleeve means having a locking portion telescopically received within said upper sleeve, a lower jackscrew housing, and a test valve; means to releasably secure said inner mandrel assembly to said full-opening mandrel including a plurality of detent means received in said sleeve openings and held in said spaced recesses by said portion of said locking sleeve; said upper sleeve being co-rotatively secured to said locking sleeve means and being rotatively attached on said lower jackscrew housing, said jackscrew housing being threadedly connected to said locking sleeve means, means for co-rotatively securing said jackscrew housing to said outer housing; said test valve including a tubular member telescopically received on the lower end of said jackscrew housing, each of said jackscrew housing and said tubular member having test ports therein adapted to be placed in fluid communication in one longitudinal position of said tubular member relative to said jackscrew housing in response to relative longitudinal movement therebetween; means to normally hold said tubular member and said jackscrew housing in relative positions wherein said jackscrew housing ports are closed, means on said outer housing adapted to co-operate with said tubular member in response to longitudinal movement of said full-opening mandrel to place said test ports in a condition of fluid communication.

8. A well tool comprising: a tubular housing having a lower end arranged for connection with a packing means; a tubular full-opening outer mandrel telescopically received within said tubular housing and having a plurality of circumferentially-spaced recesses in its inner wall; means to rotatably mount said outer mandrel relative to said tubular housing; a retrievable inner mandrel assembly disposed within said outer mandrel, said inner mandrel assembly including an upper sleeve having opening therein, a locking sleeve means having a locking portion telescopically received within said upper sleeve, and a lower jackscrew housing; means to releasably lock said inner mandrel assembly to said outer mandrel including a plurality of detent means received in said sleeve openings and held in said spaced recesses by said locking portion of said locking sleeve means; said upper sleeve being co-rotatively secured to said locking sleeve means and being rotatively attached on said lower jackscrew housing; said jackscrew housing being threadedly connected to said locking sleeve means, and means for co-rotatively securing said jackscrew housing to said tubular housing whereby rotation of said outer mandrel displaces the locking portion of said locking sleeve from said openings permitting the release of detent means from the spaced recesses in the outer mandrel; a test valve including a tubular member telescopically received on the lower end of said jackscrew housing, each of said jackscrew housing and said tubular member having test ports therein adapted to be placed in fluid communication in one longitudinal position of said tubular member relative to said jackscrew housing in response to relative longitudinal movement therebetween; means to normally hold said tubular member and said jackscrew housing in relative positions wherein said jackscrew housing ports are closed; and means on said tubular housing adapted to co-operate with said tubular member in response to longitudinal movement of said outer mandrel to place said test ports in a condition of fluid communication.

9. A well tool comprising: a tubular housing having a lower end arranged for connection with a packing means; a tubular full-opening outer mandrel telescopically received within said tubular housing and having a plurality of circumferentially-spaced recesses in its inner wall; means to rotatably mount said outer mandrel relative to said tubular housing; a retrievable inner mandrel assembly disposed within said outer mandrel, said inner mandrel assembly including an upper sleeve having openings therein, a locking sleeve having a locking portion

telescopically received within said upper sleeve, and a lower jackscrew housing; means to releasably lock said inner mandrel assembly to said outer mandrel including a plurality of detent means received in said sleeve openings and held in said spaced recesses by said locking portion of said locking sleeve, a tubular jackscrew mandrel slidably received on said locking sleeve for limited longitudinal movement, resilient means between said jackscrew mandrel and said locking sleeve to bias said jackscrew mandrel and locking sleeve to an extended position, whereby said jackscrew mandrel and locking sleeve are movable between an extended position holding said detent means in said recesses and a collapsed position permitting release of said detent means from said recesses, means to co-rotatively secure said upper sleeve and said jackscrew mandrel to one another, resilient means between portions of said jackscrew housing and said upper sleeve to bias said jackscrew housing and said upper sleeve to an extended position, a threaded connection between said jackscrew mandrel and said jackscrew housing, and means to co-rotatively secure said jackscrew housing and said tubular housing to one another whereby rotation of said outer mandrel displaces the locking portion of said locking sleeve from said openings permitting the release of said detent means from the spaced recesses in the outer mandrel.

10. In combination with a pair of telescopically-arranged upper and lower members adapted to be moved relative to one another, an indexing slot system and index pin therefor respectively located on each of said members, said slot system including recessed portions in one of said members, said recessed portions including an annular end portion forming one extremity of the said system and permitting free angular rotation of the pin therein, a first slot extending in a longitudinal direction relative to said member having an end portion opening into said annular end portion, a second slot extending in a longitudinal direction and spaced circumferentially from said first slot in one direction and having one end portion comprising the other extremity of said system, a third slot inclined relative to said first and second slots and connecting the remaining end portion of said first slot to said second slot at a point intermediate the ends of said second slot, a fourth slot extending in a longitudinal direction and spaced circumferentially from said second slot in one direction and having an end portion opening into said annular end portion, a fifth slot extending in a longitudinal direction and spaced circumferentially intermediate said second and fourth slots and having opposed end portions spaced inwardly from said extremities, a sixth slot inclined relative to said longitudinal slots in an opposite direction to said third slot and connecting the remaining end portion of said second slot to one of the end portions of said fifth slot, a seventh slot inclined relative to said longitudinal slots similar to said sixth slot and connecting the remaining end portions of said fourth and fifth slots, and a gating member for said fourth slot slidably received within said one member to produce a one-way gating function upon relative longitudinal movement of said telescopically-arranged members, said gating member being actuated by said pin to permit movement of said pin from said fourth slot upon relative longitudinal movement of said members in one direction yet prevent the pin from entering said fourth slot when said telescopically arranged members are moved relative to one another in an opposite direction.

11. A well tool comprising: a tubular housing having circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening outer mandrel slidably received within said tubular housing having an upper end arranged for connection with a string of tubing and lateral circulation ports spaced intermediate of its ends, said lateral circulation ports opening into the interior of said outer mandrel; an inner retrievable mandrel assembly disposed

19

within said outer mandrel, means for releasably locking said inner mandrel assembly to said outer mandrel; and a swab-type packer disposed between said inner mandrel assembly and said outer mandrel above said outer mandrel circulation ports whereby when said circulation ports are placed in fluid communication said inner mandrel may be reverse circulated through the string of tubing.

12. As a subcombination, a retrievable mandrel assembly including a first tubular mandrel, a tubular housing at one end of said first mandrel having a portion thereof telescopically received by said first mandrel, means to secure said first mandrel and said housing to one another in a longitudinally fixed relation while permitting relative rotation therebetween, a locking sleeve telescopically received in said first mandrel and means for threadedly connecting said sleeve to said housing.

13. A well tool comprising: a tubular housing having a lower end arranged for connection with a packing means; a tubular full-opening mandrel slidably received within said housing and having an upper end arranged for connection with a string of tubing; a retrievable inner mandrel assembly disposed within said full-opening mandrel; means to releasably secure said inner mandrel assembly to said full-opening mandrel including a plurality of detent means interlocking said inner mandrel assembly and said full-opening mandrel; and means to release said detent means from a locking position by relative rotation between said full-opening mandrel and said tubular housing.

14. A well tool comprising: a tubular housing member to be releasably secured in a well bore; a tubular mandrel member received within said housing member for relative rotational movement and longitudinal movement between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member being arranged for coupling with a string of pipe; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves therebetween, said first splines being received by said recessed portion; said one member having second splines and second spline grooves therebetween spaced longitudinally from said shoulder a distance greater than the length of said first splines to provide said intermediate position, said one member further having third splines and third spline grooves therebetween disposed along said recessed portion adjacent said one shoulder with said third spline grooves arranged for receiving said first splines thereby to co-rotatively lock said mandrel member to said housing member in one of said end positions; said first splines being arranged to be passed through said second spline grooves when said first splines are longitudinally aligned with said second spline grooves thereby to pass to said other end position; said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; and means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is moved to said other end position.

15. A well tool comprising: a tubular housing member to be releasably secured in a well bore; a tubular mandrel member received within said housing member for relative rotational and longitudinal movement between longitudinally spaced end positions and a position intermediate of said end positions; said mandrel member arranged for coupling with a string of pipe; a normally-closed test valve at the lower end of said mandrel member; one of said longitudinal positions placing said test valve in an open position permitting fluid communication between the lower end of said housing member and the interior of said mandrel members; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed

20

portion; said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the length of said first splines to provide said intermediate position; said one member further having third splines and third spline grooves disposed adjacent said one shoulder with said third spline grooves arranged for receiving said first splines thereby to co-rotatively lock said mandrel member to said housing member in one of said end positions, said first splines being arranged to be passed through said second spline grooves when said first splines are longitudinally aligned with said second spline grooves thereby to pass to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; and means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is moved to said other end position.

16. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having a lateral port spaced intermediate its ends and a lower end arranged for connection with a packing means; a tubular full-opening mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member having a lateral port spaced intermediate its ends and an upper end arranged for connection with a string of pipe, one of said longitudinal positions placing said mandrel member port in fluid communication with said housing member port; sealing means disposed between said housing member and said mandrel member arranged to prevent fluid communication between said mandrel member port and said housing member port when said mandrel member is in another of said longitudinal positions; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the length of said first splines to provide said intermediate position, said first splines being arranged to be passed through said second spline groove when said first splines are longitudinally aligned with said second spline groove thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; and means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is removed to said other end position.

17. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having lateral ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member having lateral ports spaced intermediate of its ends and an upper end arranged for connection with a string of pipe; a normally-closed test valve at the lower end of said mandrel member; one of said longitudinal positions placing said test valve in an open position permitting fluid communication between the lower end of said housing member and the interior of said mandrel member; the other of said longitudinal positions placing said mandrel mem-

ber ports in fluid communication with said housing member ports; sealing means disposed between said housing member and said mandrel member arranged to prevent fluid communication between said mandrel member ports and said housing member ports when said mandrel member is in said intermediate position; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the width of said first splines to provide said intermediate position, said one member further having third splines and third spline grooves disposed adjacent and said one shoulder with said third spline grooves arranged for receiving said first splines thereby to co-rotatively lock said mandrel member to said housing member in one of said end positions, first splines being arranged to be passed through said second spline groove when said first splines are longitudinally aligned with said second spline grooves thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; and bearing means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is removed to said other end position and to facilitate relative rotational movement between said members.

18. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having lateral ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member having lateral ports spaced intermediate of its ends and an upper end arranged for connection with a string of pipe, one of said longitudinal positions placing said mandrel member ports in fluid communication with said housing member ports; sealing means disposed between said housing member and said mandrel member arranged to prevent fluid communication between said mandrel member ports and said housing member ports when said mandrel member is in another of said longitudinal positions; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the width of said first splines to provide said intermediate position, said first splines being arranged to be passed through said second spline grooves when said first splines are longitudinally aligned with said second spline grooves thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; bearing means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is removed to said other end position to facilitate relative rotational movement between said members; and indexing means including a guide system on one of said members and follower means on the other of said members, said guide system and follower means arranged to rotatively position said first splines relative to said second splines so

that said first and second splines are selectively engageable at said intermediate position.

19. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having lateral ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member having lateral ports spaced intermediate of its ends and the upper end of said mandrel member being arranged for connection with a string of pipe; an inner mandrel assembly having a closed portion releasably secured in the lower end of said mandrel member; one of said longitudinal positions placing said mandrel member ports in fluid communication with said housing member ports; sealing means disposed between said housing member and said mandrel member arranged effectively to prevent fluid communication between said mandrel member ports and said housing member ports when said mandrel member is in another of said longitudinal positions; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the width of said first splines to provide said intermediate position, said first splines being arranged to be passed through said second spline groove when said first splines are longitudinally aligned with said second spline groove thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is moved to said other end positions; and indexing means including a guide system on one of said members and follower means on the other of said members, said guide system and follower means arranged to rotatively position said first splines relative to said second splines so that said first and second splines may be selectively engaged at said intermediate position.

20. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having a lower end arranged for connection with a packing means; a tubular mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, and the upper end of said mandrel member being arranged for connection with a string of pipe; an inner mandrel assembly releasably secured in the lower end of said mandrel member and having at its lower end a normally-closed test valve; one of said longitudinal positions placing said test valve in an open position permitting fluid communication between the lower end of said housing member and the interior of said inner mandrel assembly; sealing means disposed between said mandrel member and said inner mandrel assembly arranged effectively to prevent fluid communication therebetween; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the length of said first splines to provide said intermediate

23

position, said first splines being arranged to be passed through said second spline groove when said first splines are longitudinally aligned with said second spline groove thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is moved to said other end position; and indexing means including a guide system on one of said members and follower means on the other of said members, said guide system and follower means arranged to rotatively position said first splines relative to said second splines so that said first and second splines may be selectively engaged at said intermediate position.

21. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having lateral ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate said end positions, said mandrel member having lateral ports spaced intermediate of its ends and the upper end of said mandrel member being arranged for connection with a string of pipe; an inner mandrel assembly releasably secured in the lower end of the tubular mandrel member and having a closed portion; one of said longitudinal positions placing said mandrel member ports in fluid communication with said housing member ports; sealing means disposed between said housing member and said mandrel member arranged to prevent fluid communication between said mandrel member ports and said housing member ports when said mandrel member is in another of said longitudinal positions; said housing member being arranged to cooperate with said mandrel member ports in the remaining one of said longitudinal positions to place said mandrel member ports in fluid communication with the interior of said housing member below said closed portion; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the length of said first splines to provide said intermediate position, said one member further having third splines and third spline grooves disposed adjacent to said one shoulder with said third spline grooves arranged for receiving said first splines thereby to co-rotatively lock said mandrel member to said housing member in one of said end positions, said first splines being arranged to be passed through said second spline grooves when said first splines are longitudinally aligned with said second spline grooves thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; bearing means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is removed to said other end position to facilitate relative rotational movement between said members; and indexing means including a guide system on one of said members and follower means on the other of said members, said guide system and follower means arranged to rotatively position said first splines relative to said second and third splines so that said first and third splines mesh in said one end position and said first and second splines are selectively engageable at said intermediate position.

24

22. A well tool for use in a well bore comprising: a tubular outer housing having a lower end arranged for connection with a packing means thereby to permit releasably securing the housing in a well bore; a tubular full opening outer mandrel telescopically and rotatively received within said outer housing, said outer mandrel having a plurality of circumferentially spaced recesses in its inner wall and having an upper end arranged for coupling to and rotational movement with a string of pipe; a retrievable inner mandrel assembly disposed within said outer mandrel and including an upper tubular sleeve having openings therein, a lower jackscrew member, and locking sleeve means having a locking portion telescopically received within said upper sleeve, said upper sleeve being co-rotatively secured to said locking sleeve means and being rotatively attached on said lower jackscrew member, said jackscrew member being threadedly connected to said locking sleeve means for co-rotatively securing said jackscrew member to said outer housing; and detent members for releasably locking said inner mandrel assembly to said outer mandrel, said detent members being received by said upper sleeve openings and extending into said outer mandrel recesses when said locking portion of said locking sleeve means is adjacent said openings, said inner mandrel assembly being releasable upon relative rotation between said outer mandrel and said outer housing during which time, the threadedly connected locking portion of said locking sleeve means is displaced longitudinally of said upper sleeve thereby to release said detent members from positions in said recesses in said outer mandrel.

23. A well tool for use in a well bore comprising: a tubular outer housing having a lower end arranged for connection with a packing means thereby to permit releasably securing the housing in a well bore; a tubular full opening outer mandrel telescopically and rotatively received within said outer housing, said outer mandrel having detent-receiving recessed portions in its inner wall and having an upper end arranged for coupling to and rotational movement with a string of pipe; a retrievable inner mandrel assembly disposed within said outer mandrel and including an upper tubular sleeve, detent means received by said sleeve for releasably locking said inner mandrel assembly to said outer mandrel, a lower jackscrew member, and locking sleeve means having a locking portion cooperating with said upper sleeve to retain said detent means in said recessed portions, said locking sleeve means being co-rotatively secured to said outer mandrel; said jackscrew member being threadedly connected to said locking sleeve means for co-rotatively securing said jackscrew member to said outer housing; said inner mandrel assembly being releasable upon relative rotation between said outer mandrel and said outer housing during which time, the threadedly connected locking portion of said locking sleeve is displaced thereby to release said detent means from said recessed portions in said outer mandrel.

24. A well tool comprising: a tubular outer housing to be releasably secured in a well bore, said outer housing having circulation ports intermediate of its ends; a tubular full-opening outer mandrel telescopically received within said outer housing and arranged for limited longitudinal movement therein between end positions and an intermediate position, said outer mandrel having circulation ports therein arranged to provide a fluid communication path with said outer housing circulation ports between the interior of said outer mandrel and the exterior of said outer housing in one of said end positions; means on said outer housing and outer mandrel to co-rotatively lock said outer housing and said outer mandrel to one another in said one end position; an inner mandrel assembly sized to be received within said outer mandrel and including a test valve at its lower end, said test valve being responsive to positioning of said outer mandrel in said other end position to permit fluid flow therethrough; means on said outer housing and inner mandrel assembly to co-

25

rotatively lock said outer housing and said inner mandrel assembly to one another in said other end position; means for releasably locking said inner mandrel assembly to said outer mandrel and responsive to relative rotation between said outer mandrel and said outer housing when said outer mandrel is in said other end position to release said inner mandrel assembly; and sealing means for said test valve and said circulation ports to prevent fluid flow therethrough when said outer mandrel is in said intermediate position.

25. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, a retrievable valve assembly in said passage and including detent means for releasably engaging said mandrel member to hold said retrievable valve assembly in said mandrel member, and locking means movably mounted in said retrievable valve assembly between a position normally holding said detent means in locking engagement with said mandrel member and a position releasing said detent means, whereby said locking means may be moved by a tool lowered through the well string to release said detent means, and means coupled to said locking means and to said mandrel and housing members also for moving said locking means between said positions thereby to release said detent means, said last mentioned means moving said locking means in response to relative rotation between said mandrel and housing members.

26. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, a retrievable valve assembly sized for reception in said passage and including detent means for releasably engaging said mandrel member, and locking means including a locking sleeve and locking means engageable by a fishing tool for longitudinal movement to release said detent means, and means including a pair of tubular jackscrew members having a threaded driving connection and arranged for relative rotation upon relative rotation of said mandrel and housing members for longitudinally displacing said locking sleeve to release said detent means.

27. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends adapted for connection in a well string and defining a passage through said tool, a retrievable valve assembly sized for reception in said passage and including detent means for releasably securing a first portion of said assembly to said mandrel member, a second portion of said assembly including a normally-closed test valve adapted for selectively opening and closing said passage and including telescoping valve members, one of said valve members being engageable with said housing member upon downward movement of said mandrel member relative to said housing member for opening said test valve.

28. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, a retrievable valve assembly sized for fluid-tight reception in said passage and including detent means for releasably securing a first portion of said assembly to said mandrel member, a normally-closed test valve for opening said passage to test fluid in its open position, and keying means for engaging said housing member and responsive to downward movement of said mandrel member relative to said housing

26

member for opening said test valve, said valve assembly further including locking means responsive for force transmitted through said detent and keying means upon relative rotation of said members for releasing said detent means.

29. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, and indexing means including a slot system on one of said members and a follower carried by the other of said members and received in said slot system, said slot system including an annular slot permitting full rotation of said member, at least two longitudinal slots offset from one another and terminating at one end in said annular slot to define angular positions for longitudinal movement of said mandrel member relative to said housing member, a transverse slot connecting said two slots near their other end, and a movable gate member adjacent the junction of one of said two slots with said annular slot to prevent re-entry of said follower into said one slot from said annular slot as said follower is moved progressively around said slot system.

30. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, and a circulating valve for opening said passage to the exterior of said housing member in an extended position of said members, a retrievable test valve assembly sized for reception in said passage and including detent means for releasably engaging said members and a normally-closed test valve opened in response to force coupled through said detent means upon movement of said members to a contracted position, said circulating valve and said test valve being closed in an intermediate position of said members, and indexing means carried by said members and responsive to longitudinal reciprocation of said mandrel member relative to said housing member to guide said members positively in sequence between said extended, intermediate and contracted positions.

31. A well tool comprising: a tubular housing member, a tubular mandrel member slidably and rotatably received in said housing member, said members having opposite ends accessible for connection in a well string and together defining a passage through said tool continuing the full bore of the well string, and a circulating valve for opening said passage to the exterior of said housing member in the extended position of said members, a retrievable test valve assembly sized for reception in said passage and including detent means for releasably engaging said members and a normally-closed test valve opened in response to force coupled through said detent means upon movement of said members to their contracted position, said circulating valve and said test valve being closed in an intermediate position of said members, and indexing means carried by said members and responsive to longitudinal reciprocation of said mandrel member relative to said housing member to guide said members positively in sequence between said extended, intermediate and contracted positions, said indexing means including a follower and a slot system having an annular portion receiving said follower for full rotation of said mandrel member relative to said housing member in one of said positions, said detent means being releasable by such full rotation.

32. A well tool comprising: a tubular housing having circulation ports spaced intermediate of its ends and a lower end arranged for connection with a packing means; a tubular full-opening mandrel slidably received within said housing and having an upper end arranged for con-

nection with a string of tubing, said tubular mandrel further having lateral circulation ports spaced intermediate of its ends and opening into the interior of said tubular mandrel, said tubular mandrel and said housing having means for guiding their limited, relative longitudinal movement between first, second and third positions, said mandrel circulation ports being in fluid communication with said housing circulation ports in said first position, said mandrel circulation ports being displaced from said housing ports in said second position, and means for preventing fluid communication through said mandrel circulation ports in said second position; and a retrievable mandrel assembly sealingly received by said tubular mandrel, means to releasably lock said retrievable mandrel assembly to said tubular mandrel, said retrievable mandrel assembly having a test valve supported at its lower end, sealing means normally closing said test valve to fluid flow from below said lower end when said tubular mandrel and said housing are in the aforesaid first and second positions, said test valve being operative in said third position to open the interior of said tubular mandrel to fluid flow from the interior of said housing below said lower end of said tubular mandrel.

33. A well tool comprising: a tubular housing member to be releasably secured in a well bore, said housing member having a lower end arranged for connection with a packing means; a tubular full-opening mandrel member slidably received within said housing member and arranged for limited telescopic movement therein between longitudinally spaced end positions and a position intermediate of said end positions, said mandrel member having an upper end arranged for connection with a string of pipe; one of said members having an elongated recessed portion terminating in at least one shoulder; said other member having first splines and spline grooves, said first splines being received by said recessed portion and adapted to engage said one shoulder in one of said end positions, said one member having second splines and second spline grooves spaced longitudinally from said shoulder a distance greater than the width of said first splines to provide said intermediate position, said first splines being arranged to be passed through said second spline grooves when said first splines are longitudinally aligned with said second spline grooves thereby to permit passage of said mandrel member to said other end position, said first splines further serving to engage with said second splines when said first and second splines are longitudinally aligned at said intermediate position; bearing means cooperating between said mandrel member and said housing member to limit longitudinal movement of said mandrel member relative to said housing member when said mandrel member is removed to said other end position to facilitate relative rotational movement between said members; and indexing means including a guide system on one of said members and follower means on the other of said members, said guide system and follower means arranged to rotatively position said first splines relative to said second splines so that said first and second spline are selectively engageable at said intermediate position.

34. A well tool comprising: a tubular housing having a lower end arranged for connection with a packing means; a tubular full-opening mandrel slidably received within said housing and having an upper end arranged for connection with a string of tubing; a retrievable inner mandrel assembly disposed within said full-opening mandrel; means to releasably secure said inner mandrel assembly to said full-opening mandrel including detent means interlocking said inner mandrel assembly and said full-opening mandrel; and means to release said detent means from a locking position by relative rotation between said full-opening mandrel and said housing including, unlocking means mounted in said inner mandrel assembly for longitudinal movement, means for co-rotatively coupling said unlocking means to said inner mandrel assembly, actuating means threadedly connected to said unlocking means, means for

holding said actuating means against substantial axial movement relative to said inner mandrel assembly, means for co-rotatively coupling said actuating means to said housing so that relative rotation between said full-opening mandrel and said housing can longitudinally move said unlocking means and release said detent means from a locking position.

35. The device of claim 13 where said release means includes a locking sleeve telescopically received in said inner mandrel assembly and is movable to unlock said detent means, said locking sleeve having a lower threaded end, a jackscrew housing with an upper threaded end coupled to said lower threaded end of said locking sleeve, means coupling said jackscrew housing co-rotatively to said tubular housing, and means coupling said full-opening mandrel co-rotatively to said locking sleeve and means for preventing axial movement of said jackscrew housing.

36. The apparatus of claim 33, wherein said indexing means includes a slot system having an annular slot permitting full rotation of said member.

37. In a tester valve adapted to be disposed in a well bore on a tubular string: relatively movable inner and outer tubular members having a passage therethrough, one of said members being connectible to the tubular string; barrier means in at least a first of said members closing said passage and proportioned to be movable out of said first member; releasable latch means operatively associated with said barrier means; retaining means engaging said latch means to prevent its being shifted to released position to prevent movement of said barrier means from said passage; and means responsive to relative movement between said members for shifting said retaining means downwardly of said latch means to a position permitting release of said latch means, whereby said barrier means can move upwardly out of said first member and upwardly through the tubular string.

38. In tester and reversing valve apparatus adapted to be disposed in a well bore on a tubular string extending to the top of the well bore: inner and outer tubular members movable longitudinally with respect to each other and having a tester passage therethrough, said inner member being within said outer member, said members providing a reversing passage for fluid between the interior of said members and the interior of the tubular string thereabove, on the one hand, and the well bore externally thereof, on the other hand; first co-engageable means on said members adapted to occupy one relative position opening said tester passage in response to relative longitudinal movement between said members in one direction and adapted to occupy another relative position closing said tester passage in response to relative longitudinal movement between said members in the opposite direction; second co-engageable means on said members adapted to occupy one relative position opening said reversing passage in response to relative longitudinal movement between said members in one direction and adapted to occupy another relative position closing said reversing passage in response to relative longitudinal movement between said members in the opposite direction; and means on said members for controlling relative longitudinal movement therebetween to determine the open and closed conditions of said tester passage and reversing passage.

39. In tester and reversing valve apparatus adapted to be disposed in a well bore on a tubular string extending to the top of the well bore: inner and outer tubular members movable longitudinally with respect to each other and having a tester passage therethrough, said inner member being within said outer member, said members providing a reversing passage for fluid between the interior of said members and the interior of the tubular string thereabove, on the one hand, and the well bore externally thereof, on the other hand; first coengageable means on said members adapted to occupy one relative position opening said tester passage in response to relative longitudinal movement between said members in one di-

rection and adapted to occupy another relative position closing said tester passage in response to relative longitudinal movement between said members in the opposite direction; second coengageable means on said members adapted to occupy one relative position opening said reversing passage in response to relative longitudinal movement between said members in one direction and adapted to occupy another relative position closing said reversing passage in response to relative longitudinal movement between said members in the opposite direction; and means on said members for controlling relative longitudinal movement therebetween to selectively control said passages, whereby said tester passage and reversing passage are concurrently in closed position, said tester passage is in open condition while said reversing passage

is in closed condition, or said tester passage is in closed condition while said reversing passage is in open condition.

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