

May 16, 1967

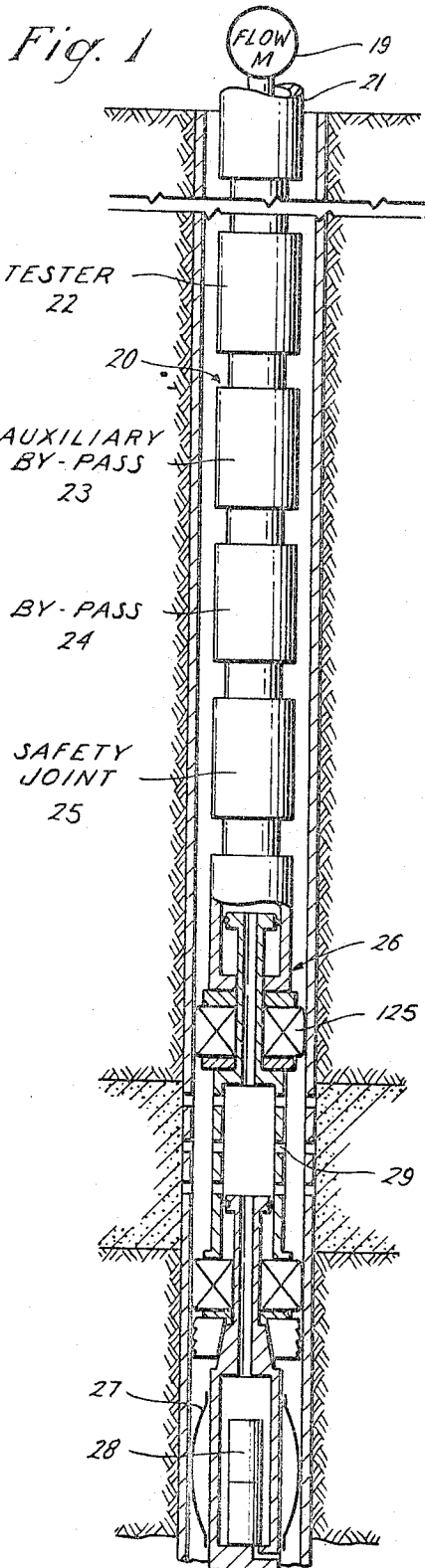
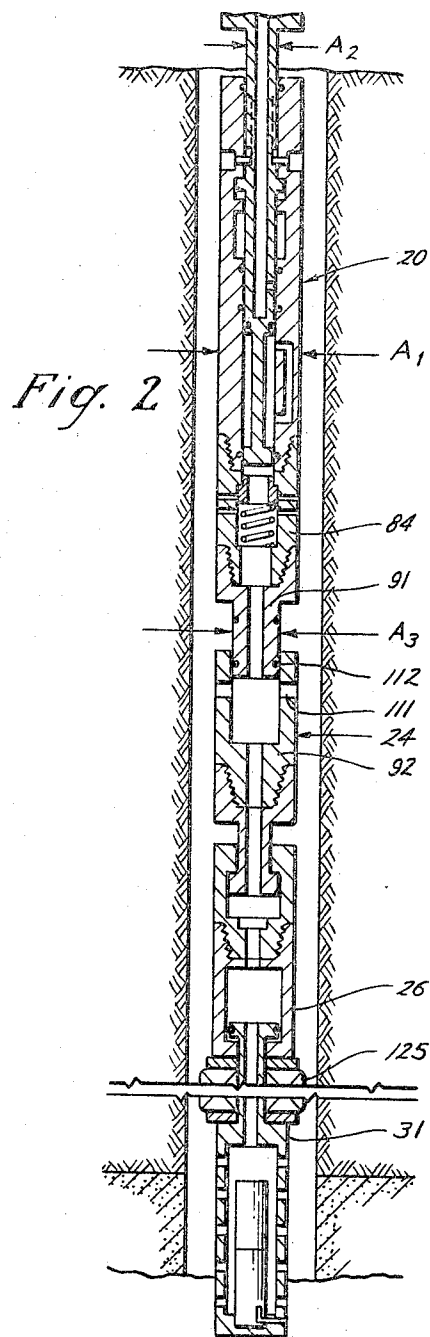
J. C. GRAFF

3,319,718

WELL TESTER

Original Filed Dec. 24, 1963

4 Sheets-Sheet 1



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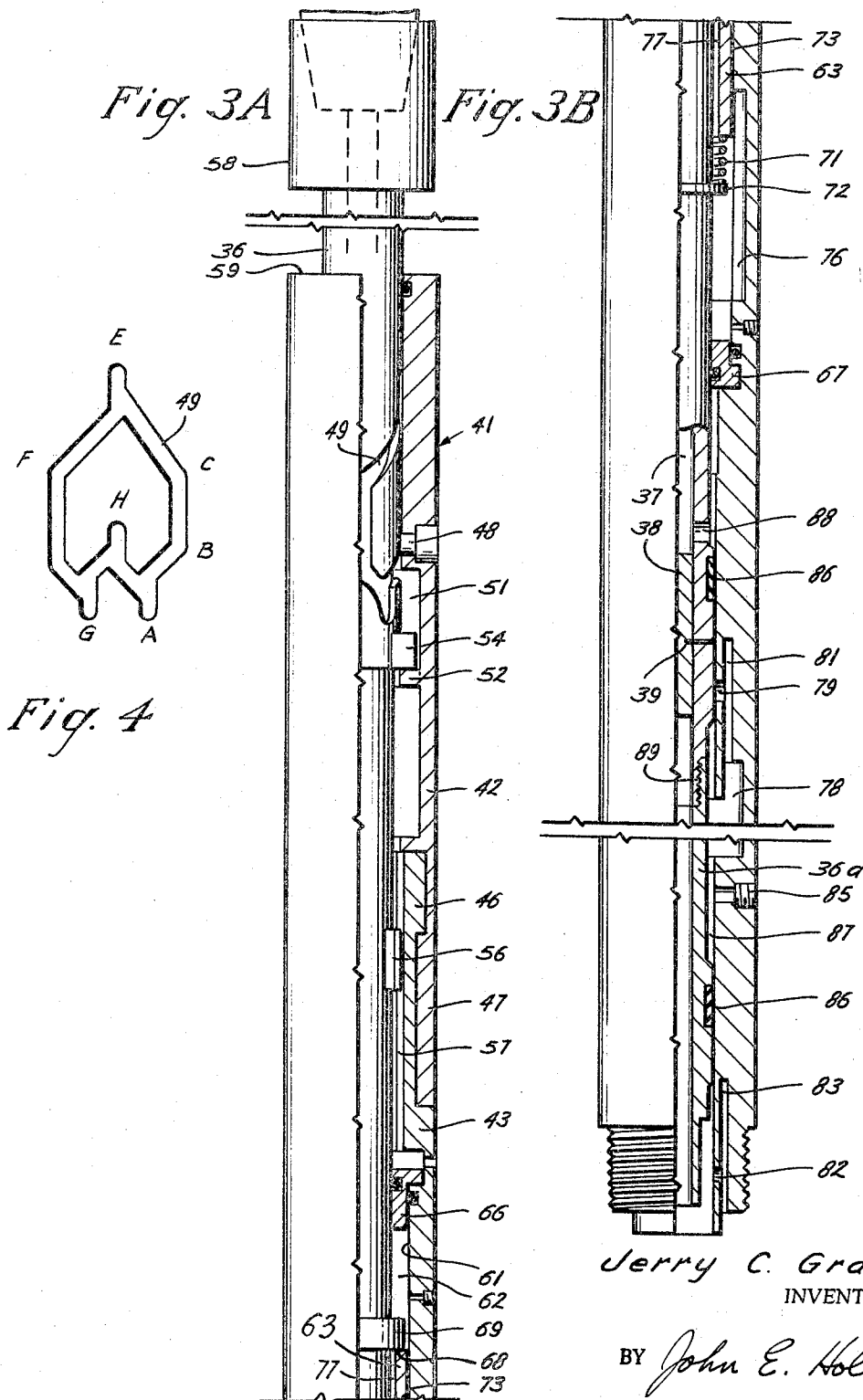
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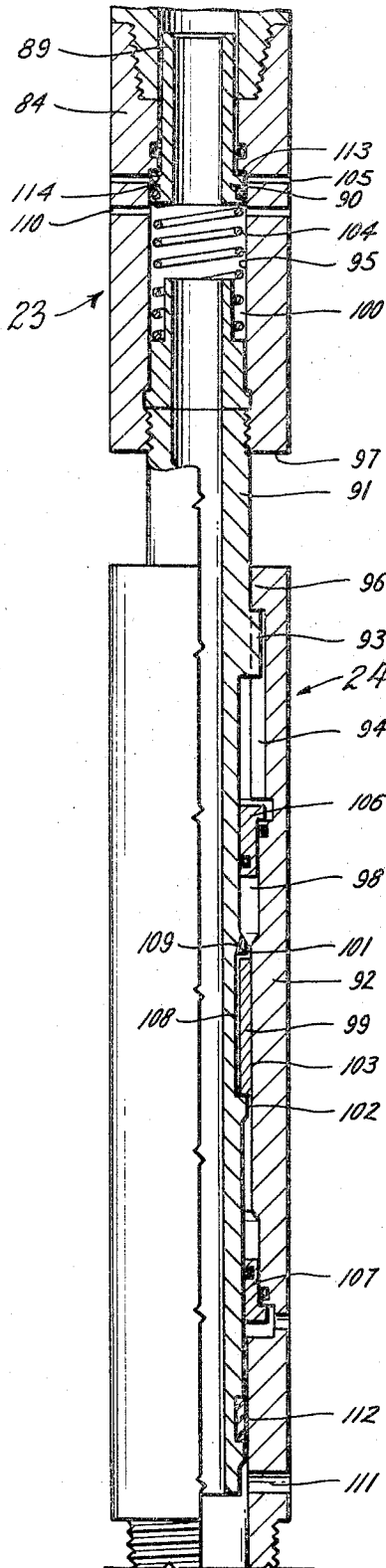


Fig. 5

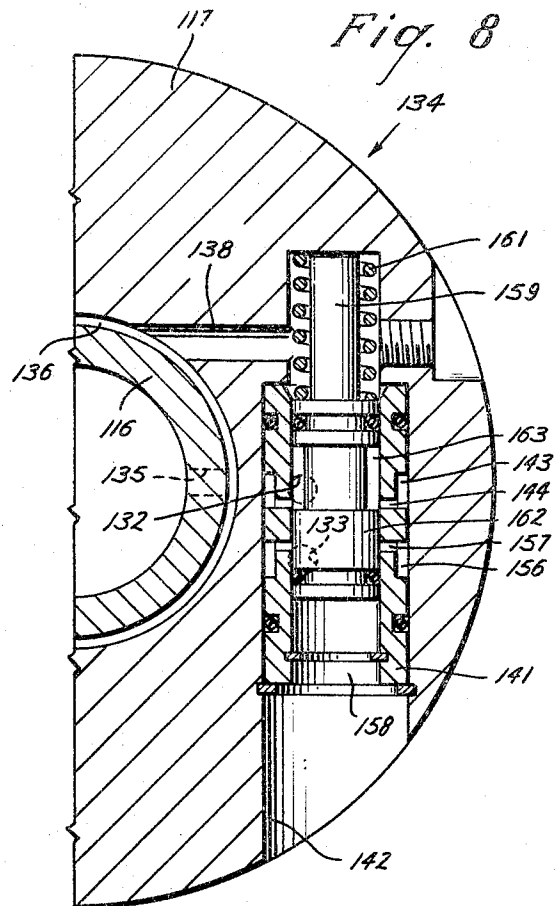


Fig. 8

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Fig. 6

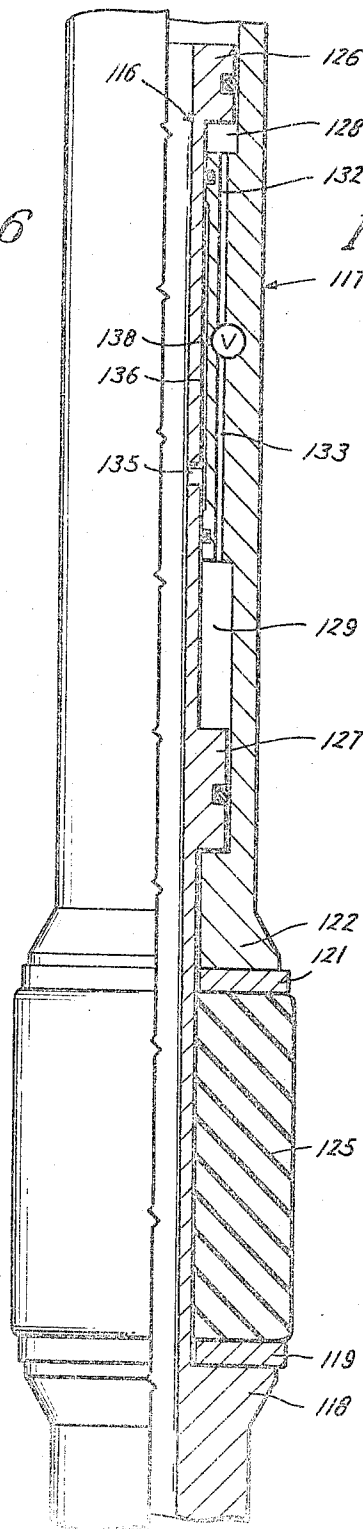
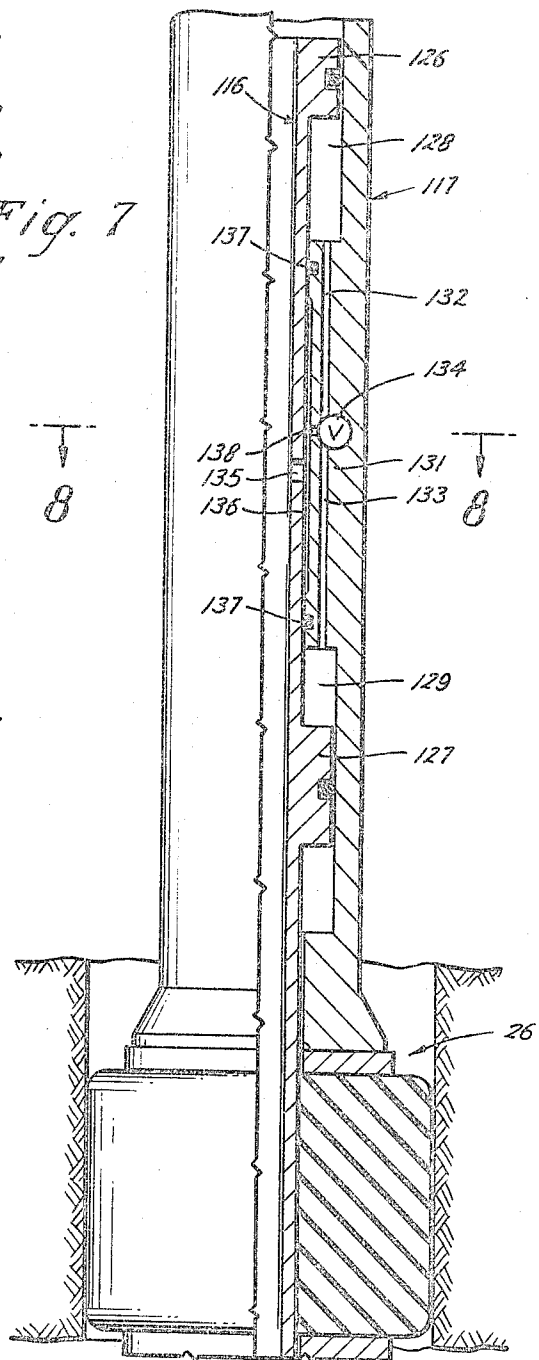


Fig. 7



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3,319,718

WELL TESTER

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Continuation of application Ser. No. 333,223, Dec. 24, 1963. This application Oct. 31, 1966, Ser. No. 591,018 16 Claims. (Cl. 166—150)

This application is a continuation of copending application Ser. No. 333,223, filed Dec. 24, 1963, now abandoned.

This invention relates to apparatus for use in a well bore and more particularly to apparatus for making multiple flow tests in a well bore.

Drill stem tests are normally performed by lowering a string of tools including a testing tool, a bypass valve, and a packer to a desired depth of testing. The packer is set usually by applying force through the drill string, the packer isolating or packing-off the formation to be tested. Subsequently, a test valve in the testing tool is opened and closed by rotation of the drill string while the force on the drill string is maintained on the packer. The number of times that such a test valve may be opened and closed is limited to one or two separate openings and closings and requires a given number of rotations for each operation. Rotation or torquing of the drill string for opening and closing operations is disadvantageous in that all the threaded connections in a tubing string may not be completely made up, therefore the given number of rotations may be taken up by the string of tubing without effecting an operation of the valve in the tool. Also the tubing string may become lodged in the hole intermediate the length of the tubing so that the string of tubing twists above the lodged point without transferring the rotating motion to the tool. Subsequently, the tubing string may twist itself free and then make several uncontrolled revolutions on the lower part of the tubing string which may adversely affect the valve operation. These features of torquing movement involving the uncertainty of the number of turns of the tubing string give the operator little evidence of the position of the tool element in the operations being performed by the tool.

Additionally, the bypass valve is inserted in a tool string to provide a bypass for the circulation of well fluids through the tools and around the packer element which is being inserted in the well bore. Without such a bypass, the packer element, having a large cross-section relative to the well bore, will retard the insertion of the tool string into the well bore by restricting the passage of such fluids around the packer element. The bypass valve is often constructed to close upon anchoring or bottoming of the tools in the well bore. Therefore, if the tool string should encounter a bridge or obstruction in the well bore above the testing point, the bypass valve may close prematurely thus making it difficult to further insert the tool string into the well bore.

It is therefore an object of the present invention to provide a new and improved apparatus for making multiple flow tests in a well bore which apparatus utilizes a vertical movement of the tubing string to perform the various operations in the tool.

Another object of the present invention is to provide a new and improved bypass valve.

Yet another object of the present invention is to provide a bypass valve operated by longitudinal motion, which will pass obstructions in the well bore without closing the valve.

A still further object of the present invention is to provide a new and improved series of full-opening tools which utilize longitudinal movement to make multiple tests of a formation.

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With these and other objects in view, the present invention contemplates an apparatus for making multiple tests on a formation. More particularly, the apparatus includes a series of tools each including telescopically mounted members arranged to selectively move between longitudinally spaced operating positions. The series of tools including tester means, bypass means, jar means, safety joint means and packer means.

The tester means includes means permitting opening and closing of a flow valve by longitudinal stroking movement of the drill string to place the telescoping members in spaced longitudinal positions and in each of such positions, force can positively be applied to the packer.

The bypass means includes means for quick closing of the valve and delayed or retarded opening so that the tester valve can be operated and additionally includes an auxiliary bypass means for maintaining bypass circulation upon encountering bridges or obstructions in the well bore.

The jar, and safety joint means are provided to uncouple the tester and tubing string from the packer in the event of sticking and are compatible to the operation of the tester valve.

The packer means (in one embodiment) can be locked expanded during testing to enable upward and downward movement of the testing tool without unseating the packer.

The novel features of the present invention are set forth in 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 way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a view in elevation of a series of well tools suspended from a string of pipe including an apparatus connected in the series of tools for isolating the formation to be tested;

FIG. 2 is an elevation of the series of tools arranged for going into the well;

FIGS. 3A and 3B are detailed vertical sections of the well testing tool in accordance with the present invention;

FIG. 4 is a developed view of an index slot system used in the tester;

FIG. 5 is a detailed vertical section of a bypass valve, including an auxiliary bypass subsection attached to the upper end of the bypass;

FIGS. 6 and 7 are detailed vertical sections of a releasably locked packer device;

FIG. 8 is an enlarged detailed cross-sectional view taken along line 8—8 of FIG. 7 of a valve utilized in the packer device.

Referring first to FIG. 1, a well tool 20 is arranged to be connected to the lower end of a string of pipe or tubing 21 and includes a tester section 22, an auxiliary bypass section 23, a main bypass section 24, a safety joint section 25, a straddle packer section 26, and a conventional wall anchor section 27. The anchor carries conventional pressure recorders 28 and has perforations 29 in the wall of the packer section to permit fluid to flow into a bore in the packer and up through the string of tools. Two pressure recorders are provided, one recorder measuring pressure externally of the anchor and the other measuring pressure internally of the anchor.

In the operation of the well tool as shown in FIG. 1, the assembled tool 20 is attached to the string of pipe 21, and lowered into the well bore to the formation to be tested. The bypass section 23 of the well tool permits fluids in the well bore to bypass around the packer section 26 as the tool is lowered into the well bore and thereby permits a more rapid descent of the tool into the well bore. If an obstruction or bridge should be encountered

in the well bore intermediate of the formation to be tested, the auxiliary bypass will maintain a fluid bypass around the packer even upon premature closing of the main bypass valve in section 24. When the tools are positioned opposite the formation to be tested, the anchor 27 engaging the side of the borehole, permits manipulation of the packer to set the slips whereupon further downward pressure on the tool will cause elastomer packer elements 125 above and below the formation to be expanded in the well bore to isolate the formation to be tested from the rest of the well bore. Formation fluids enter the tool through the perforations 29 in the packer section and flow upwardly through the various tools to the tester section 22. Valves in the tester section are opened and closed to flow and shut in the formation fluids. The recorders housed in the anchor section are used to measure the pressure of the fluids during the flowing and shut-in periods.

FIG. 2 illustrates an alternative method of locating the well tool tester with respect to the formation to be tested wherein a conventional bottom anchor 31 is used to position the tool 20 on the bottom of the well bore. When the anchor is seated on the bottom, further downward pressure on the tool will cause an elastomer packer element 125 to be expanded in the well bore to isolate the formation to be tested from the rest of the well bore.

Referring now to FIGS. 3A and 3B, details of the tester section of the tool will now be described. The tester section 22 generally includes a telescopically-arranged mandrel 36 and housing 41 respectively arranged for coupling between a pipe string 21 and the other sections of the tool. The tester mandrel 36 has a central bore 37 formed therein and intermediate of the length of the bore is a closure plug or barrier 38 (FIG. 3B) shear pinned at 39 to the mandrel and sealingly received therein. The housing 41 is divided into an upper housing section 42 and lower housing section 43 which are rotatably connected to one another by interlocking and cooperating flanges 46, 47 on the sections 42, 43. Flanges 46, 47 provide a swivel type connection so that the upper housing 42 can be rotated with respect to the lower housing 43.

The upper housing 42 has an index pin 48 projecting into an indexing slot system 49 formed in the mandrel 36. The indexing slot system is shown in a developed view in FIG. 4 and will hereinafter be more fully explained. The upper housing 42 also has an internal recess 51 with an inwardly-projecting spline or lug 52 disposed intermediate of the length of the recess. Housing spline 52 forms an abutment for an upper spline 54 projecting outwardly from the mandrel 36 into the housing recess 51. Splines 52, 54 are engaged and disengaged by operation of the slot system. Mandrel 36 further has a lower outwardly-extending spline 56 which is slidably received within a longitudinally-extending spline groove 57 in the interior of the lower housing.

The slot system as shown in FIG. 4 includes an upper pocket E, an intermediate pocket H and a pair of lower pockets G and A. The upper pocket and intermediate pocket are longitudinally aligned relative to one another while lower pockets G and A are equidistantly spaced to either side of the intermediate pocket H. Inclined and longitudinal slots are provided to connect the upper and intermediate pockets to one another and guide the index pin 48 in a predetermined manner. For example, if the index pin is initially in the lowermost pocket A, the following sequence of movements will produce the following described travel of the index pin:

(a) Upon downward movement of the mandrel, the index pin is guided from the lower pocket A to the upper pocket E;

(b) Upon upward movement of the mandrel, the index pin is guided from the upper pocket E to the lower pocket G;

(c) Upon downward movement, the index pin is guided from the lower pocket G to the intermediate pocket H;

(d) Upon longitudinal movement of the mandrel upwardly relative to the upper housing, the index pin is guided from the intermediate pocket H to the lower pocket A.

From this description, it will be readily grasped that as the mandrel is moved longitudinally up and down, the index pin will follow a predetermined cyclic path. Hence, with the lower housing section 43, held stationary, the spline 56 and spline groove 57 maintain the mandrel 36 against rotation and the upper housing section 42 will be rotated by virtue of the index pin 48 following the slot system 49.

The slot system functions to place the upper housing spline 52 and mandrel spline 54 in engagement when the index pin is in the intermediate pocket H so that downward forces can be transmitted from the mandrel directly to the housing 41 and specifically, to the lower housing section 43 via the splines 52, 54 and the upper housing section 42. In this manner, the mandrel 36 can be pushed down on the housing 41 to apply weight to the string of tools therebelow. When the index pin is moved to the lower pocket A and then toward the upper pocket, the splines are meshed when the index pin moves between points B and C on the slot system (by virtue of relative rotational displacement) and a collar 58 on the upper end of the mandrel 36 can be brought into abutting relationship with the upper end 59 of the upper housing 41 when the index pin is moved to the upper pocket E so that the mandrel can again be pushed down on the housing.

The lower housing 43, below the spline grooves 57, has a bore portion 61 with an enlarged internal diameter forming a cylinder 62 which receives a hydraulic delay piston 63 in the form of a sleeve between the cylinder wall and the mandrel. This annulus formed between the bore 61 and mandrel 36 is filled with a hydraulic fluid and sealed by floating annular piston and seal members 66 and 67, positioned at each end of the bore (FIGS. 3A, 3B). The delay piston 63 abuts on one end against an upper, annular valve seat 68 formed by a flange 69 on the mandrel 36. A delay valve spring 71 is disposed between a lower flange 72 on the mandrel 36 and the lower end of the piston 63. Spring 71 normally urges the piston 63 to seat 68 on the valve seat flange 69. The outer diameter of the piston 63 is less than the diameter of the bore 61 to form a restricted orifice 73. Hence, as the mandrel 36 is moved downwardly relative to the housing 41, the piston 63 seats on the valve seat flange 69 and fluid in the cylinder 62 is metered between the piston 63 and cylinder wall 61 through the restricted orifice 73. This has the effect of delaying movement of the mandrel downwardly relative to the housing.

At the lower end of the bore 61 is relief chamber 76 with a larger diameter so that when the piston 63 is moved into the relief chamber 76, a large fluid flow passage is provided between the piston and the housing. This permits the mandrel to make a sudden movement downwardly until the collar 58 engages the upper end 59 of the housing 41 sending a shock wave to the surface through the string of pipe.

On the other hand, when the mandrel is moved upwardly relative to the housing, the fluid above the piston 63 will move the piston downwardly relative to the mandrel to compress the spring 71. The inner wall of the piston is provided with longitudinal grooves 77 which permit the fluid to bypass between the piston 63 and the mandrel 36 so that the mandrel can be picked up relative to the housing relatively fast as compared to the downward movement of the mandrel.

Below the hydraulic delay system, the housing has a bore portion (FIG. 3B) which slidably and sealingly receives the lower end of the mandrel. The housing bore portion is recessed to provide an annular trap or sample chamber 78 between the housing 41 and mandrel 36. A flow port 79 is provided in the bore portion above the

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recess 78 and extends between the wall of the bore portion and an annular cavity 81 in communication with the recess. Below the recess in the bore portion, the bore portion is similarly provided with a flow port 82 extending between the wall of the bore and an annular cavity 83 in the end of the housing.

The mandrel has spaced sealing elements 86 disposed to either side of a recessed portion 87, the sealing elements being arranged to seal the mandrel 36 relative to the bore above each of the housing flow ports 79, 82. The mandrel 36 also has a flow port 88 disposed above the upper seal and above the plug 38. When the mandrel is moved downwardly relative to the housing, the mandrel recess 87 between the mandrel sealing elements places the lower flow port 82 in communication with the sample chamber 78 and the upper flow port 79 in communication with the mandrel port 88.

In FIG. 5 the auxiliary bypass section 23 and the main bypass section 24 of the tool are illustrated. The auxiliary bypass section includes an auxiliary bypass housing 84 which is tubular in form. A sleeve 89 is slidably received within the housing. A flange portion 90 is formed on the lower end of the sleeve and extends outwardly therefrom. An annular recessed portion 95 which is formed in the bore of the housing intermediate its ends is sized to slidably receive the flange portion of the sleeve and an O-ring seal on the peripheral surface of the flange sealingly engages the recessed bore wall of the housing. Another O-ring seal positioned in the bore of the housing above the recessed portion sealingly engage the outer wall of the sleeve which is slidably received thereon. The upper end of the sleeve 89 extends upward sufficiently to be engaged by the lower end of the tester mandrel 36 upon downward stroking of the tester mandrel.

The lower end of the auxiliary bypass housing has a longitudinal annular slot 100 formed in the wall of the housing with the upper end of the slot opening into the lower end of the annular recess. A coil spring 104 is positioned in the bore of the housing with the lower part of the spring extending into the slot 100 and the upper end of the spring engaging the bottom of the flanged portion 90 of the sleeve 89. This spring serves to bias an upper surface 113 of the flange 90 into engagement with a shoulder 114 forming the upper end of the recess portion 95.

A series of upper ports 105 are formed through the wall of the housing at the upper end of the recessed portion 95 to provide fluid communication between the bore and outside of the housing. A series of lower or auxiliary bypass ports 110 are likewise formed through the wall of the housing and are spaced intermediate the upper ports and the lower end of the recessed portion. Upon downward movement of the sleeve 89 in the housing bore by a downward stroking of the tester mandrel, the lower ports are sealed off by the flange portion and fluid entering the upper ports under hydrostatic pressure serves to act down upon the upper surface 113 of the flange to maintain the sleeve in a down position against the force of spring 104, thereby closing off the auxiliary bypass ports 110.

The lower end of the auxiliary bypass housing is threaded for connection to the upper threaded end of a tubular bypass mandrel 91 which is telescopically received within a tubular housing 92, the mandrel and housing respectively being adapted for coupling in the string of tools 20. A spline 93 on the upper part of the mandrel cooperates with a spline groove 94 in the bypass housing permitting relative reciprocation but preventing relative rotation therebetween. The spline 93 engages a flange 96 on the housing in an expanded position of the bypass section while a shoulder 97 on the mandrel engages the housing flange 96 in a contracted position. Intermediate of the housing is a bore portion 98 forming a cylinder which slidably receives a tubular sleeve piston 99 slidably mounted for limited longitudi-

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nal movement between a bypass flange 101 and seat flange 102 on the mandrel. The sleeve piston 99 has a slightly smaller diameter than the diameter of the cylinder bore thereby forming a restricted orifice 103. The ends of the annular chamber 98 formed between the mandrel and housing are closed by a pair of floating, compensation pistons 106, 107 which enclose a fluid within the chamber. When the mandrel 91 is moved downwardly relative to the housing 92, the fluid in the chamber moves the sleeve piston 99 upwardly and longitudinally-extending grooves 108 in the interior of the sleeve as well as passageways 109 in the bypass flange permit fluid to easily bypass the sleeve piston 99 and permit the bypass section to be rapidly moved to a contracted position. However, when the mandrel 91 is moved upwardly relative to the housing 92 to an expanded position, the fluid above the piston 99 causes the piston to seat on the seat 102 and fluid is metered through the restricted orifice 103 between the sleeve piston and cylinder bore. Hence, the mandrel movement upwardly relative to the housing is delayed and retarded.

The lower end of the housing has a bypass port 111 while the lower end of the mandrel has a sealing element 112 so that, in the contracted position of the mandrel and housing, the bypass port is closed by the sealing element 112 and the floating piston seal 107.

An alternative bypass arrangement is set forth in FIGURE 2 wherein the bypass section 24, which is suspended below the auxiliary bypass section 23 and tester section 22, has a mandrel 91 that is threadably secured to the bottom of the auxiliary bypass housing 84 and is slidably but nonrotatably coupled within a bypass housing 92 by any suitable means (not shown), for example, the spline, groove and flange arrangement shown in FIG. 5. The bypass housing 92 has bypass ports 111 formed therein. Seals 112 which are positioned on the bypass mandrel serve to seal off the bypass ports 111 when the bypass mandrel is in a down position. Upward movement on the bypass mandrel will position the lower seal 112 above the port 111 to provide fluid communication from the interior of the bypass section to the annular space in the well bore. A packer 125 which is positioned below the bypass 24 may depend for its expanded condition upon the bypass valve or port 111 being closed to prevent hydrostatic pressure in the well bore from entering the interior of the bypass housing. Therefore, the maintenance of the bypass in a closed position is important and will be explained.

The bypass is maintained in its closed position by the action of fluid forces on exposed areas of the tester and bypass members. After the bypass is closed, the forces, which act down on the tester housing and bypass mandrel, are maintained greater than the forces acting up on the tester housing and bypass mandrel. The forces acting down can be calculated by multiplying the hydrostatic pressure in the well bore P_h times the difference between the area of the tester housing and the area of the tester mandrel ($A_1 - A_2$) (see FIG. 2). The forces acting up on the system may be calculated by multiplying the hydrostatic pressure P_h times the area of the tester housing minus the area of the bypass mandrel ($A_1 - A_3$) plus the formation pressure P_f times the area of the bypass mandrel minus the area of the tester mandrel ($A_3 - A_2$). This figure ($A_3 - A_2$) is conditioned on the fact that the area of the tester mandrel A_2 is the same as the bore through the auxiliary bypass housing 84 as shown in FIG. 2. Therefore, the difference in this area and the area of the bypass mandrel A_3 represents the effective area subjected to formation pressures P_f . The total force down F_d may be calculated by subtracting the forces up from the forces down as shown in the following equations:

$$F_d = P_h(A_1 - A_2) - P_h(A_1 - A_3) - P_f(A_3 - A_2) \quad (1)$$

$$F_d = P_h(A_3 - A_2) - P_f(A_3 - A_2) \quad (2)$$

$$F_d = (P_h - P_f)(A_3 - A_2) \quad (3)$$

Therefore, if the hydrostatic pressure in the well bore is maintained greater than the formation pressure, the forces acting on the tester and bypass after closure of the bypass valve will serve to maintain the bypass valve in a closed position.

In order to open the bypass, an upward acting force must be applied to the tester housing and bypass mandrel which will overcome the predominant downward forces. This is accomplished by applying lifting force on the tubing string which is sufficient to shift the balance of forces in an upward direction.

It may be appreciated from the foregoing discussion of this bypass system that longitudinal upward and downward movements of the tubing string to manipulate the multiple test section would not open the bypass but rather an upward force calculated to shift the balance of forces must be applied to the bypass mandrel to open the bypass.

The closing of the main bypass valve 111 both as shown in FIG. 5 or alternatively as shown in FIG. 2 is accomplished by the retardation of movement of the bypass housing with continued downward movement of the tool string and the bypass mandrel. This closing may prematurely occur if packer 125 meets an obstruction or bridge in the well bore. The auxiliary bypass section is provided in the tool string in the event that such premature closing of the main bypass takes place.

Upon a bridging action of the packer, auxiliary bypass port 110 remains open to permit bypassing of fluid through the packer section. When the tool string is positioned in the well bore at the depth to be tested and it is desirable to close the auxiliary bypass, the tester mandrel is moved downwardly. Upon such downward movement, the lower end of the tester mandrel engages the upper end of the sleeve 89 and pushes the sleeve down against the action of the spring 104. The flange portion 90 of the sleeve and the seal thereon serve to cover and seal off the auxiliary bypass ports 110. The upper ports 105, at the same time, are uncovered and well fluids under hydrostatic pressure enter the upper ports to act down on the upper surface 113 of the flange 90. The force of the formation fluids in the bore of the now closed bypass plus the force of the spring 104 are less than the force of the well fluids acting down upon the flange. Therefore, the sleeve 89 will remain in the downward position to cover auxiliary bypass 110. When the main bypass port is once again opened by an upward force on the main bypass mandrel, the well fluids under hydrostatic pressure enter the auxiliary bypass bore and balance the hydraulic forces acting upon the flange 90 of sleeve 89. The force of spring 104 then is effective to force the sleeve upwardly in the bore to open the auxiliary bypass ports 110.

In the event that the formation pressure should approach the hydrostatic pressure of the well fluid, the spring may be effective to prematurely force the sleeve upwardly and thereby open the auxiliary ports 110. Therefore, in the alternative, the spring 104 may be removed from the apparatus, thus requiring the formation pressure to exceed the hydrostatic pressure before the valve will prematurely open. In this embodiment, a shear pin connected to the housing 84 will be inserted through the sleeve 89 to keep the sleeve from moving downwardly to close the auxiliary bypass ports 110 before such time as it is desired to close off the ports. When it is desired to close the ports, the downward stroke on the tester mandrel to engage the sleeve 89 will suffice to sever the shear pin and permit downward movement of the sleeve 89 to close the ports 110.

The packer assembly is shown in FIGS. 6-8. The packer assembly includes telescopically-mounted mandrel 116 and housing 117 which are respectively arranged for coupling to the tool sections above and below the assembly. At the lower end of the mandrel is a flange 118 and an annular back-up plate 119. An annular elastomer packing element 125 is received on the mandrel be-

tween the lower back-up plate and an upper back-up plate 121. The housing has a flange 122 abutting the upper back-up plate. It will be appreciated that if the housing 117 is moved downwardly relative to the mandrel 116, the packing element 125 can be expanded to engage the wall of the well bore as shown in FIG. 7.

In the upper part of the mandrel and housing is a system for releasably retaining the packer element in an expanded condition. For this system the mandrel has upper 126 and lower flange portions slidably and sealingly received in the housing and forming a recess or chamber 128, 129 therebetween, the chamber being filled with a hydraulic fluid. The housing has an inwardly-extending piston 131 which is slidably received in the chamber and forms upper 128 and lower 129 recess portions. Upper 132 and lower 133 passageways extend longitudinally through the piston to a valve 134. It will be appreciated that if the valve is opened in the position shown in FIG. 6, connecting the upper 132 and lower 133 passageways to one another, fluid will pass from the lower recess portion 129 to the upper recess portion 128 when the housing 117 is moved downwardly relative to the mandrel 116 to the position shown in FIG. 7. With the packer element 26 expanded, closing of the valve 134 and taking the upper 132 and lower 133 passageways out of communication will trap fluid in the upper recess portion 128 and prevent the housing from moving upwardly relative to the mandrel.

The valve system includes a port 135 in the mandrel 116 opened to a recess portion 136 of the piston between spaced seals 137 and a control port 138 in the piston opening to the valve 134. As shown in FIG. 8, the valve includes a sleeve 141 retained in a bore 142 of the housing, the sleeve 141 having a first annular groove 143 and ports in communication with a first passage 144 and a second annular groove and ports 156 in communication with a second passageway 157. It will be appreciated that FIG. 8 illustrates both upper 132 and lower 133 passageways for convenience of understanding although one of the passageways would not be seen in the section view. The illustration also demonstrates that the upper and lower passageways are offset relative to one another at their access points to the valve.

A bore 158 in the sleeve 141 opens at one end to the exterior of the tool and at the other end to the control port 138. Received in the sleeve bore is a spool type piston 159 arranged for movement between a position placing the upper and lower passageways 132, 133 in communication and a position where the upper and lower passageways are isolated from one another. A spring 161 is provided to normally urge the piston to a position placing the passageways in fluid communication with one another. The piston in the position illustrated has a first portion 162 closing off the sleeve ports leading to passageway, the first portion, however, having a slightly smaller diameter than the bore of the sleeve permitting some fluid leakage to occur. When fluid pressure exterior of the housing is greater than fluid pressure at the control port 138 (which is connected by the piston recess 136 and mandrel port 135 to the interior of the mandrel) and the force of the spring 161, the piston 159 will assume the illustrated position where the first portion 162 of the piston isolates the first 144 and second 157 passageways from one another. When the fluid pressure exterior of the housing is less than the fluid pressure at the control port 138 and the force of the spring 161, the piston is shifted so that a recessed portion 163 of the piston places passageways 144, 157 in communication with one another.

The fluid leakage mentioned above is for the purpose of obtaining release of the valve eventually should a malfunction occur. Thus the packer is never irretrievably set in the well bore.

The differential pressures to control the spool valve are obtained in a manner which will hereinafter be more fully explained.

The operation of the apparatus of FIGS. 3-10 may best be understood by the use of the following table in connection with the description following.

As the tester mandrel is moving down to open the tester valve, the lower end of the tester mandrel abuts and pushes down on the sleeve 89 in the auxiliary bypass

	Going in—	Setting packer	Open tester	Close tester
Tester section 22.....	Expanded.....	Expanded, slowly-moving to contracted...	Contracted..	Expanded to intermediate position.
Index position.....	A.....	A toward C.....	C to E.....	E to G to H.
Shoulder 58, housing end 59.....	Not engaged..	Not engaged..	Engaged.....	Not engaged.
Splines 52, 54.....	do.....	Moving to meshing relationship.....	Not engaged.	Engaged.
Test port 88.....	Closed.....	Closed.....	Open.....	Closed.
Sample chamber 78.....	do.....	do.....	do.....	Do.
Auxiliary bypass section 23.....	Expanded.....	Contracted..	Contracted..	Contracted.
Port 110.....	Open.....	Closed.....	Closed.....	Closed.
Bypass section 24.....	Expanded.....	Contracted..	Contracted..	Contracted.
Port 111.....	Open.....	Closed.....	Closed.....	Closed.
Packer assembly 26.....	Expanded.....	Contracted..	Contracted..	Contracted.
Packer element.....	Contracted..	Expanded.....	Expanded.....	Expanded.
Valve 134.....	Open.....	Open.....	Closed.....	Closed.

CONDITION 1

In going-in the well bore, the various elements and tool parts are in the conditions above noted. In the packer assembly, the valve 134 (FIG. 8) is open because the pressure of the fluids within the packer mandrel 126 are the same as the pressure of the fluids on the exterior of the tool so that the spring 161 places the spool piston 159 in a position where the upper and lower passageways 132, 133 are in fluid communication.

The bypass 24 is held in an expanded position by the weight of the tool attached to the bypass housing 92 so that the bypass port 111 is open and fluid can pass through the packer mandrel 126 and return to the well bore via the bypass port 111.

In the event that a bridge has been encountered by the packer in going in the hole and the bypass port 111 is closed, the auxiliary bypass port 110 will still be open to provide for fluid passage around the packer.

In the testing section, the sample chamber 78 and test ports are closed while the index pin is disposed in pocket A.

CONDITION 2

Upon reaching the level of the test, the packer element 125 is expanded. This occurs because the packer mandrel 126 is fixed relative to the well bore. Fixing the mandrel may be by contact with the bottom by the perforated anchor 27 or by setting a hook wall anchor as shown in FIG. 2. It should be noted that for use of a hook wall packer, the conventional J slot control can be operated because all of the sections are spline connected to permit rotation. While splines are not shown in the packer assembly 26, it will be appreciated that this connection can easily be furnished between the mandrel 126 and housing 117.

As stated heretofore, the packer mandrel is fixed and a downward motion on the string of pipe is transmitted through the tool sections to move the upper packer housing 117 relative to the packer mandrel 126 and expand the packer element 125. As the packer element expands, the bypass section 24 contracts to close the bypass port 111 bringing the bypass mandrel shoulder 97 into abutment with the bypass housing. In the tester section the fluid in the delay system is trapped below the piston 63 and very slowly meters through the restricted orifice 73. At this time, the index pin is moving from pocket A toward pocket E and rotating the upper housing 42 to place the splines 52, 54 in meshing relationship to one another. Well before the tester section becomes contracted the packer is fully expanded and the main bypass is closed.

CONDITION 3

After the packer is fully expanded, the delay piston 63 in the tester section reaches the recessed portion 76 and very quickly permits the tester mandrel and housing to contract and very quickly opens the mandrel test port 88 and sampling chamber 78 to the bore of the well tool which extends down to the perforated anchor 27 below the expanded packer.

to close the auxiliary bypass port. This quick motion is apparent at the surface of the earth and gives an indication to the operation that the tool is properly operating. Because the interior of the string of pipe and the formation pressures are considerably less than the hydrostatic pressure of the well fluid above the expanded packer, the valve 134 in the packer is closed trapping fluid in the upper recess 128 of the packer assembly. At this time, the tester mandrel shoulder 58 engages the upper housing 42, the bypass shoulder 97 engages the bypass housing 92 and downward pressure on the string of pipe can be continuously maintained on the packer element to ensure that it will remain expanded. During this condition, the index pin has traveled from position C into the pocket E.

CONDITION 4

After fluid has flowed for a sufficient period of time, say fifteen minutes, the tester is closed for say, five minutes, to obtain a shut-in pressure. To close the tester the string of pipe is picked up a sufficient distance to index the pin from the upper pocket E to the lower pocket G and then set down to index the pin to the intermediate pocket H.

In picking up the string of pipe, the delay valve in the tester opens to permit quick bypass of fluid around the delay valve and movement of the tester section to the expanded condition. At the same time, the delay valve in the main bypass retards movement of the bypass to an expanded position and the closed valve 134 in the packer assembly prevents release of the expanded packer element 125. The auxiliary bypass is maintained closed by the action of fluid pressure entering the now open ports 105 to act down upon the flange 90. The splines 52, 54 in the tester section are meshed once again and the mandrel spline 54 is disposed above the housing spline 52. Thus, when the string of pipe is set down and the index pin goes to the intermediate pocket, the splines are brought into abutment and direct force on the string of pipe is once again directly transmitted to the packer assembly to positively hold the packer element expanded to close off the formation while the pressure of the formation fluids is measured.

When the tester is closed a fluid sample is trapped in the sample chamber 78. If it is desired to retrieve the well tool, picking up of the drill pipe moves the index pin from pocket H to pocket A.

On the other hand, it is often desirable to repeat the above sequence of operations a number of times which permits the formation fluids to eventually flush out the filtrate and a true recovery from the formations to be obtained.

To determine when the fluid recovery is formation fluids, a gas flowmeter 19 (FIG. 1) is connected to the string of pipe at the surface. As fluids enter the string of pipe the displacement of air in the pipe is indicated by the flowmeter. At a point where the formation fluid flow stabilizes the gas flow becomes constant indicating completion of the test.

In order to retrieve the tool string 20 and the fluid sample trapped in the chamber 78, the packer element 125 must be contracted to release the tools from the well bore. This step may be accomplished by picking up on the tool string to close the tester valve and trap a fluid sample at formation pressures. Therefore, the bypass mandrel 91 is lifted up relative to the bypass housing 51. A continued lifting force on the mandrel 91 will permit sufficient fluids to leak by the bypass piston 99 through the restricted orifice 103 to allow the mandrel and seal 112 to uncover the bypass port 111. The opening of port 111 subjects the inner bore of the tool sections to the hydrostatic pressure of the well fluids thereby increasing the inner bore pressure and consequently communicating the increased pressure with the control port 135 of the packer. This pressure in turn acts with spring 161 to move the piston 159 forward and open the valve 134 to connect the upper and lower passageways 132 and 133. The valve opening permits expanding movement of the packer mandrel and housing to release the packer element 125 from compression and engagement with the well bore. The opening of bypass valve 111 also subjects the bore of the auxiliary bypass to the hydrostatic pressure to balance the force acting down on flange 90 and thereby render the spring 104 effective to move the flange 90 and sleeve 89 upward to open the auxiliary bypass ports 110.

Further upward movement of the tubing string will withdraw the tool string from the well bore.

If the tool string should become lodged in the well bore below the safety joint, the tubing string may be rotated above the joint to release the upper part of the string for retrieval to the surface. In order to affect the loosening of the threads in the safety joint, it may be necessary to lower an explosive element or string shot into the full open bore of the tool string to the level of the safety joint whereupon the shot is detonated to loosen the joint for subsequent unthreading by rotation of the tubing string. The knock out plug 38 which serves the purpose of blocking the tester section mandrel bore 37 during flow testing of the well may be removed by dropping an object in the bore of the tubing string which object serves to shear the pin 39 to knock out the plug 38. This opens the bore for lowering of the string shot to the safety joint section 25.

After retrieving the tool to the surface, it is necessary to analyze the sample trapped in the chamber 78 at the conditions under which it was trapped. To effect this purpose, a plug 85 is threadably received in the wall of the lower tester housing 43 (FIG. 3B). Manipulation of the tester members will permit sealing off of this plug port for removal of the plug and insertion of test instruments while maintaining the sample at reservoir conditions. Subsequently, the tester mandrel is moved to uncover the plug port and place the instruments in communication with the sample chamber for analysis of the trapped fluid.

Different well testing apparatus is usually designed for use in open and cased well bores. While this invention is primarily directed to apparatus for testing open well bores it will be appreciated that features of the present invention can have application for testing apparatus for cased well bores.

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 bypass system for use in a string of tools being inserted into a well bore, said string of tools including a first portion with at least one longitudinally movable part, said bypass system comprising first telescoping members having main bypass valve means for permitting flow

of well fluid between the exterior and interior of said members to facilitate insertion of the string of tools in a well bore, and second telescoping members connected in said string of tools to said first portion, said second telescoping members having auxiliary bypass valve means for providing an additional fluid bypass between the exterior and interior of said second telescoping members, one of said second telescoping members being engageable with said part to permit independent operation of said auxiliary bypass valve means in response to longitudinal movement of said part.

2. A device for equalizing pressure between the interior and exterior of a string of pipe within a well bore comprising: a bypass tool having tubular telescopically arranged members for connection in a string of tools, a main bypass valve in said members for selectively bypassing fluids between the exterior and interior of said string of pipe, means on said bypass tool for permitting an unrestricted closing of said bypass valve while retarding the opening of said valve, an auxiliary bypass valve on said bypass tool for bypassing fluids between the exterior and interior of said string of pipe when said unrestricted closing valve prematurely closes, and means for operating said auxiliary bypass valve independently of said main bypass valve.

3. A device for equalizing pressures between the interior and exterior of a string of pipe within a well bore comprising: a bypass tool having tubular telescopically arranged members for connection in a string of tools, a main bypass valve in said members for selectively bypassing fluids between the exterior and interior of said string of pipe, means on said bypass tool for permitting an unrestricted closing of said bypass valve while retarding the opening of said valve, an auxiliary bypass valve on said bypass tool for bypassing fluids between the exterior and interior of said string of pipe when said unrestricted closing valve prematurely closes, means operative upon longitudinal movement of said string of pipe for selectively closing said auxiliary bypass valve, and means operative upon the opening of said main bypass valve for opening said auxiliary valve.

4. Apparatus forming a valve system in a well tool suspended from a string of pipe including: a main valve means having a port and movable means for selectively passing fluid through the port, and an auxiliary valve means having longitudinally spaced ports and means for selectively passing fluid through one of said longitudinally spaced ports, said last mentioned valve means being responsive to longitudinal positioning of said string of pipe for selectively closing said auxiliary valve means.

5. Apparatus forming a valve system in a well tool suspended from a string of pipe including: a main valve means having a port and movable means for selectively controlling fluid flow through the port, and an auxiliary valve means having longitudinally spaced ports and means for selectively controlling fluid flow through one of said longitudinally spaced ports, said other port providing a passage through which fluid pressure can act on said flow controlling means when said one port is closed to exert a force on said flow controlling means, said auxiliary valve means being responsive to longitudinal positioning of said string of pipe for selectively closing said auxiliary valve means.

6. Apparatus in a well bore containing a well fluid for flow testing the well including, telescopically arranged tester members movable between spaced longitudinal positions, valve means in said tester members for controlling flow through said tester members in said positions, packer means arranged to be expanded into packing off relationship, bypass means intermediate said tester members and said packer members, said bypass means having a first valve means for providing a fluid communication path between the well annulus space above and below said packer means, said first valve means including telescopically arranged tubular members movable between expanded

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and contracted positions for opening and closing said fluid communication path, said bypass means additionally having a second valve means for providing a fluid communication path between the well annulus spaces above and below said packer means even though said first valve is closed, and means for closing said second valve means in response to movement of one of said tester members.

7. Apparatus in a well bore containing a well fluid for flow testing the well including: telescopically arranged tester members movable between spaced longitudinal positions, valve means in said tester members for controlling flow through said tester member in said positions, packer means including telescopically mounted parts and a packer element disposed on one of said packer parts and arranged to be expanded by relative motion between said telescoping packer parts, first hydraulic means for releasably holding said telescoping packer parts against movement when said packer element is expanded, bypass means intermediate said tester members and said packer means, said bypass means having a first valve means for providing a fluid communication path between the well annulus spaces above and below said packer element, said first valve means including telescopically arranged tubular members movable between expanded and contracted positions to open and close said fluid communication path, said bypass means also having a second valve means for providing a fluid communication path between the well annulus spaces above and below said packer element even though said first valve is closed, means for closing said second valve means in response to the longitudinal movement of one of said tester members, second hydraulic means for releasably holding said second bypass valve means closed, means responsive to the opening of said first bypass valve means for releasing said first hydraulic means to permit relative movement of said packer parts, and means responsive to the opening of said first bypass valve means for releasing said second hydraulic means for said second bypass valve means.

8. A well tool having telescopically mounted tester, packer and bypass means adapted for coupling in a string of pipe and passage through a well bore containing well fluids for the purpose of testing earth formations, said tester means including members telescopically arranged for movement between expanded and contracted positions, each of said tester members having separate passageways and valve means responsive to positioning of the members in said positions to place said passageways into and out of fluid communication with one another, said packer means including a packer element for packing off the well bore and means for directing fluids from earth formations below said packer element to said tester means, said packer element being disposed between telescopically mounted members so as to expand upon relative movement therebetween, said packer means further having means for releasably holding said packer telescopic members in a position where said packer element is expanded, said bypass means including a pair of tubular telescopically arranged bypass members arranged for movement between spaced longitudinal positions, said bypass means having a first bypass port formed therein for placing the exterior and interior of said bypass members in fluid communication, said first bypass port being respectively opened and closed in said longitudinal positions of the bypass members, and means operative when said first bypass port is closed for retarding the relative movement of the bypass members to delay the opening of the bypass port, said bypass means having a second port formed therein for placing the exterior and interior of said bypass members in fluid communication, said second bypass port being opened and closed in response to the positioning of one of said tester members.

9. A well tool having a bypass means adapted for coupling in a string of pipe and passage through a well bore containing well fluids, said bypass means including a mandrel and housing member telescopically arranged

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for movement between expanded and contracted positions, said bypass means having a first valve providing a fluid communication path between the exterior and interior of the well tool in one of said positions, means for restricting relative movement between said mandrel and housing member when said first valve is closed while permitting rapid movement of said mandrel and housing member to said other position to close said first valve, said bypass means having a second valve for providing a fluid communication path between the exterior and interior of the well tool when said first valve is closed, and means independent of the relative movement of said mandrel and housing member for closing said second valve.

10. Apparatus for providing selective fluid communication between the inside and outside of a well tool comprising: a tubular housing having a longitudinally extending passageway therethrough, said housing having a portion defining an annular recess intermediate the ends of the housing; a sleeve valve movably received in said passageway, said sleeve valve having an annular portion extending outwardly into said annular recess to form an annular chamber between said annular portion and one end of said recess; a bypass port in the wall of said housing adapted, when open, to provide fluid communication between said passageway and the outside of said housing; another port in the wall of said housing at all times providing fluid communication between the outside of said housing and said annular chamber; means normally urging said sleeve valve toward a position where said bypass port is open; and means for forcibly moving said valve element against the action of said urging means to a position where said valve element closes said bypass port.

11. Apparatus for providing selective fluid communication between the inside and outside at a well tool comprising: a housing having a bore therethrough, said housing having means providing a recess therein; a tubular valve element slidably received in said housing, said bore in said housing and the interior of said valve element providing a passageway extending longitudinally through said well tool, said valve element having an enlarged portion extending into said recess; a bypass port in the wall of said housing adapted, when open, to provide fluid communication between said passageway and the outside of said housing; another port in the wall of said housing providing fluid communication between the outside of the said housing and said recess on one side of said enlarged portion; and means for shifting said valve element between a first position where said bypass port is open and a second position where said valve element closes said bypass port, said another port being in communication with said recess on said one end of said enlarged portion in both of said positions.

12. Apparatus for providing selective fluid communication between the inside and outside of a well tool comprising: a tubular housing having a longitudinally extending passageway therethrough, said housing having a portion defining an annular recess intermediate the ends of the housing; a sleeve valve movably received in said passageway, said sleeve valve having a longitudinal passageway therethrough and an annular portion extending outwardly into said annular recess to form an annular chamber between said annular portion and one end of said recess; a bypass port in the wall of said housing adapted, when open, to provide fluid communication between said passageway and the outside of said housing; another port in the wall of said housing at all times providing fluid communication between the outside of said housing and said annular chamber; and means normally maintaining said sleeve valve in a position where said bypass port is open; said sleeve valve being forcibly movable to overcome said maintaining means and thereby move to a position where said sleeve valve closes said bypass port.

13. Apparatus for providing selective fluid communication

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tion between the inside and outside at a well tool comprising: a housing having a bore therethrough, said housing having means providing a recess therein; a tubular valve element slidably received in said housing, said bore in said housing and the interior of said valve element providing a passageway extending longitudinally through said well tool, said valve element having an enlarged portion extending into said recess; a bypass port in the wall of said housing adapted, when open, to provide fluid communication between said passageway and the outside of said housing; and another port in the wall of said housing providing fluid communication between the outside of said housing and said recess on one side of said enlarged portion; said valve element being shiftable between a first position where said bypass port is open and a second position where said valve element closes said bypass port, said other port being in communication with said recess on said one end of said enlarged portion in both of said positions.

14. A bypass device for use in a string of tools being inserted into a well bore, said bypass device comprising: first telescoping members having main bypass valve means for passing well fluid between the exterior and interior of said members to facilitate insertion of the tool string in a well bore; second telescoping members connected to said first telescoping members, said second telescoping members having auxiliary bypass valve means for providing an additional fluid bypass; and means movable into engagement with one of said second telescoping members for selectively operating said auxiliary bypass valve means independently of said main bypass valve means.

15. A well tool for use in a string of tools in a well bore including; first and second bypass valves for selectively permitting fluids to flow between the interior and exterior of said string of tools, said first bypass valve including telescopically arranged tubular members coupled to one another for substantially unrestricted relative motion in at least one direction to facilitate closing of said first bypass valve, said second bypass valve including telescopically arranged members coupled to one another and including means for maintaining said second

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bypass valve in a normally open position, one of said members of said second bypass valve being shiftable after closing of said first bypass valve to close said second bypass valve, and hydraulic means in said second bypass valve ported to the exterior of said string of tools for maintaining said second bypass valve in a closed position.

16. In a string of well tools having a formation tester and packer members below said formation tester for isolating earth formations traversed by a well bore, a first bypass valve in said string of well tools above the packer members for bypassing fluids between the exterior and interior of said string of well tools to facilitate insertion of the tool string in the well bore, said first bypass valve having telescopically arranged tubular members coupled to one another for substantially unrestricted relative movement in at least one direction for facilitating closing of said first bypass valve, a second bypass valve positioned in said string of well tools between said first bypass valve and the formation tester for bypassing fluids between the exterior and interior of said string of well tools to facilitate insertion of the tool string in the well bore, said second bypass valve having telescopically arranged members coupled to one another and including means for maintaining said second bypass valve in a normally open position, and means in said second bypass valve movable in response to operation of said formation tester for closing said second bypass valve.

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