United States Patent [19]

Scott

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[45] **June 24, 1975**

[54] **ANNULUS PRESSURE CONTROLLED TESTING APPARATUS**

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[73] Assignee: **Byron Jackson Inc.,** Long Beach, Calif.

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[21] Appl. No.: **430,989**

[52] **U.S. Cl.** **166/133;** 166/.5; 166/152; 166/162

[51] **Int. Cl.** **E21b 49/00**

[58] **Field of Search** ..... 166/133, 142, 152, 151, 166/150, 169, 162, 226, 148, 149, .5, 264; 73/151

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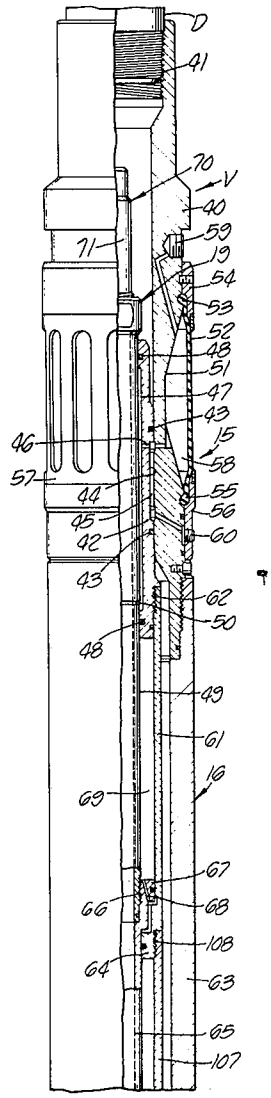
Primary Examiner—David H. Brown

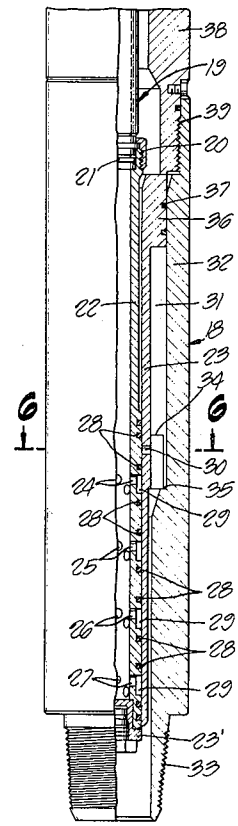
Attorney, Agent, or Firm—John O. Evans, Jr.

[57] **ABSTRACT**

An annulus pressure controlled testing tool is disposed in a well bore above a packer which is set in the well bore and separates the productive earth formation from the annular space above the packer. The testing tool is a shut-in valve assembly having a valve openable for successive periods under the control of an annulus pressure actuated escapement mechanism which allows the formation fluid to flow through the shut-in valve for a desired period of time.

28 Claims, 15 Drawing Figures





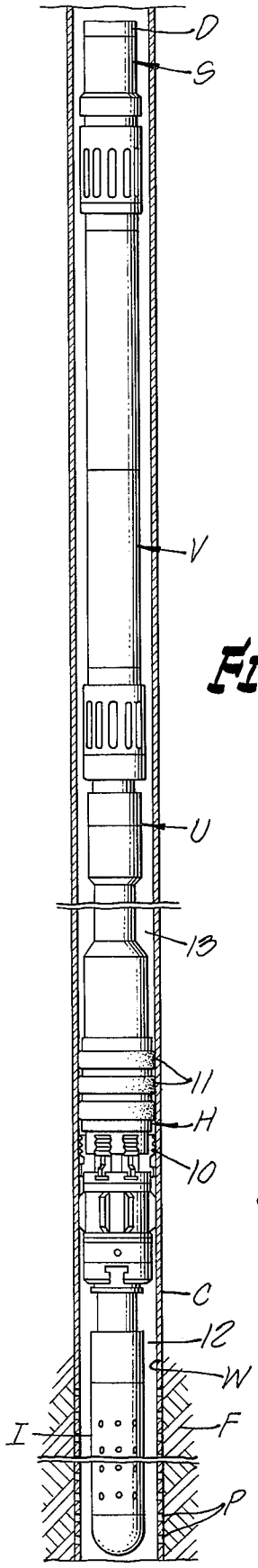


FIG. 1.

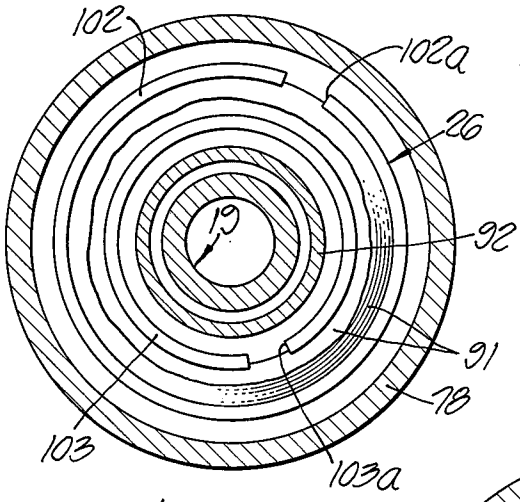


FIG. 3.

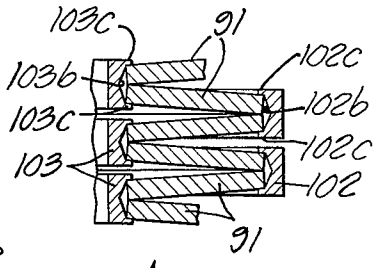


FIG. 7.

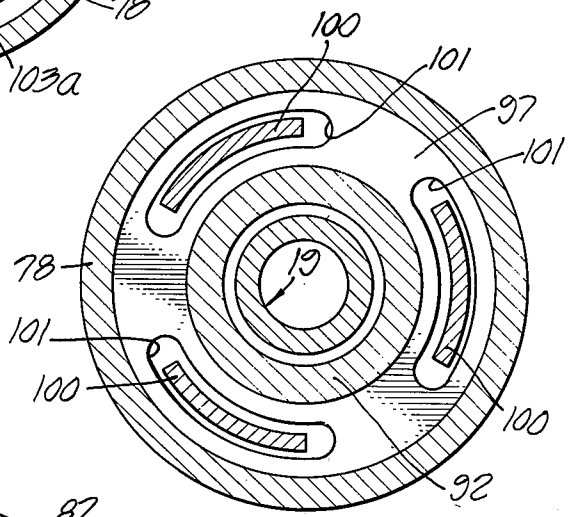


FIG. 4.

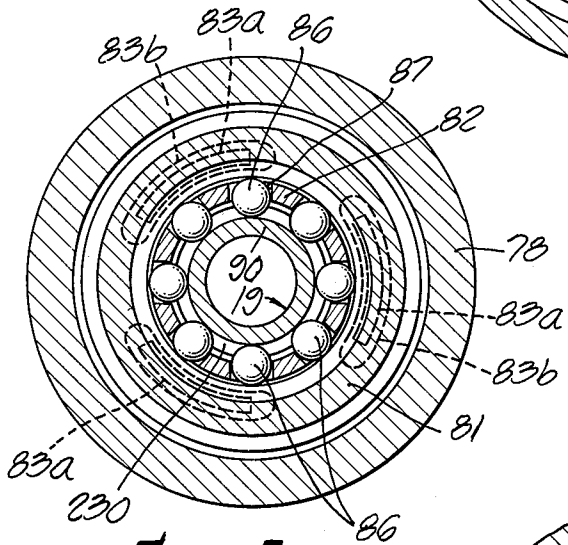


FIG. 5.

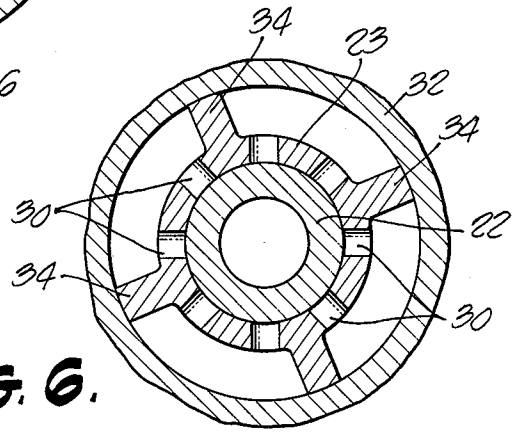


FIG. 6.

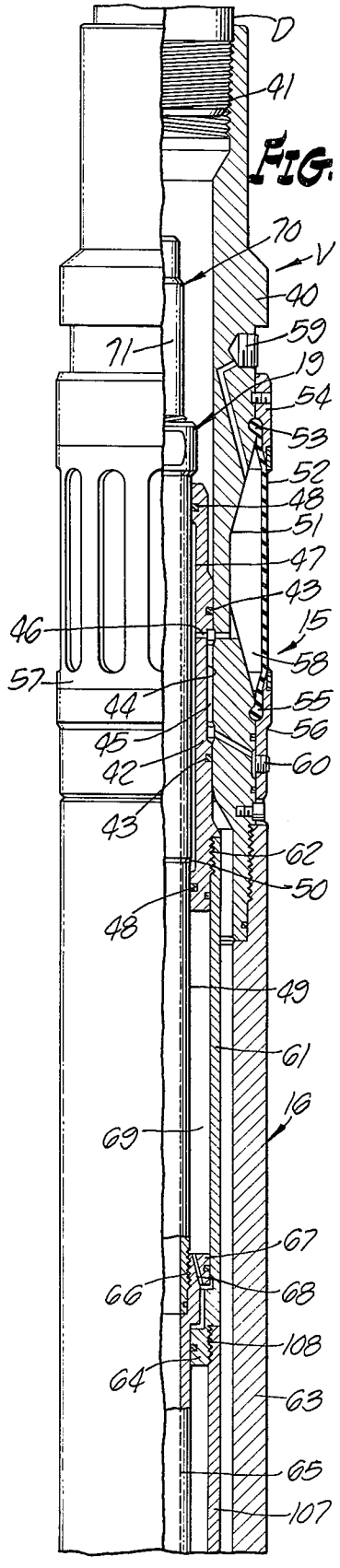


FIG. 2a.

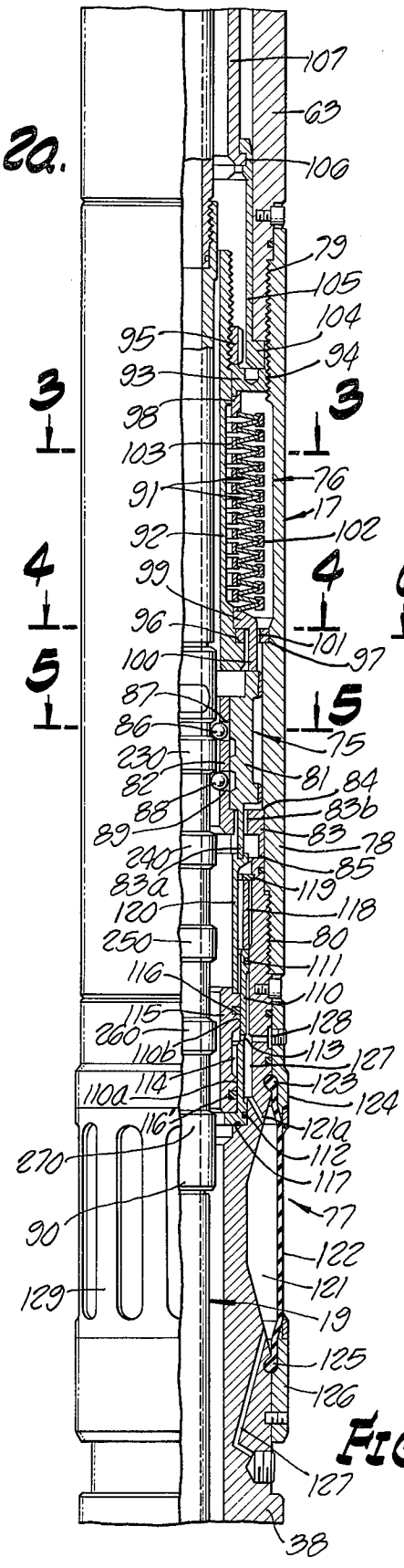


FIG. 2b.

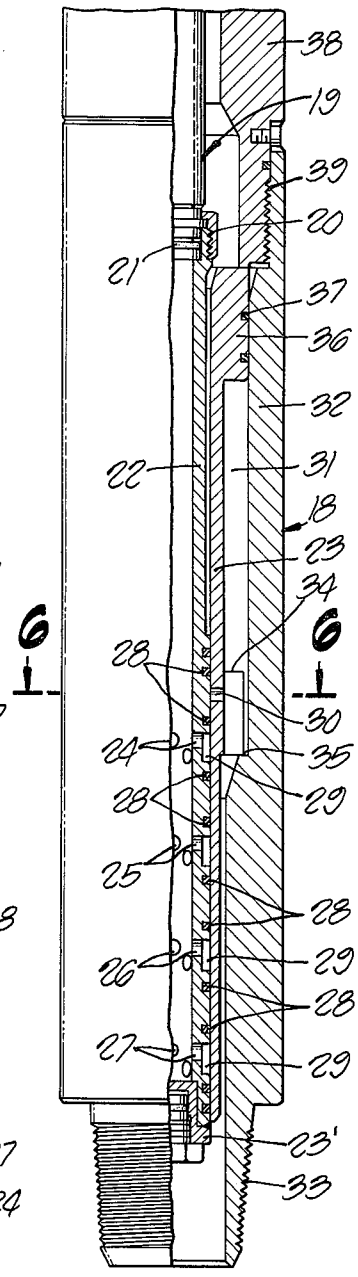


FIG. 2c.

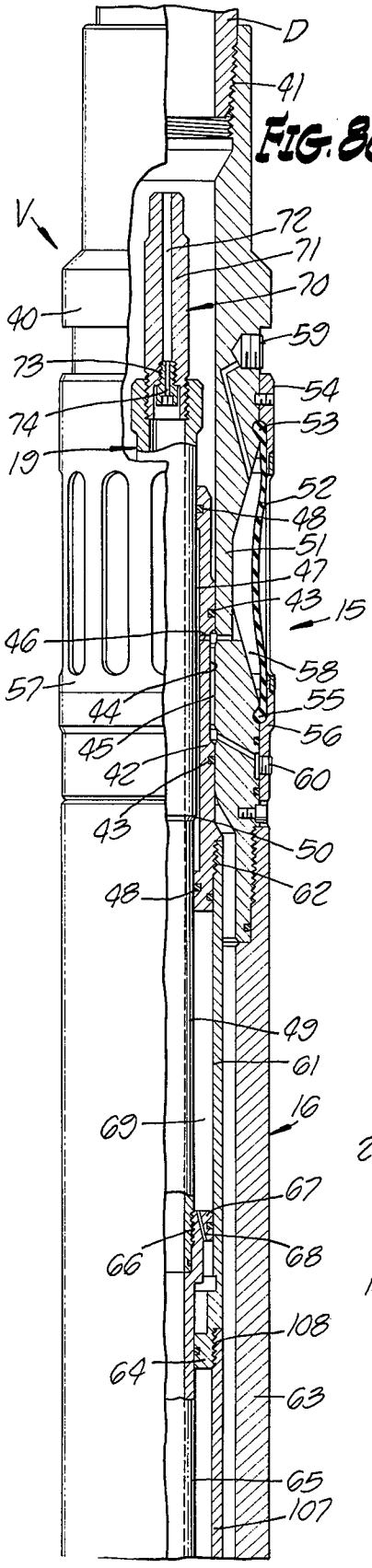


FIG. 8a.

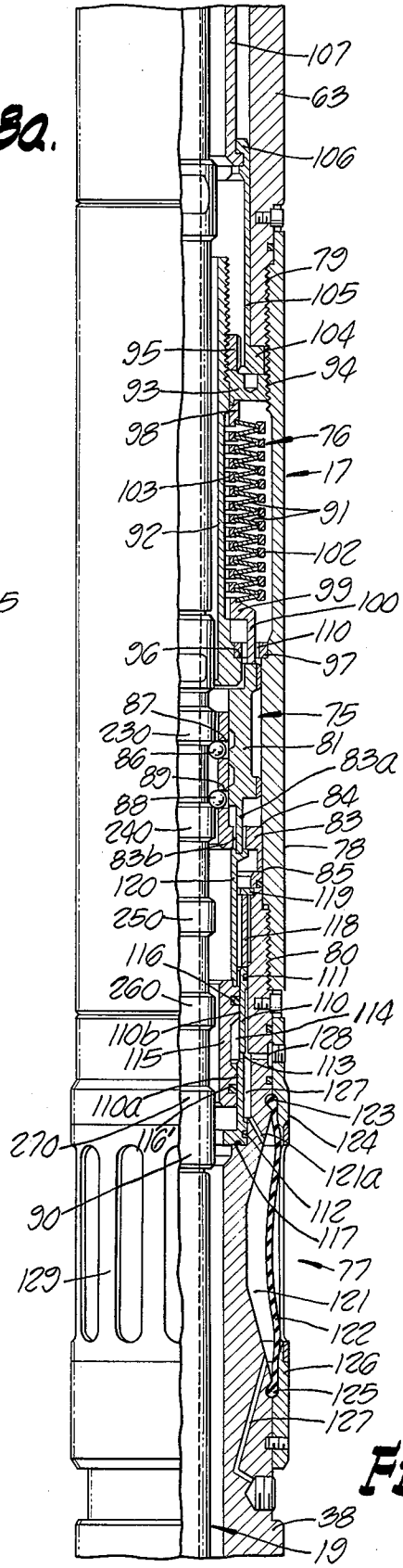


FIG. 8b.

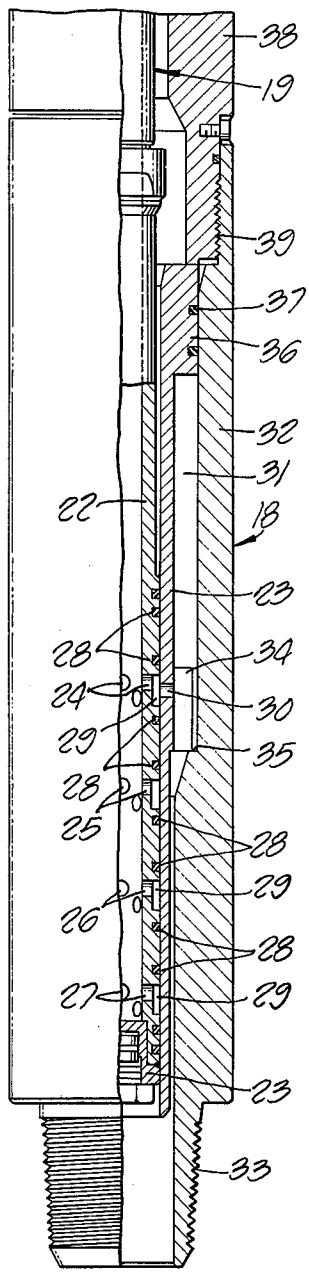


FIG. 8c.

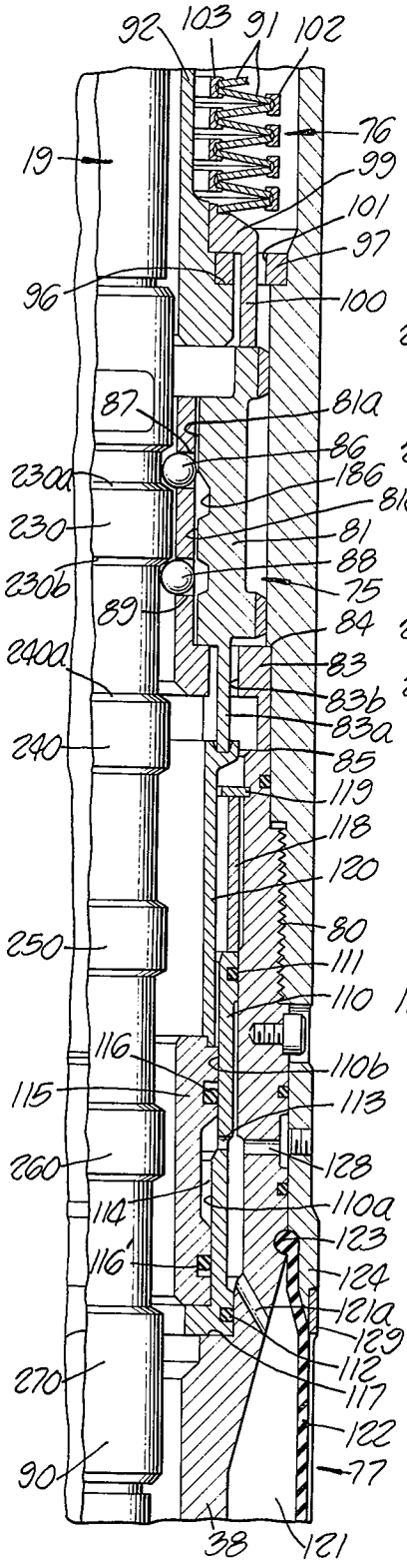


FIG. 9.

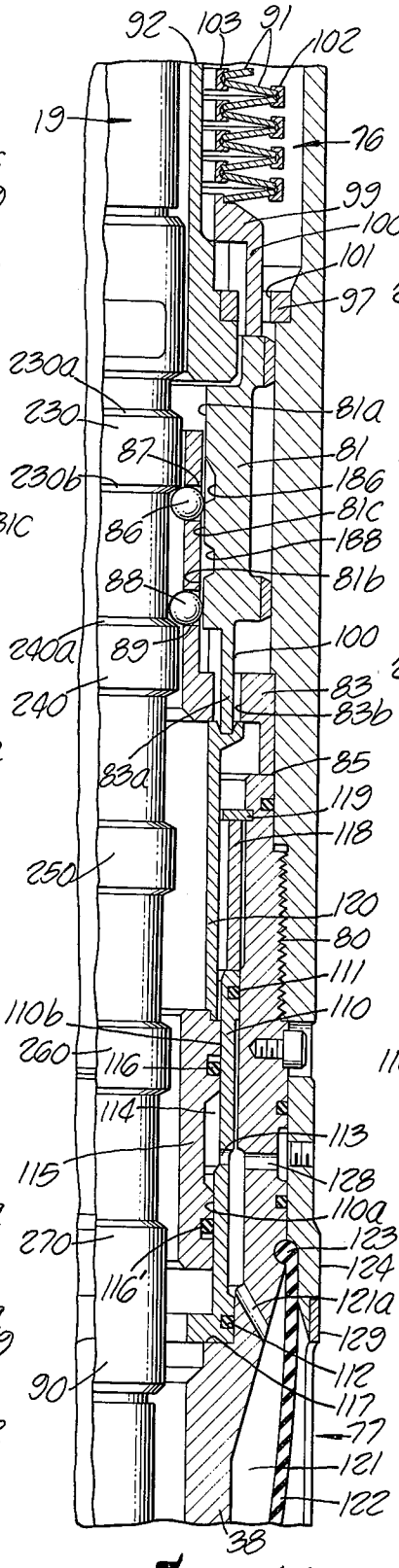


FIG. 10.

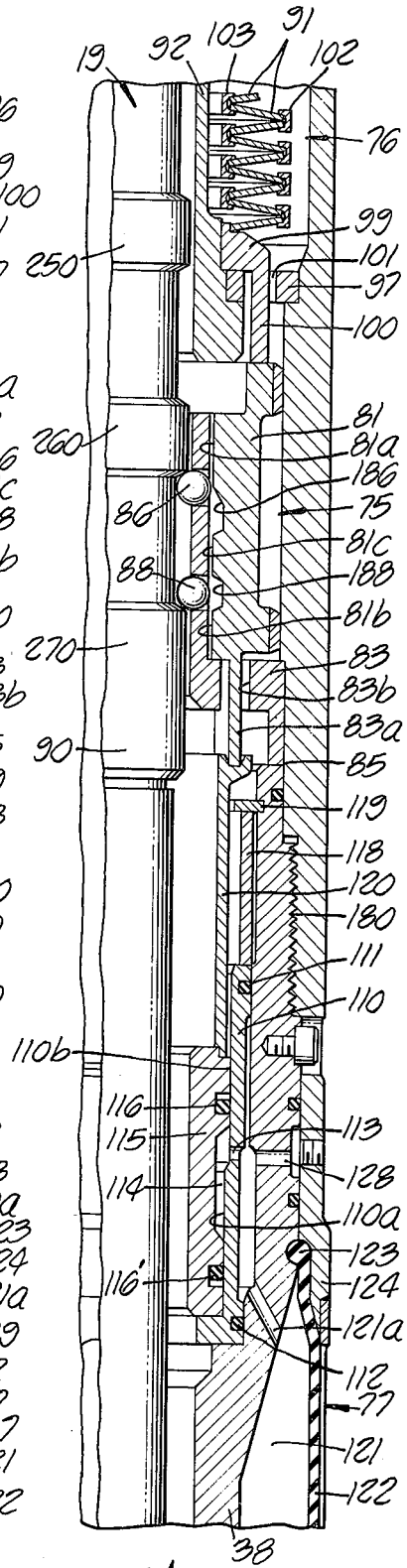


FIG. 11.

ANNULUS PRESSURE CONTROLLED TESTING APPARATUS

BACKGROUND OF THE INVENTION

Testing tools or apparatus for use in performing drill stem tests of earth formations are well known. An example is the drill stem fluid sampler of my prior U.S. Pat. No. 3,437,138, granted Apr. 8, 1969.

Typically, drill stem testing tools have been operated in response to rotation or longitudinal movement of the string of drill pipe in which the testing tool is installed and by which the testing tool is run into the well. When the testing operations are being performed from a stable platform, in most cases, these prior tools have been quite satisfactory, since the rotative or longitudinal movement of the drill string can be readily accomplished with the usual hoist mechanism. However, in the case of slant-hole drilling or drilling from an unstable platform, such as a floating vessel, the control of testing tools by manipulation of the pipe is very difficult. When slant-hold drilling, friction of the drill pipe within the well casing renders very uncertain the actual position or orientation of the drill pipe at any given depth due to twist or stretch of the pipe. When performing a drill stem test from an unstable platform such as a floating or partially submerged vessel or platform in the ocean which is subject to motion caused by tidal and wave action, longitudinal movement of the drill pipe string cannot be relied upon for the control of drill stem testing equipment.

Another problem encountered in the performance of drill stem testing operations from a floating or partially submerged platform is that in the event of heavy seas, the platform may be pulled from its moorings rupturing the drill pipe string between the vessel and the downhole drill stem tester. If the drill stem tester does not automatically close, then well fluid may flow into the sea.

SUMMARY OF THE INVENTION

The present invention provides a shut-in valve for drill stem testing of a productive earth formation traversed by a well bore, wherein the shut-in valve is normally closed by formation pressure and is adapted to be opened by the application of pressure to the annulus above a packer which isolates the productive formation. With such a drill stem tester or formation testing tool, a bumper sub or telescopic joint can be employed in the drill pipe string above the shut-in valve to compensate for the rise and fall of the floating or semi-submerged platform. In the event the drill pipe string ruptures for any reason, a normally closed shut-in valve will confine the productive formation fluids against flow into the sea.

More particularly, the shut-in valve is constructed to enable it to be successively opened and closed to enable a series of drill stem tests, under the control of an escapement mechanism activated in response to the pressure of fluids in the annulus above the packer and spring means adapted to be overcome by annulus fluid pressure to release the escapement mechanism for one increment of motion. The spring means comprises a stack of Belleville spring washers which occupy a small space and which may have a constant spring rate.

The shut-in valve and the escapement mechanisms are influenced by the pressure of formation fluid below the packer to hold the shut-in valve closed. When the escapement mechanism is released, the formation pressure acts on the shut-in valve to shift the shut-in valve to an open position. In the absence of sufficient formation pressure to effect opening of the shut-in valve, the testing tool also includes energizing means responsive to pressure in the annulus above the packer to assist in the shifting of the shut-in valve to an open position.

Since under some differential pressure conditions the forces acting to open the shut-in valve may be substantial, the tool also includes buffer means for limiting the rate of movement of the shut-in valve towards the open position, thereby minimizing potentially destructive inertia forces otherwise applicable to the escapement mechanism.

Among the objects of the invention is the provision of a drill stem testing tool which is particularly well suited for performing drill stem testing operations in a well drilled from a floating or partially submerged platform subject to vertical motion caused by tide or wave action, the tool being operable by annulus fluid pressure and being safe and reliable in its operation.

This invention possesses many other advantages, and has other purposes which may be made more clearly apparent from a consideration of the form in which it may be embodied. This form is shown in the drawings accompanying and forming part of the present specification. It will now be described in detail, for the purpose of illustrating the general principals of the invention; but it is to be understood that such detailed description is not to be taken in a limiting sense, since the scope of the invention is best defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagramatic view illustrating a testing tool string in accordance with the invention and disposed in a well bore;

FIGS. **2***a* through **2***c* together constitute a view partly in elevation and partly in longitudinal section illustrating the shut-in valve of the invention in a running-in condition;

FIG. **3** is a transverse section as taken on the line **3—3** of FIG. **2***b*;

FIG. **4** is a transverse section as taken on the line **4—4** of FIG. **2***b*;

FIG. **5** is a transverse section as taken on the line **5—5** of FIG. **2***b*;

FIG. **6** is a transverse section as taken on the line **6—6** of FIG. **2***c*;

FIG. **7** is an enlarged fragmentary detail view in longitudinal section illustrating the Belleville spring pack centering means;

FIGS. **8***a* through **8***c* together constitute a view partly in elevation and partly in longitudinal section illustrating the shut-in valve of the invention in a testing condition;

FIG. **9** is an enlarged fragmentary view in longitudinal section showing the escapement mechanism in the running-in condition;

FIG. **10** is a view corresponding to FIG. **9**, but showing the escapement mechanism in the testing condition; and

FIG. **11** is a view corresponding to FIGS. **9** and **10**, but showing the escapement mechanism in the retrieving condition.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As seen in the drawings referring first to FIG. **1**, a testing tool string S is shown in a well bore W in which casing C has been set and perforated at P to establish communication between a productive formation F and the inside of the casing C. At its lower end, the testing tool string S has a perforated testing instrument I which is adapted to record flow, and if desired, pressure and/or temperature of production fluid flowing from the formation F upwardly through the testing tool S under the control of the annulus controlled shut-in valve assembly V, in accordance with the invention. Between the shut-in valve V and the instrument I is a typical hook-wall packer assembly H adapted to form a seal with the casing C, as is well known. Such packers are adapted to be set in the well bore with slips **10** in anchoring engagement with the casing C, and with resilient packing ring elements **11** deformed into sealing engagement with the casing C to isolate the annular space **13** above the packer H. Preferably, the tool string S includes above the packer H an unloader valve assembly U openable when it is desired to retrieve the testing tool string S to balance the fluid between the annuli **12** and **13.** Above the testing tool V is a drill pipe string D adapted to extend to the platform at the top of the well, and, as will be recognized by those skilled in the art, when the platform is a floating or partially submerged platform, the pipe string D will incorporate a bumper sub or telescopic joint adapted to compensate for relative vertical movement between the platform and the stationary elements anchored in the casing C by the packer H.

Referring particularly to FIGS. 2*a* through 2*c*, the shut-in valve assembly V is shown in detail in a condition with the shut-in valve means closed. The shut-in valve assembly comprises an elongated outer tubular assembly including an upper energizing section **15,** beneath which is a buffer section **16,** escapement mechanism section **17,** and a valve section **18.** Extending longitudinally within the tubular assembly is an inner tubular mandrel, generally denoted at **19,** through which fluid from the formation F is adapted to flow when the shut-in valve means is actuated by annulus fluid pressure above the packer **14.**

At its lower end, the tubular mandrel **19** is connected by a coupling **20,** sealed by an O-ring **21,** to a downwardly extending, elongated valve sleeve **22** having a plug **23'** closing its lower end. This valve sleeve is reciprocable within a stationary cylindrical valve body **23,** and the valve sleeve **22** has a vertically spaced series of ports **24, 25, 26,** and **27** located between vertically spaced sealing rings collectively designated **28.** The sealing rings **28** prevent the passage of fluid between the valve sleeve and the inner wall of the valve body **23,** these seals being spaced above and below annular grooves **29** with which the respective ports **24** through **27** communicate. In the valve body **23** is a set of radial valve ports **30** spaced circumferentially of the body and communicating with the annular space **31** defined between the valve body **23** and an outer tubular body section **32,** which has at its lower end a threaded pin **33** adapted for connection to the downwardly extending test string, say to the upper end of the unloader valve u, as shown in FIG. **1.** The fluid in the annular space **31** will be the fluid which enters the well through the perforations P, enters the testing instrument I, enters the packer H and passes on upwardly into the annular **31.** As will be later described, the valve sleeve **22** is adapted to move progressively upwardly in increments of motion so that the ports **24, 25, 26** and **27** are progressively in communication with the valve ports **30,** and alternatively, the valve ports **30** are closed off between the progressively vertically spaced sealing rings **28.**

The valve body **23** is fixedly mounted within the outer body section **32** by means of a spider formed by radiating flanges **34** projecting outwardly from the valve body **23** in the region of the ports **30** into centering engagement within the outer body **32,** these ribs setting on a shoulder **35** within the body **32.** At its upper end, the valve body **23** has a radially outwardly extended flanged section **36** engaged within the outer body **32,** and provided with sealing rings **37,** the flange **36** abutting with the lower end of an upwardly extended tubular outer body section **38** which is threaded into and sealed at **39** in the upper end of the lower body section **32.**

As is apparent in FIG. 2*c*, the lower end of the valve sleeve **22** is exposed to the pressure of fluid coming from the formation F which provides a force biasing the valve sleeve **22** and the entire mandrel assembly **19** upwardly. This upward movement is assisted by the energizing section **15** of the tool, is dampened by the buffer section **16** of the tool, and is controlled by the escapement section **17** of the tool.

The energizing section **15** comprises an upper and outer main body **40** of tubular form threaded, as at **41,** to the upwardly extending drill pipe string D. Within the body **40** is a cylinder sleeve **42** having a pair of vertically spaced outer sealing rings **43** sealingly engaged within the cylindrical inner wall of the body **40.** The cylinder sleeve **42** has a reduced diameter mid-section **44** between the seal rings **43** and opposed by the inner wall of the body **40** to form a chamber **45** which communicates with a radial port **46** in the cylinder sleeve **42.** The port **46** leads to an inner annular chamber **47** defined between upper and lower sealing rings **48** which slideably engage the upper section **49** of the inner mandrel assembly **19.** At its upper end, the mandrel section **49** is of an enlarged diameter to provide a differential piston area **50** within the chamber **47** on which pressure acts to complement the force derived from well fluid pressure acting to shift the mandrel assembly **19** upwardly. The pressure acting on the piston area **50** is the pressure in the well bore annulus **13** above the packer H. Since such fluid is not clean fluid, means are provided for transmitting the annulus fluid pressure to the piston area **50** while protecting the working parts from the annulus fluid.

More particularly, the body **40** has a reduced mid-section **51** spanned by a circular bladder **52.** At its upper end, the bladder has a bead **53** clamped against the body **40** by a gage ring **54.** At its lower end the bladder has a similar bead **55** clamped against the body **40** by a gage ring **56.** A slotted protective sleeve **57** is disposed about the bladder between the gage rings **54** and **56.** The bladder and the body portion **51** define a chamber **58,** a clean fluid such as oil being utilized to fill the chamber **58,** as well as the annular space **45,** between the body **40** and the cylinder sleeve **42** and the chamber **47** between the cylinder sleeve **42** and the

mandrel section **49.** Suitable fill and bleed openings and passages are provided at **59** and **60.**

The buffer section **16** comprises an elongated cylinder **61** threaded at **62** to the lower end of the cylinder sleeve **42** and extends downwardly within an upper outer body section **63.** At the lower end of the cylinder **61** is a head **64** slideably and sealingly engaged with a lower inner mandrel section **65** which is threaded at **66** to the above described upper mandrel section **49.** At its lower end, the mandrel section **49** has a flange **67** slideably and sealingly engaged within the cylinder **61** and having an orifice **68.** During assembly, the annular space **69** between the cylindrical sleeve **61** and the mandrel section **49** above the cylinder head **64** is filled with fluid such as oil, so that upward movement of the mandrel assembly **19** is dampened due to the transfer of oil through the orifice **68** as the mandrel moves upwardly.

From the foregoing, it will be recognized that upward movement of the mandrel **19** is adapted to establish communication successively between the valve sleeve ports **24, 25, 26** and **27** and the valve body ports **30,** so that fluid from the well bore below the well packer H is enabled to flow upwardly through the shut-in valve assembly V, and more particularly, through the tubular mandrel **19,** and thence into the drill pipe string D. Such flow is controlled by a conventional choke **70** comprising a tubular body **71** having a flow passage **72** in which is installed the usual flow bean **73** having a flow controlling orifice **74.** It is desired that the mandrel **19** be moved upwardly to establish communication between the valve sleeve ports **24** through **27** and the valve body ports **30** in response to an increase in the pressure of fluid in the annulus **13** between the well casing and the valve assembly V, and that the increments of motion of the inner mandrel **19** correspond to the axial spacing between the valve ports **24** through **27.**

The escapement mechanism **17** of the invention is provided to accomplish these purposes, and includes a stop mechanism **75** normally biased by spring means **76** to cooperate with the mandrel **19** to limit upward movement of the mandrel **19.** Annulus pressure responsive means **77** is provided for operating the stop mechanism **75** and to allow an increment of upward movement of the mandrel **19** in response to the application of pressure to the fluid in the annulus **13,** whereby the shut-in valve assembly V is operable independently of pipe string motion, while the lower portion of the pipe string D and the shut-in valve, as well as the test instrument I, are all precisely located within the well bore with respect to the formation F to be tested.

The escapement mechanism comprises an outer housing or tubular body **78** threadedly connected at **79** to the lower end of the previously described upper housing **63** and threadedly connected at **80** at its lower end to the previously described lower body section **38.** Within the housing **78** is an axially shiftable, annular indexing guide **81.** Concentric within the indexing guide **81** is an annular ball cage **82** having a supporting flange **83** disposed between a stop shoulder **84** in the housing **78** and the upper end shoulder **85** on the body **38,** whereby the ball cage **82** is fixed with respect to the indexing guide **81** in the housing **78.** The ball cage **82** has an upper set of circumferentially spaced balls **86** disposed and captive in radial openings **87** in the cage **82** and constituting upper detent means and a lower set of circumferentially spaced balls **88** disposed and captive in radial openings **89** in the cage **82** and constituting lower detent means. The arrangement of the balls **86,** as shown in FIG. **5,** is typical of the sets of balls **86** and **88.** These balls **86** and **88,** as will be more particularly described hereinafter, cooperate with a number of axially spaced lands **230, 240, 250, 260** and **270** spaced longitudinally of a section **90** of the tubular mandrel **19** to progressively locate the valve sleeve **22** to open and close the shut-off valve means, when annulus fluid pressure applicable to the pressure responsive means **77** is increased and decreased.

The spring means **76** normally acts to shift the indexing guide **81** in a downward direction. In the form shown, the spring means comprises a cartridge including a stack of frusto-conical spring washers **91** disposed in peripheral engagement so as to be axially deformed, such spring washers being generally known as Belleville springs. The stack of Belleville springs, as shown, is constructed and supported so as to minimize hysteresis which can be caused by the centering of the Belleville springs on inner or outer centering means. Such a stack of spring washers is more particularly the subject of the co-pending application for U.S. Pat. Ser. No. 430,980, filed contemporaneously herewith, in the name of Felix Kuus, for "Belleville Spring Cartridge." The Belleville spring cartridge, as herein illustrated, comprises an inner sleeve **92** disposed within the outer body **78** and supported by the latter in an upper support ring **93,** threaded at **94** into the body **78,** the inner sleeve **92** having a supporting collar **95** threaded thereon and engaged with the ring **93.** At its lower end, the sleeve **92** receives in a seat **96** a lower support ring **97.** Beneath the upper ring **93** is a stop ring **98** against which the uppermost Belleville spring **91** abuts at its inner periphery, the lowermost Belleville spring **91** abutting at its inner periphery with a thrust collar **99.** As seen in FIG. **4,** the thrust collar **99** has downwardly extending fingers **100** spaced circumferentially which entend through circumferentially spaced arcuate slots or openings **101** in the lower ring **97** into abutting contact with the upper end of the indexing guide **81.** Upward movement of the indexing guide **81** from the position of FIG. **9** to the position of FIG. **10** causes corresponding upward movement of the thrust collar **99** and compression of the Belleville springs **91.** The Belleville springs are preferred because they occupy a relatively small space as compared with conventional coiled compression springs and provide a high load spring which, as is well known, can have a constant spring rate. The Belleville springs **91,** as best seen in FIGS. **3** and **7,** are centralized or maintained in concentric relation with respect to one another without contacting either the outer housing **78** or the inner support sleeve **92** by means of outer peripheral centering rings **102** and inner peripheral centering rings **103.** The stack of Belleville springs, as a whole, is centralized on the ring **98** and on the thrust collar **99,** as seen in FIG. **2***b*. The centering ring **102** is radially split at **102**a and the centering ring **103** is radially split at **103**a, these rings being resiliently expansible to facilitate their application to the peripheries of the Belleville springs as well as to minimize constraint of the peripheral expansion which occurs as the frusto-conical springs are axially deformed. In addition, the inner periphery of each of the outer peripheral centering rings **102** is provided with a

circumferentially extended groove **102***b* and the outer periphery of each of the inner peripheral centering rings **103** is provided with a corresponding groove **103**b, these grooves **102***b* and **103***b* being generally V-shaped and affording clearance space enabling the contacting edges of the Belleville springs **91** to expand outwardly and inwardly, respectively, upon axial deflection, thereby minimizing friction and resultant hysteresis.

At the upper and lower inner edges of the outer centering ring **102** are retainer flanges **102***c* which project radially inwardly and retain the contacting peripheries of adjacent Belleville spring washers in assembled relation at their outer peripheries. Corresponding radial flanges **103***c* engage the inner peripheries of the Belleville springs to retain the same in assembled relation. Thus, the entire stack of Belleville springs can be installed as a unit over the upper end of the inner support member **92** before assembly of the stop ring **98** and the upper ring **93** in the support sleeve **92.** The collar **95** can be threaded downwardly on the sleeve **92** to appropriately preload the Belleville spring assembly before it is installed in the housing **78** to overcome the hydrostatic pressure of fluid in the well bore annulus **13.** The upper retainer rings **93** also clamps a lower flange **104** of a supporting sleeve **105** against the lower end of the housing section **63,** this support sleeve **105** being connected at **106** to an upwardly extended member **107** which in turn is threadedly connected at **108** to the cylinder sleeve **61** which fixedly supports the cylinder sleeve **42** of the energizing section **15** previously described.

The annulus pressure responsive means **77** is adapted to apply an upward force to the indexing guide **81** to compress the Belleville springs **91** and shift the indexing guide **81** upwardly with respect to the ball cage **82** when the mandrel is to be allowed to move upwardly. Accordingly, within the body section **38** is a cylinder sleeve **110** having a sealing ring **111** at its upper end and a lower sealing ring **112** engaged within the body **38.** This cylinder sleeve **110** has a suitable number of radial ports **113** communicating with an internal chamber **114** defined between the inner periphery of the cylinder sleeve **110** and the outer periphery of an annuluar differential piston **115** having an upper sealing ring **116** and a lower sealing ring **116'** slideably engaged with the cylinder sleeve **110** to confine pressure fluid within the chamber **114.** The inner periphery of the cylinder sleeve below the ports **113** is of a smaller diameter at **110***a* than the larger diameter **110***b* above the ports **113,** and the differential piston **115** has complemental smaller and larger diameters which determine the differential pressure responsive area of the piston **115.** Different size cylinder sleeve **110** and piston **115** sets can be utilized in the assembly depending upon the desired pressure response of the apparatus. The cylinder sleeve **110** is held against an upwardly facing shoulder **117** by a suitable spacer sleeve **118** which engages the upper end of the cylinder sleeve **110** and abuts with an upper retainer ring **119** snapped into the body section **38,** facilitating substitution of different sizes of the cylinder sleeve **110** and the piston **115.**

Disposed between the upper end of the piston **115** and fingers **83***a* which depend from the indexing guide **81** through slots **83***b* in the guide flange **83,** is a thrust sleeve **120** by which the indexing guide **81** is forced upwardly when pressure fluid is applied to the differential piston chamber **114** to force the piston **115** upwardly. Here again, the fluid by which the piston **115** is pressurized is preferably a clean fluid, such as oil, rather than the usually dirty fluid in the well bore annulus **13.** Accordingly, the body **38** has an annular cavity **121** covered by an annular bladder **122.** The bladder **122** has an upper bead **123** clamped against the body **38** by a gage ring **124** and a lower bead **125** clamped against the body **38** by a lower gage ring **126.** Suitable fill and bleed openings **127** and **128** are provided, whereby the chamber **121,** the annular space **127** and the piston chamber **114** can be filled with clean oil. Extending between the gage rings **124** and **126** is a slotted protective sleeve **129.** When the annulus **13** outside the shut-in valve assembly is pressurized, fluid in the chamber **121** will be displaced through ports **121**a in the body **38** and from the chamber **127** through the ports **113** in the cylinder sleeve **110** into the piston chamber **114,** forcing the piston **115,** the thrust sleeve **120** and the indexing guide **81** upwardly from the position of FIG. **9** to the position of FIG. **10,** thereby, as will now be described, allowing the mandrel **19** to move upwardly one increment of motion.

As best seen in FIGS. **9, 10, 11,** the land **230** has an upwardly facing shoulder **230***a* and a downwardly facing shoulder **230***b*. The indexing guide **81** has an upper inner cylindrical surface **81**a engageable with the balls **86,** when the indexing sleeve is in its lowermost position, for holding the balls **86** in an inwardly displaced location engageable by the upwardly facing shoulder **230***a*, thereby preventing upward movement of the mandrel **19.** Thus, the mandrel is held in its lowermost position, as seen in FIGS. **2***a* through **2***c*, with the valve passages **24** through **27** all closed. When by the application of annulus pressure to the piston **115,** the piston and the indexing sleeve **81** are moved upwardly to the position of FIG. **10,** the balls **86** are traversed by a clearance space or annular groove **186** in the inner periphery of the indexing guide **81** allowing the balls **86** to shift outwardly, releasing the mandrel **19** for upward movement under the influence of differential pressure across the lower end of the valve sleeve **22** and the upward bias of the energizing means **15,** as previously described. The land **230** passes over the balls **86,** but upward movement of the mandrel **19** is limited by engagement of an upper shoulder **240***a* on the land **240** with the balls **88** which are held in an inwardly displaced condition by a lower inner cylindrical surface **81***b* of the indexing guide **81.** At this same time, the lower shoulder **230***b* of the land **230** prevents downward movement of the mandrel **19,** since the balls **86** are held in the inwardly displaced position by an intermediate cylindrical surface **81***c* within the indexing guide **81.** The lands **230** and **240** are spaced apart and correspondingly the balls **86** and **88** are spaced apart axially of the assembly a distance corresponding to the distance necessary for the mandrel **19** to travel upwardly to bring the valve sleeve ports **24** into communication with the valve body ports **30** in one increment of motion of the mandrel **19,** further upward motion being prevented, as seen in FIG. **10,** by engagement of the land shoulder **230***a* with the balls **88.**

When annulus pressure is relieved, the Belleville springs **91** will force the indexing guide **81** downwardly until the balls **88** are again free for outward movement into an annular relief groove **188** within the indexing guide **81.** The balls **86** are again held inwardly dis-

placed by the indexing guide surface **81***a*, thereby allowing the mandrel **19** to move upwardly until the land shoulder **240***a* contacts the inwardly held balls **86.** This latter increment of motion of the mandrel **19** is sufficient to move the sealing ring **28** below the valve sleeve ports **24** to a location above the valve body port **30** and will locate the cylindrical valve sleeve **22,** with the body port **30** straddled by the sealing rings **28,** below the sleeve port **24** and above the sleeve port **25,** at which position the valve is again closed. This operation can be repeated until each of the additional lands **250, 260** and **270** have been moved upwardly to a stop position engaged by the balls **88** at which position the successive ports **25, 26** and **27** of the valve sleeve have been opened. Various numbers of lands on the mandrel and ports in the valve may be utilized, but in general, it has been found that in the typical drill stem testing of an oil or gas well the valve is not opened more than three or four times at the most. On the other hand, if more openings are desired, the above operations can be reversed and the mandrel can be forced downwardly by dropping a plug through the drill pipe string which will land on top of the mandrel, closing the choke **70,** and can be pressurized through the drill pipe string to overcome formation pressure acting upwardly on the mandrel and force the mandrel back downwardly. Such a plug is well known in the oil well drilling and producing fields.

From the foregoing, it will now be apparent that the present invention provides a simple, efficient drill stem testing apparatus, including a novel shut-in valve aseembly which can be operated responsive to annulus pressure above the packer, so that the testing operation is independent of motion of a floating vessel from which the testing operation is being performed.

I claim:

1. Apparatus for performing a drill stem test in a well bore traversing an earth formation in which casing is set comprising: a test string adapted to be connected to a string of pipe and run into the well casing, said test string including a packer having anchor means and packing means expansible into anchoring and sealing engagement with said well casing above said earth formation to anchor said test string in said casing and separate said formation from the casing above said packer, test instrument means associated with said packer and in communication with said earth formation, and shut-in valve means above said packer for controlling the flow of fluid from said formation through said test string, said shut-in valve means including a body connected in said test string, said body having therein a tubular mandrel shiftable longitudinally of said body, valve means including a valve member carried by said mandrel and shiftable therewith to a plurality of successive open and closed positions for enabling and for shutting off the flow of fluid from said formation through said mandrel a plurality of times as said tubular mandrel is shifted longitudinally in one direction, and escapement control means responsive to the pressure of fluid in said well casing above said packer for controlling the progressive movement of said mandrel and said valve member in said one direction through said plurality of successive positions.

2. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body.

3. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body, including stops on said mandrel and detent means carried by said body and engageable with said stops, means responsive to said fluid in said well casing for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position.

4. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body, including stops on said mandrel and detent means carried by said body and engageable with said stops, means responsive to said fluid in said well casing for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, said spring means comprising a plurality of Belleville springs stacked in concentric relation in edge-to-edge peripheral engagement.

5. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body, including stops on said mandrel and detent means carried bu said body and engageable with said stops, means responsive to said fluid in said well casing for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, said spring means comprising a plurality of Belleville springs stacked in concentric relation to edge-to-edge peripheral engagement, and adjustable means for preloading said springs.

6. Apparatus as defined in claim **1,** wherein said mandrel is sealed in said body and exposed to the pressure of fluid in said formation to urge said mandrel through said positions.

7. Apparatus as defined in claim **1,** wherein said mandrel is sealed in said body and exposed to the pressure of fluid in said formation to urge said mandrel through said positions, and including energizing means responsive to the pressure of fluid in said casing above said packer also urging said mandrel through said positions.

8. Apparatus as defined in claim **1,** wherein said mandrel is sealed in said body and exposed to the pressure of fluid in said formation to urge said mandrel through said positions, and including energizing means responsive to the pressure of fluid in said casing above said packer also urging said mandrel through said positions, and means for dampening such movement of said mandrel.

9. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body, including stops on said mandrel and detent means carried by said body and engageable with said stops, means responsive to said fluid in said well casing for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, and including energizing means responsive to the pressure of fluid in said casing above said packer for urging said mandrel through said positions when said detent means are released.

10. Apparatus as defined in claim **1,** wherein said control means comprises escapement means on said mandrel and in said body, including stops on said mandrel and detent means carried by said body and engageable with said stops, means responsive to said fluid in said well casing for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, and including energizing means responsive to the pressure of fluid in said casing

above said packer for urging said mandrel through said positions when said detent means are released, and means for dampening such movement of said mandrel.

11. A shut-in valve for use in performing drill stem tests in a well bore, comprising: an elongated tubular body, an elongated tubular mandrel axially shiftably disposed in said body, said body and said mandrel having valve means successively openable and closeable a plurality of times upon longitudinal movement in one direction of said mandrel relative to said body to enable and to prevent the flow of fluid through said mandrel, escapement means for controlling said longitudinal movement of said mandrel within said body and limiting said movement of said mandrel to successive positions at which said valve means is opened and closed, and fluid pressure operated means for operating said escapement means to enable successive movements of said mandrel in said body.

12. A shut-in valve as defined in claim **11**, wherein said escapement means comprises successive stops on said mandrel and detent means carried by said body, said means for operating said escapement means including fluid pressure responsive means for releasing said detent means.

13. A shut-in valve as defined in claim **11**, wherein said escapement means comprises successive stops on said mandrel and detent means carried by said body, said means for operating said escapement means including fluid pressure responsive means for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position.

14. A shut-in valve as defined in claim **11**, wherein said escapement means comprises successive stops on said mandrel and detent means carried by said body, said means for operating said escapement means including fluid pressure responsivve means for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, said spring means comprising a plurality of Belleville springs stacked in concentric relation in edge-to-edge peripheral engagement.

15. A shut-in valve as defined in claim **11**, wherein said escapement means comprises successive stops on said mandrel and detent means carried by said body, said means for operating said escapement means including fluid pressure responsive means for releasing said detent means, and spring means normally biasing said detent means to a mandrel stopping position, said spring means comprising a plurality of Belleville springs stacked in concentric relation in edge-to-edge peripheral engagement, and adjustable means for preloading said springs.

16. A shut-in valve as defined in claim **11**, wherein said fluid pressure operated means comprises differential piston and cylinder means in said body, and means including a bladder exposed externally of said body and confining a quantity of oil for actuating said piston means responsive to external pressure applied to said bladder.

17. A shut-in valve as defined in claim **11**, wherein said fluid pressure operated means includes a cylinder sleeve in said body having differential internal diameters, an annular piston slideably engaged with said sleeve and defining therewith a pressure chamber, said piston having differential areas exposed to the pressure of fluid in said chamber.

18. A shut-in valve as defined in claim **11**, wherein said fluid pressure operated means includes a cylinder sleeve in said body having differential diameters, an annular piston slideably engaged with said sleeve and defining therewith a pressure chamber, said piston having differential areas exposed to the pressure of fluid in said chamber, and means removably mounting said cylinder sleeve and said piston in said body.

19. A shut-in valve as defined in claim **11**, wherein said mandrel is sealed in said body to be responsive to the pressure of fluid in said body to move said mandrel.

20. A shut-in valve as defined in claim **11**, including energizing means for moving said body responsive to applied fluid pressure.

21. A shut-in valve as defined in claim **11**, including energizing means for moving said body responsive to applied fluid pressure, said energizing means comprising an annular piston on said mandrel and a cylinder sleeve encircling said annular piston and defining with said mandrel a pressure chamber, and means for applying pressure to fluid in said chamber.

22. A shut-in valve as defined in claim **11**, including energizing means for moving said body responsive to applied fluid pressure, said energizing means comprising an annular piston on said mandrel and a cylinder sleeve encircling said annular piston and defining with said mandrel a pressure chamber, and means for applying pressure to fluid in said chamber including a bladder exposed at the exterior of said body.

23. A shut-in valve as defined in claim **11**, including energizing means for moving said body responsive to applied fluid pressure, said energizing means comprising an annular piston on said mandrel and a cylinder sleeve encircling said annular piston and defining with said mandrel a pressure chamber, and means for applying pressure to fluid in said chamber, and said body and said mandrel having cylinder and piston meanse for dampening movement of said mandrel.

24. A shut-in valve as defined in claim **11**, wherein said escapement means comprises a plurality of circumferential lands spaced longitudinally of said mandrel and each having an upwardly facing stop shoulder, a ball cage surrounding said mandrel and having vertically spaced ball detents radially shiftably carried thereby, an axially shiftable indexing guide disposed about said ball cage and having internal axially spaced ball detent engaging surfaces and intermediate clearance spaces for receiving said ball detents, said fluid pressure operated means including means acting on said indexing guide to shift the latter axially in one direction, spring means acting on said indexing guide to force the latter axially in the other direction, said shoulders, said ball detents, said ball detent engaging surfaces and said relief spaces being axially spaced so that said ball detents alternately are held radially inwardly for engagement by one of said shoulders and are free to move radially outwardly upon axial movement of said indexing guide in opposite directions to open and close said valve means successively upon each increment of movement of said mandrel.

25. A shut-in valve as defined in claim **11**, wherein said escapement means comprises a plurality of circumferential lands spaced longitudinally of said mandrel and each having an upwardly facing stop shoulder, a ball cage surrounding said mandrel and having vertically spaced ball detents radially shiftably carried thereby, an axially shiftable indexing guide disposed

about said ball cage and having internal axially spaced ball detent engaging surfaces and intermediate clearance spaces for receiving said ball detents, said fluid pressure operated means including means acting on said indexing guide to shift the latter axially in one direction, spring means acting on said indexing guide to force the latter axially in the other direction, said shoulders, said ball detents, said ball detent engaging surfaces and said relief spaces being axially spaced so that said ball detents alternately are held radially inwardly for engagement by one of said shoulders and are free to move radially outwardly upon axial movement of said indexing guide in opposite directions to open and close said valve means successively upon each increment of movement of said mandrel, said fluid pressure operated means further including a cylinder sleeve in said body having differential internal diameters, an annular piston slideably engaged with said sleeve and defining therewith a pressure chamber, said piston having differential areas exposed to the pressure of fluid in said chamber, and means removably mounting said cylinder sleeve and said piston in said body.

26. A shut-in valve as defined in claim **11,** wherein said escapement means comprises a plurality of circumferential lands spaced longitudinally of said mandrel and each having an upwardly facing stop shoulder, a ball cage surrounding said mandrel and having vertically spaced ball detents radially shiftably carried thereby, an axially shiftable indexing guide disposed about said ball cage and having internal axially spaced ball detent engaging surfaces and intermediate clearance spaces for receiving said ball detents, said fluid pressure operated means including means acting on said indexing guide to shift the latter axially in one direction, spring means acting on said indexing guide to force the latter axially in the other direction, said shoulders, said ball detents, said ball detent engaging surfaces and said relief spaces being axially spaced so that said ball detents alternately are held radially inwardly for engagement by one of said shoulders and are free to move radially outwardly upon axial movement of said indexing guide in opposite directions to open and close said valve means successively upon each increment of movement of said mandrel, said fluid pressure operated means further including a cylinder sleeve in said body having differential internal diameters, an annular piston slideably engaged with said sleeve and defining therewith a pressure chamber, said piston having differential areas exposed to the pressure of fluid in said chamber, and means removably mounting said cylinder sleeve and said piston in said body, said mandrel and said body having means defining an energizing piston chamber, and said mandrel having a piston area exposed to the pressure of fluid in said energizing piston chamber to move said mandrel longitudinally as aforesaid.

27. A shut-in valve as defined in claim **11,** wherein said escapement means comprises a plurality of circumferential lands spaced longitudinally of said mandrel and each having an upwardly facing stop shoulder, a ball cage surrounding said mandrel and having vertically spaced ball detents radially shiftably carried thereby, an axially shiftable indexing guide disposed about said ball cage and having internal axially spaced ball detent engaging surfaces and intermediate clearance spaces for receiving said ball detents, said fluid pressure operated means including means acting on said indexing guide to shift the latter axially in one direction, spring means action on said indexing guide to force the latter axially in the other direction, said shoulders, said ball detents, said ball detent engaging surfaces and said relief spaces being axially spaced so that said ball detents alternately are held radially inwardly for engagement by one of said shoulders and are free to move radially outwardly upon axial movement of said indexing guide in opposite directions to open and close said valve means successively upon each increment of movement of said mandrel, said fluid pressure operated means further including a cylinder sleeve in said body having differential internal diameters, an annular piston slideably engaged with said sleeve and defining therewith a pressure chamber, said piston having differential areas exposed to the pressure of fluid in said chamber, and means removably mounting said cylinder sleeve and said piston in said body, said mandrel and said body having means defining an energizing piston chamber, and said mandrel having a piston area exposed to the pressure of fluid in said energizing piston chamber to move said mandrel longitudinally as aforesaid, said pressure chamber of said fluid pressure operated means and said energizing piston chamber being filled with oil and including bladders exposed externally of said body and confining said oil in said chamber.

28. A shut-in valve as defined in claim **11,** wherein said mandrel is sealed in said body to be responsive to the pressure of fluid in said body to move said mandrel, and said escapement means normally limits movement of said mandrel to a position at which said valve means is closed.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,891,033 Dated June 24, 1975

Inventor(s) LYLE B. SCOTT

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 21, after "space" insert --12 in the casing below the packer H from the annular space--.
Col. 4, line 2, "annular" should be --annulus--.
Col. 6, line 40, "entend" should be --extend--.
Col. 7, line 25, "rings" should be --ring--.
Col. 7, line 44, "annuluar" should be --annular--.
Col. 12, line 37 (Claim 23) "meanse" should be --means--.

Signed and Sealed this

eleventh Day of *May 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks