United States Patent [19]

Nutter

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[54] **PRESSURE CONTROLLED TESTER VALVE**

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[52] **U.S. Cl.** **166/152;** 166/226

[51] **Int. Cl.²** **E21B 49/00**

[58] **Field of Search** ..... 73/151; 166/152, 150, 162, 166/226, .5, 155

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Primary Examiner—David H. Brown

Attorney, Agent, or Firm—David L. Moseley; William R. Sherman; Stewart F. Moore

[57] **ABSTRACT**

In accordance with an illustrative embodiment of the present invention disclosed herein, an annulus pressure controlled formation testing valve includes a valve actuator mandrel with a piston head that normally is subject to balanced pressure during the application of an operating pressure sufficient to cause the test valve to open. However, should the operating pressure exceed a normal range, annulus fluid is admitted to act on the piston head as a supplemental closing force to automatically move the valve to closed position.

12 Claims, 4 Drawing Figures

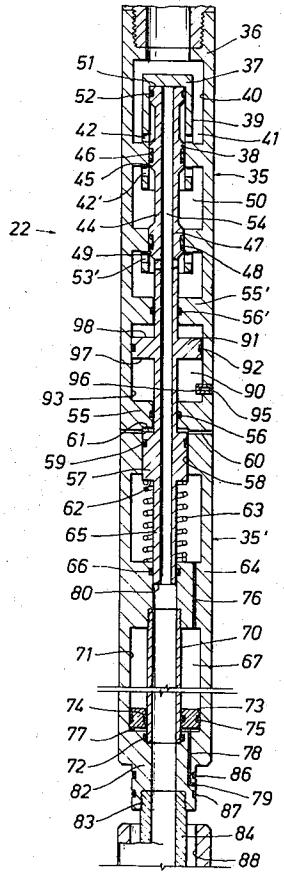


FIG. 1

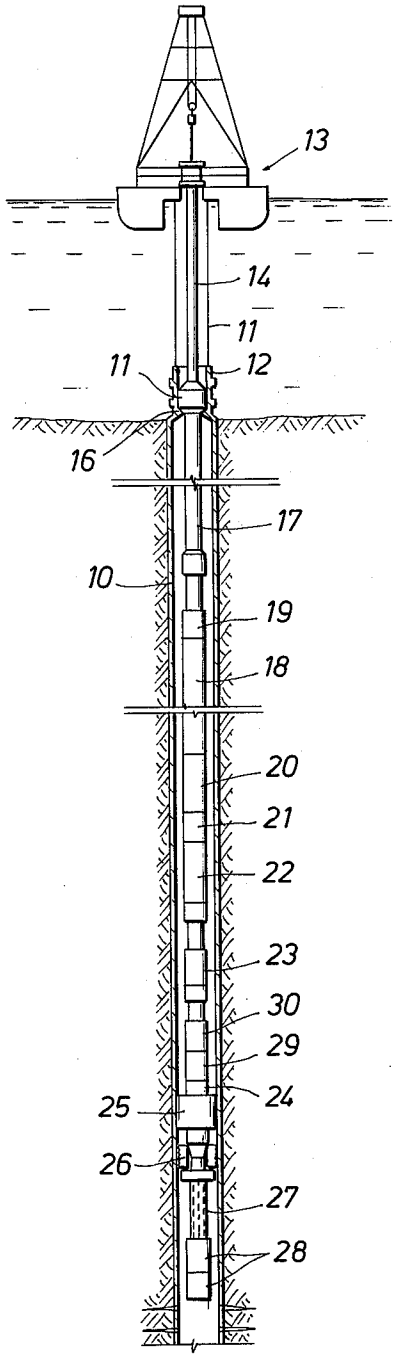

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FIG. 2

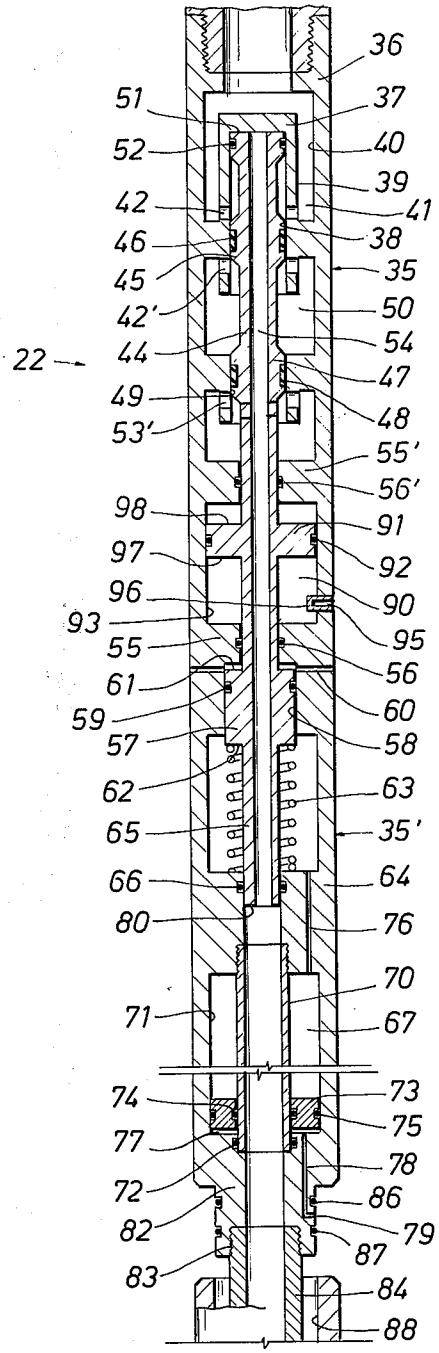

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FIG. 3

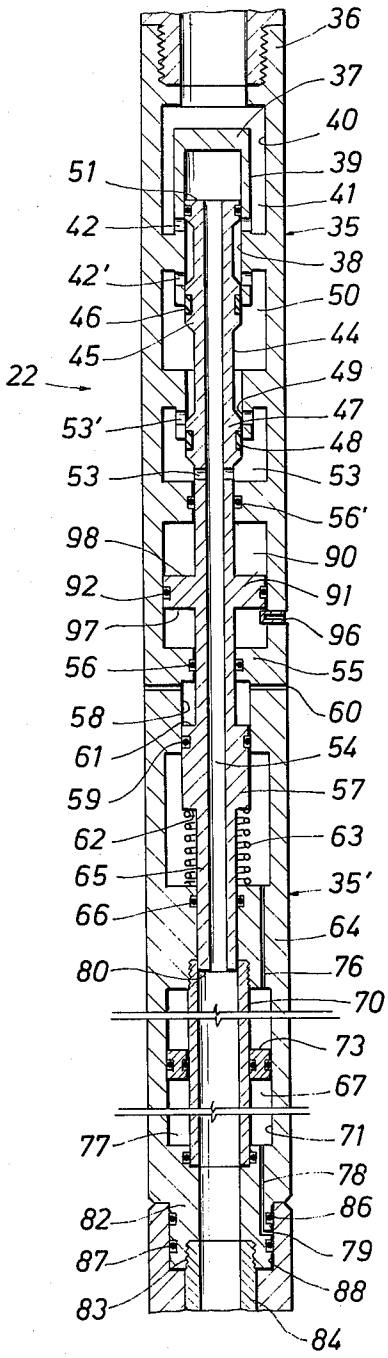
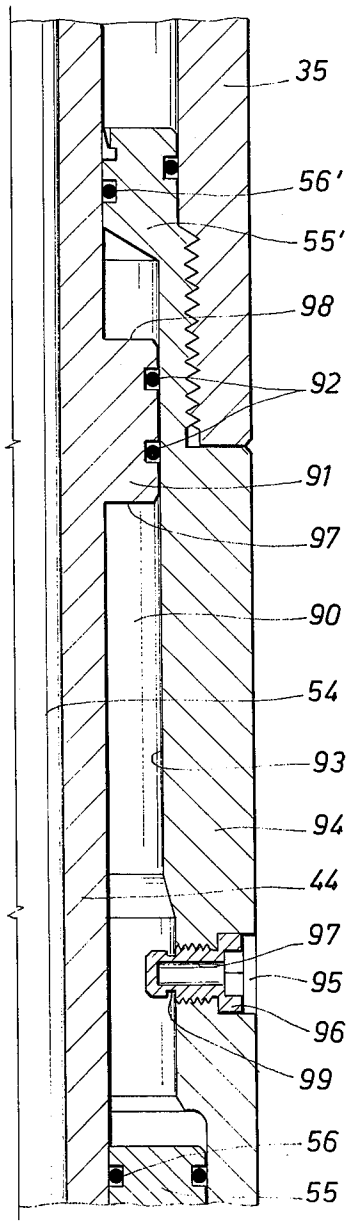

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FIG. 4


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PRESSURE CONTROLLED TESTER VALVE

This invention generally relates to drill stem testing, and specifically to an annulus pressure operated drill stem testing valve apparatus having provision for automatically closing the test passage should the annulus pressure exceed a predetermined amount.

Formation testing systems for conducting a drill stem test of an offshore well from a floating drilling vessel typically are arranged with valves that respond to changes in pressure in the well annulus in order to open and close a test passage leading from the isolated formation interval upwardly toward the surface. Such a system is shown, for example, in my U.S. Pat. No. 3,824,850, assigned to the assignee of this invention. The test valve, which normally is closed, is opened by increasing the annulus pressure and is closed by bleeding off the increase in pressure to thereby enable the isolated formation interval to flow and to be shut-in a selected number of times during which pressure data is instrumentally recorded.

It is desirable to provide for automatic closure of the test valve in the event the annulus pressure, for any reason, becomes excessive. This could occur, for example, where the pipe string that leads to the surface develops a leak which causes the annulus outside the pipe to be charged with formation pressure. Should this occur, a hazardous situation may arise if the operator is unable to close the test valve.

It is the principal object of the present invention to provide a new and improved valve apparatus of the type described that is moved from its normally closed to its open position in response to the application of a hydraulic operating pressure, and which is automatically moved to closed position should the said operating pressure exceed a predetermined magnitude.

This and other objects of the present invention are attained through the provision of a test valve apparatus having a valve actuator including a piston that is subject on one side to the pressure of fluids in the well annulus and on the other side to a closing force. When the annulus pressure predominates over the closing force, a valve element operatively associately with the actuator is moved to open position; when the closing force predominates, the valve element is moved to closed position. In combination therewith is provided a means operable at a predetermined magnitude of annulus pressure predominance for applying the said annulus pressure as a supplemental closing force to cause the valve actuator to shift to the valve element to the closed position. In this manner, should annulus pressure be raised either purposely or due to some unforseen circumstance to an excessive level, the valve is automatically closed to block the flow passage leading to the formation interval undergoing test.

The present invention has other objects, features and advantages which will become more readily apparent in connection with the following detailed description of a preferred embodiment, taken in conjunction with the appended drawings in which:

FIG. 1 illustrates somewhat schematically a drill stem test being conducted in an offshore well from a floating rig;

FIG. 2 is a detailed cross-sectional view of the present invention with parts in position for running into the well and with the control valve closed;

FIG. 3 is a view similar to FIG. 2 except with the parts in the positions occupied during a portion of a test where the test valve is open; and

FIG. 4 is an enlarged fragmentary cross-sectional view of a portion of the apparatus shown in FIGS. 2 and 3.

Referring initially to FIG. 1, a drill stem test using equipment constructed in accordance with the principles of the present invention is shown being conducted in an offshore well. Although the well may be open hole, it is usually cased at 10 as shown. A riser 11 normally extends from a subsea well head assembly 12 upward to the floating drilling rig or vessel 13 which is anchored or otherwise moored on location. A pipe string 14 extends from the vessel 13 downward into the well and is used to lower the test tools to test depth. The pipe string 14 can include a sub sea control vave assembly 15 of typical design and providing a landing shoulder 16 that is seated in the well head assembly 12 so that the pipe string and test tools therebelow are suspended from a fixed point not subject to vertical motion which the vessel 13 experiences under the influence of wave and tide action.

A major string of pipe 17, such as a suitable length drill pipe, is connected to a minor string of pipe 18, such as drill collars having a preselected weight, by a slip joint and safety valve combination tool 19 of the type disclosed in U.S. Pat. No. 3,652,439, Kisling, assigned to the assignee of this invention. The lower end of the minor string 18 may be connected to a reversing valve 20 which is in turn connected to a choke assembly 21, the reversing valve and choke assembly being conventional items of equipment whose details form no part of the present invention. Of course the choke assembly 21 limits the rate of upward flow of formation fluids during a test, and the reversing valve 20 can be operated in such a manner as to enable fluids that are produced into the pipe string during a test to be recovered at the surface before the test equipment is retrieved.

A pressure controlled test valve 22 that is constructed in accordance with the principles of this invention is next connected in the string of tools and will be described in detail herebelow. The test valve 22 may be coupled to the upper end of a flow control valve 23 of the type shown in my U.S. Pat. No. 3,308,887, also assigned to the assignee of this invention, the valve 23 being operated in response to only vertical motion of the pipe string. For purposes of isolating the well interval to be tested from the hydrostatic head of fluids thereabove, a well packer 24 is provided and includes packing elements 25 to seal off the well bore and slips 26 to anchor at the proper level above the well interval to be tested. The packer 24 can be of the type shown in U.S. Pat. No. 3,399,727, McGill, assigned to the assignee of the invention, and includes an integral fluid bypass arrangement that enables well fluid to bypass through the packing element 25 during lowering, but is closed off when the packer is set. The elements 25 seal off the cross-section of the well bore to isolate the zone to be tested from the fluid in the annulus thereabove, and of course at the end of the test the bypass referred to above is opened to equalize pressure and enable release of the packer 24 and retrieval of the tools to the surface. Suspended below the packer 24 is a perforated nipple 27 to enable fluid entry during the test, and of course suitable pressure recorders 28 are provided to

make a record of the pressures of fluids versus time as the test proceeds. Other typical equipment such as a safety joint 29 and a jar 30 can be connected between the control valve 23 and the packer 24 but are shown only schematically to simplify this disclosure.

In general terms, a formation test amounts to a temporary completion of the well, in that the isolated formations are allowed to produce fluids into the pipe string. The formation is then shut-in and the pressure allowed to build up over a period of time. A record of the pressure build-up curve can be analyzed by known techniques to determine formation permeability and the initial or virgin formation pressure, plus other parameters that are invaluable aids to a reservoir engineer in coming to a decision on whether to recommend a permanent completion of the well. Several flow and shut-in pressure records can be obtained for additional information.

Turning now to FIG. 2, one embodiment of a pressure operated test valve assembly 22 that is constructed in accordance with the principles of the present invention will be described. The valve assembly 22 includes, in general, an upper sampler and valve section 35 and lower valve operating section 35'. The sections are formed by a tubular housing member 36 having its upper end adapted as shown for connection to a pipe string and with its through bore closed by a barrier 37 located above an annular valve seat 38. The outer side walls 39 of the barrier 37 are spaced laterally inwardly with respect to the surrounding internal walls 40 of the adjacent housing section to provide a space 41 for fluid passage. One or more side ports 42 in the walls of the barrier 37 communicate the bore thereof with the space 41. A vertically movable valve mandrel 44 has its upper end portion slidably received within the bore of the barrier 37, and a valve head 45 carries seal elements 46 which engage the valve seat 38 when the valve mandrel is in its upper or closed position. A second valve head 47 is provided on the valve mandrel 44 in spaced relation to the upper valve head 45 and also carries seal elements 48 which normally engage a lower annular valve seat 49. The annular space 50 surrounding the valve mandrel 44 between the seats 38 and 49 provides a sample chamber for trapping the last flowing sample of formation fluids as will be described further below. The center bore 54 of the valve mandrel 44 is open from one end to the other so that fluid pressures are free to act on the upper end surface 51 thereof, however the uppermost end of the mandrel is sealed with respect to the barrier 37 by a suitable seal ring 52. One or more ports 53 extend through the wall of the valve mandrel 44 below the lower valve head 47 to communicate the bore 54 with the interior of the housing section below the valve seat 49. The lower end portion of the housing section 36 has an inwardly directed shoulder 55 through which an intermediate portion of the valve mandrel 44 is sealingly slidable. Fluid leakage is prohibited by a seal ring 56.

The valve mandrel 44 has a stepped diameter outer wall surface to provide a piston section 57 whose outer periphery is sealed against the adjacent cylinder wall 58 by a seal ring 59. A plurality of ports 60 extend laterally through the wall of the housing 36 below the shoulder 55 so that the upwardly facing transverse surface 61 of the piston section 57 is subjected to the pressure of fluids in the well annulus outside the housing. The lower face 62 of the piston section 57 is engaged by a coil spring 63 whose lower end rests on an inwardly directed shoulder 64 on the housing 36. The outer surface of the lower portion 65 of the valve mandrel 44 is sealed with respect to the shoulder 64 by a seal ring 66.

An elongated chamber 67 of substantial volume is formed in a lower portion of the housing 36. The chamber 67 is defined between the outer surface of a tube 70 whose upper end is connected to the shoulder 64, and the surrounding inner wall surface 71 of the housing, the lower end of the tube 70 being sealed against the housing by a suitable seal ring 72. An annular floating piston 73 normally is disposed at the lower end of the chamber 67 and is provided with internal and external seals 74 and 75. The chamber 67 is adapted to be filled through a suitable valve port (not shown) with a compressible fluid medium such as nitrogen gas, and a suitable communication path 76 extends upwardly through the shoulder 64 so that the pressure of the nitrogen can act upwardly on the downwardly facing transverse surface 62 of the piston section 57 on the valve mandrel 44. The interior space 77 of the housing 36 below the floating piston 73 is placed in communication with the well annulus by a pressure channel that is constituted by a vertically extending port 78 which terminates in a side opening 79. Thus it will be readily appreciated that as the tester valve assembly 22 is lowered into a fluid filled well bore, the hydrostatic head of the well fluids is communicated by the ports 79, 78 and transmitted by the floating piston 73 to the nitrogen within the chamber 67. Inasmuch as the upper and lower surfaces 61 and 62 of the piston section 57 can be subjected to the same pressure, the hydrostatic head of the well fluids does not tend to move the valve mandrel 44 toward open position. Moreover, the pressure of any fluids present within the bore 54 of the valve mandrel 44 acts upwardly on the lower end surface 80 thereof, downwardly on the upper end surface 51 thereof, and on the lower transverse surface of the lower valve head 47 via the ports 53. It can be demonstrated that the fluid pressures are acting with equal force in opposite longitudinal directions, so that the valve mandrel 44 is balanced with respect to fluid pressures as the equipment is lowered to setting depth. This being the case, the valve mandrel 44 does not move vertically as the hydrostatic head increases.

The lower end of the housing 36 has a reduced diameter portion 82 which is connected by threads 83 to the mandrel 84 of the flow control valve assembly 23. The mandrel 84 is telescopically received within a housing 85 and is movable between extended and contracted positions with respect thereto. As the equipment is being lowered into the well, the mandrel 84 is in the extended position as shown so that the port 79 is open. However, when the packer 25 is set as will be subsequently described, the mandrel 84 moves downwardly with respect to the housing 85 to a position where seal rings 86 and 87 located respectively above and below the port 79 engage the inner wall 88 of a counterbore in the housing 85 to close off the port from communication with the well annulus. In this manner the hydrostatic head of the well fluids at test depth is trapped or "memorized" in the chamber 67 and does not change to any appreciable extent during operation of the valve as will become more readily apparent herebelow. The structural details of the flow control valve assembly 23 will not be set forth at length here since reference may be had to the aforementioned U.S. Pat. No. 3,308,887.

An elongated annular cylinder space 90 is provided between the inwardly directed flanges 55 and 55' on the housing section 35, with the ends of the space being sealed off by O-rings 56 and 56' which slidably engage the external surface of the mandrel 44. A piston head 91 on the mandrel 44 is slidable within the space 90 and carries a seal ring 92 that engages the inner wall surface 93 of the housing. The chamber wall 94 below the piston head 91 is provided with a radial port 95 which is closed by a threaded plug 96 having an internal bore 97 that extends into the chamber 90. So long as the plug 96 remains intact, the chamber 90 will contain air at atmospheric or other low pressure acting on the respective upper and lower faces 97 and 98 of the piston head 91 with substantially the same force, providing a balanced condition. However, it will be apparent that should the port 95 be opened, fluids in the well annulus will enter the chamber space 90 below the valve head 91 and act upwardly on the lower face 97 thereof with a force that is the product of the pressure of the fluids and the transverse cross-sectional area of the piston head.

The respective lengths of the various portions of the mandrel 44 are sized such that the plug 96 provides a stop to downward movement when the valve ports 53 and 42 are open, whereby the net opening force on the mandrel due to pressurization of the annulus fluids, as described above, is applied by the piston head 91 to the plug 96. As shown in FIG. 4, the plug 96 has an external groove 99 cut therein to provide a weakened region which will break when the force applied thereto reaches a predetermined magnitude.

In operation, the pressure operated test valve assembly 22 is prepared at the surface by injecting a charge of nitrogen gas into the chamber 67 and the chamber can be pressurized to an initial pressure that is not critical and for most tests should be about 2500 psi. A guide that can be used is to charge the chamber to a pressure about 500 psi less than the hydrostatic pressure at test depth. Of course at the surface and during the initial stages of descent into the well bore, the nitrogen pressure is well in excess of the hydrostatic head of the well fluids and thus biases the valve mandrel 44 in the closed position. The string of tools is lowered from the vessel 13 into the well casing 10 until the packer 24 is located at the proper point above the formation interval to be tested. At a location well above the setting point, the hydrostatic head will have become in excess of the precharge pressure of the nitrogen within the chamber 67, and when this occurs the floating piston 73 will begin to move upwardly somewhat as it transmits the hydrostatic head to the compressible medium within the chamber. In any event, the valve mandrel 44 remains stationary because the same pressure is acting on the opposite sides 61 and 62 of the piston section 57. Due to the fact that the medium in the chamber 67 is compressible, however, the piston section 57 can move readily downwardly when a pressure difference is imposed in a downward direction thereacross.

The length of the minor pipe string 18 is selected to provide the proper amount of weight to set the packer 24, and the landing sub 16 is located in the major string 17 at the proper spacing such that when the packer 25 is anchored at setting depth and the string 17 is suspended in the sub sea well head 12, the slip joint 19 is in its closed or contracted condition to enable the weight of the minor string 18 to be applied via the test tools to the packer. Of course this weight compresses and expands the packing elements 25 to seal off the test interval, and moves the tester housing 36 and the mandrel 84 downwardly to cause the control valve 23 to open, admitting fluids into the interior of the pressure operated test valve 22. Downward movement of the housing 36 with respect to the control valve housing 85 positions the housing portion 82 within the valve seat 88 to close off the port 79 from communication with the well annulus as shown in FIG. 3. The result is to trap or "memorize" the hydrostatic head of fluids within the chamber 67 so that a substantially constant pressure acts upon the lower surface 62 of the piston section 57 at all times during operation of the tester assembly 22.

With the blowout preventers closed in a typical fashion at the surface so that the well is completely under control, a formation test can be conducted without resort to manipulation of the pipe strings 17 or 18 in the following manner. Fluid pressure is applied by suitable surface pumps and control lines (not shown) to the well annulus 106 between the pipe strings 17, 18 and the surrounding casing 10. The pressure acts through the housing ports 60 on the upper surface 61 of the piston section 57 of the valve mandrel 44 to force the mandrel downwardly against the bias of the coil spring 63. In a typical example, an applied annulus pressure of 600 psi will start the valve mandrel 44 moving downwardly, and an applied pressure of 1200 psi will cause the valve mandrel 44 to move completely downwardly to its open position as shown in FIG. 3. In this position, a fluid flow path is opened upwardly through the tester assembly so that produced formation fluids can enter the pipe string 18, the flow path being through the tube 70, the bore 54 of the valve mandrel 44, the lower mandrel and sleeve ports 53 and 53', the sample chamber 50, the upper sleeve ports 42', the barrier wall ports 42 and the annular space 41 between the barrier 37 and the adjacent housing wall 40. The valve is left open for a relatively short flow period of time sufficient to draw down the pressures in the isolated formation interval below the packer 24 and enable connate fluids within the formation to be produced into the well bore. Then the applied annulus pressure is bled off at the surface to enable the coil spring 63 to force the valve mandrel 44 upwardly to its closed or shut-in position shown in FIG. 2. The valve mandrel 44 is left in closed position for a shut-in period of time during which the pressure recorders 28 make a record of the pressure build-up data. If desired, the valve mandrel 44 can be shifted between closed and open position repetitively by alternately applying and then releasing fluid pressure in the annulus 106.

As previously mentioned, the valve mandrel 44 is balanced against any opening movement due to hydrostatic fluid pressures during running, and the changes in fluid pressure that occur within the tester assembly 22 during the actual test do not affect the vertical position of the valve mandrel for the same reasons, that is, the pressures at any instant act with equal force in opposite longitudinal directions. Moreover, the parts are sized such that the volume of the chamber 67 that contains the compressed nitrogen gas is quite large in relation to the volume of displacement of the piston section 57 as it moves downwardly against the bias of the coil spring 63. For example the ratio of the chamber volume to displacement volume at test depth may be in the

order of 100 to 1. Consequently, there is a negligible increase in pressure within the chamber **67** as the valve mandrel **44** is shifted downwardly, and for practical purposes the magnitude of the annulus pressure that is applied to operate the valve is a function only of the modulus or rate of the coil spring **63**, which is of course quite predictable.

Each time the valve mandrel **44** is moved downwardly to the open position in response to annulus pressure, the piston head **91** abuts against the port plug **96** as shown in FIG. **3**. Normal operating pressure is, however, well below a value that would shear off the plug and enable annulus fluids to enter the chamber **90**. Should the pipe string **17** develop a leak that enables the well annulus to become changed with a pressure sufficiently high that the valve mandrel **44** cannot shift upwardly to the closed position, the valve can be closed in any event. If the value of pressure is or becomes higher than the normal operating pressure for the valve, the resulting downward force on the operating piston **57** is applied by the piston head **91** to the port plug **96** and causes the latter to shear off. Fluid admitted to the chamber **90** below the head **91** acts upwardly on the lower or high pressure side **97** thereof and assists the closing force of the spring **63** in shifting the mandrel upwardly to closed position. It also is possible for the well operator to deliberately pressurize the well annulus to a value sufficient to cause automatic closure as described above. In either event, a safety feature is provided which enables the valve to be closed.

To terminate the test, it is only necessary to lift straight upwardly on the pipe strings **17** and **18** at the surface, thereby extending the slip joint **19** and causing the control valve **23** to close as the mandrel **84** moves upwardly. The bypass associated with the packer **24** is opened to equalize pressures across the packer elements **25** so that they can retract, which is then accomplished by further lifting of the packer mandrel. Of course it will be appreciated that the reversing valve **20** can be operated in a typical fashion if it is desired to remove the fluids that have been produced into the pipe string before the tools are recovered to the surface.

As the housing **36** is elevated with respect to the control valve housing **85**, the ports **79** are exposed to the well annulus, so that the pressure of the nitrogen within the chamber **67** experiences a gradual decrease as the hydrostatic head is reduced during withdrawal of the tools from the well. At the surface the chamber **67** will have the initial precharge pressure. A sample of the last portion of flowing fluids is trapped within the sample chamber **50** upon simultaneous closure of the valve heads **45** and **47**, and can be removed for inspection and analysis at the surface.

It will now be apparent that a new and improved pressure controlled tester valve has been disclosed, the valve being operable in response to a substantially fixed value of applied annulus pressure without regard to test depth, and which automatically closes in response to excessive annulus pressure. Since certain changes or modifications may be made in the disclosed embodiments without departing from the inventive concepts involved, it is the aim of the appended claims to cover all such changes or modifications falling within the true spirit and scope of the present invention.

I claim:

1. A well tester apparatus, comprising: an elongated housing; a mandrel movable longitudinally in said housing; valve means opened in response to movement of said mandrel in one direction and closed in response to movement of said mandrel in the other direction; piston means on said mandrel sealingly slidable within cylinder means in said housing, said piston means normally having balanced pressures acting on opposite sides thereof; and means for admitting annulus well fluids to one side of said piston means to provide an unbalanced pressure thereon to cause shifting of said mandrel in said other direction and automatic closure of said valve means.

2. The apparatus of claim **1** wherein said admitting means includes port means in said housing for communicating a portion of said cylinder means with the well annulus, and blocking means normally closing said port means.

3. The apparatus of claim **2** wherein said blocking means comprises a shear plug extending into said cylinder means and providing a stop to longitudinal movement of said mandrel in said one direction, said plug being sheared off by a force of preselected magnitude on said mandrel acting in said one direction.

4. The apparatus of claim **3** wherein said piston means is arranged to engage said shear plug directly to apply said preselected magnitude of force thereto.

5. Apparatus adapted for use in a fluid-filled well bore, comprising: normally closed test valve means adapted to be opened in response to an operating pressure applied to fluids in the well annulus, said valve means including a mandrel movable longitudinally within a housing; piston means on said mandrel slidably engaged in cylinder means on said housing, said piston means having oppositely facing pressure surfaces; means for isolating said oppositely facing pressure surfaces from the pressure of fluids in the well annulus; and means responsive to a value of pressure in excess of said operating pressure to permit the pressure of fluids in the well annulus to act on one said pressure surfaces of said piston means to thereby shift said mandrel in a direction to cause closure of said valve means.

6. The apparatus of claim **5** wherein said isolating means includes a flow port in said housing, and means extending into said cylinder means for blocking said flow port.

7. The apparatus of claim **6** wherein said blocking means is a frangible plug arranged to be engaged by said piston means and broken off by a predetermined amount of longitudinal force on said mandrel to open said flow port.

8. A fluid pressure controlled well tester apparatus, comprising: housing means having a flow passage extending therethrough; pressure responsive valve means movable between positions closing and opening said flow passage; chamber means containing a compressible fluid medium, said valve means including a mandrel having first piston means with one side thereof subject to the pressure of fluids in the well annulus externally of said housing means and the other side subject to the pressure of said fluid medium; means for equalizing the pressure of said fluid medium with the hydrostatic head of the well fluids externally of said housing means; selectively operable means for closing said equalizing means so that pressure applied to the fluid externally of said housing means subsequent to the closing of said equalizing means can act on said one side of said first piston means to move said mandrel in one longitudinal direction to cause opening of said

valve means; second piston means on said mandrel sealingly slidable within cylinder means in said housing means, said second piston means normally having balanced pressures acting on opposite sides thereof; and means responsive to an excessive pressure of the fluids in the well annulus externally of said housing means for admitting well fluids to one side of said second piston means to provide an unbalanced pressure that functions to cause shifting of said mandrel in the opposite longitudinal direction and results in closing of said valve means.

9. The apparatus of claim **8** when said admitting means comprising port means in the wall of said cylinder means adjacent said one side of said second piston means, and blocking means normally closing said port means to prevent the pressure of fluids externally of said housing means from acting on said one side of said second piston means.

10. The apparatus of claim **9** when said blocking means extends into said cylinder means and is arranged to be engaged by said second piston means to provide a stop against longitudinal movement of said mandrel in said one direction.

11. The apparatus of claim **10** when said blocking means has a breakable portion positioned for engagement by said second piston means, breakage of said portion opening said port means in response to said excessive pressure acting on said one side of said first piston means with the resulting force being transmitted by said second piston means to said portion.

12. The apparatus of claim **11** wherein said one side of said first piston means and one side of said second piston means face in opposite longitudinal directions.

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