

Description

This invention relates to a multi-mode testing tool.

Well testing and stimulation operations are commonly conducted on oil and gas wells in order to determine the production potential and to enhance it if possible. In flow testing a well, a tester valve is lowered into the well on a string of drill pipe above a packer. After the packer is set, the tester valve is opened and closed periodically to determine formation flow, pressure, and rapidity of pressure recovery.

Also generally included in a testing string are a drill pipe tester valve and a circulation valve above the tester valve, the former to permit testing the pressure integrity of the string prior to conducting the test, and the latter to permit the circulation of formation fluids out of the string after the test is completed.

It is desirable, particularly when conducting tests on offshore wells, to employ a testing string which requires a minimum rotation or reciprocation of the drill pipe to operate the tools therein, so as to keep the well blowout preventers closed during the majority of the operation. So-called annulus pressure responsive downhole tools have been developed, which tools operate in response to pressure changes in the annulus between the testing string and the well bore casing. A number of these annulus pressure responsive tools are disclosed in patents. For example, testing valves are disclosed in U.S. Patents No. 3,858,649 and 3,856,085, 3,976,136, 3,964,544, 4,144,937, 4,422,506, and 4,429,748. Circulation valves are disclosed in U.S. Patents No. 3,850,250, 3,970,147, 4,113,012, 4,324,293 and 4,355,685. It is also known to operate a tool to take a sample of formation fluid with annulus pressure, as disclosed in U.S. Patents No. RE 29,562 and 4,063,593. Moreover, tools which combine multiple functions have also been developed, as disclosed in the aforesaid RE 29,562 (testing and sampling) and U.S. Patents No. 4,064,937, 4,270,610 and 4,311,197 (circulating and sampling). While many of the aforesaid tools provide a biasing source comprising an inert gas under pressure to oppose annulus pressure, it is also known to employ a compressible fluid, such as silicone oil, as disclosed in U.S. Patents No. 4,109,724, 4,109,725 and European patent specification no. 88550. Moreover, the use of a compressed gas in combination with a fluid, such as oil, is disclosed in U.S. Patents No. 4,422,506 and 4,429,748.

There exist other testing, circulating and sampling tools and the like which operate in response to annulus pressure, as disclosed in U.S. Patents No. RE 29,638, 3,796,261, 3,823,773, 3,901,314,

3,986,554, 4,403,659, 4,105,075, 4,125,165, 4,341,266, 3,891,033 and 4,399,870.

Drill pipe tester valves which operate responsive to pipe string manipulation are disclosed in U.S. Patents No. 4,295,361, 4,319,633, 4,319,634 and 4,421,172.

While the tools of the prior art are diverse in design, they suffer from a number of deficiencies in actual operation. First, while several functions have been combined into one tool in some instances, the operation thereof depends upon use of multiple pressures, shearing of pins, or pressure variation both inside and outside the pipe string. Inability to maintain precise pressure levels hampers the use of some of these tools, while the use of shear pins prevents further operation of other tools after the pins have sheared. Many prior art tools employing therein a fluid such as oil utilize fluid metering means such as flow restrictors of a jet type exemplified by the Lee Visco Jet, described in U.S. Patent No. 3,323,550, in conjunction with check valves. Such metering means and check valves are susceptible to clogging and often fail to operate properly if the fluid becomes contaminated or is of a low quality to begin with, a common occurrence in many remote areas of the world where these tools are operated. In addition, the use of fluid metering means requires an inordinate amount of time to cycle the prior art tools, thus prolonging time on the jobsite and cost to the well operator. Furthermore, temperature increases or decreases in the well bore from ambient surface temperatures change viscosity in the oils employed in these tools, thus affecting the performance of fluid metering means and altering tool cycling time. A further disadvantage resides with those tools utilizing oil, water or other liquids as an expendable fluid, as they are limited in the number of times they can be cycled downhole.

Finally, even though some attempts have been made to combine multiple functions in a single tool, there has theretofore been no successful combination of more than two functions in a single tool.

In contrast to the prior art, the present invention comprises a downhole tool which can be made to perform in different modes of operation as, for example, a drill pipe tester valve, a circulation valve and a formation tester valve, as well as providing its operator with the ability to displace fluids in the pipe string above the tool with nitrogen or another gas prior to testing or retesting. This latter function is a valuable advantage in testing of gas formations or other weak or low pressure formations which may not flow when subjected to a large hydrostatic head or which may even be damaged by the weight of fluid in the string when the formation tester valve is opened.

In the aforesaid US Patent No. 4,064,937 there is described a multi-mode downhole tool for use in a testing string disposed in a well bore, comprising: tubular housing means defining a longitudinal tool bore; valve means disposed in said housing means including a tool bore closure valve, the valve means being operable in at least a circulation valve mode and a second valve mode; and operating means adapted to change said valve means between valve modes responsive to changes in pressure proximate said tool in said well bore.

One aspect of the present invention is characterised in that the tool further comprises means for fluid displacement, the valve means further includes a sleeve valve, the second valve mode is a displacement valve mode, and the operating means comprises a mandrel means and a ball and slot ratchet means associated with the mandrel means, the ratchet slot being defined on the mandrel means, wherein the ratchet slot is formed by a continuous closed loop having a number of operating regions, each region corresponding to one of the valve modes and comprising a number of rest positions such that the ratchet means hold the valve means in the corresponding one of the valve modes for a predetermined number of pressure changes.

The ball and slot type ratchet mechanism provides the desired opening and closing responsive to a series of annulus pressure increases and decreases of a drill pipe tester/formation tester valve, a circulation valve and a nitrogen displacement valve, as well as changing between the modes of tool operation in which each of these valves function. Moreover, the opening and closing as well as changing between tool modes is preferably effected without requiring the accurate monitoring of pressure levels such as is necessary with tools that employ multiple pressure levels above a reference level or both pipe string and annulus pressure. The various tool modes are preferably mutually exclusive, that is to say, only one mode is operative at a time to ensure, for example, that the circulation valve and tester valve cannot operate at the same time. In addition, a tool of the present invention is preferably not limited to a given number of cycles in any of its modes, unlike prior art tools which employ shear pins or expendable fluids.

Further advantages which can be achieved over prior art tools include elimination of the need for a bypass below the tool since the design of the present invention precludes any operation of the circulating valve due to internal string pressure, including formation pressure from below the tool or acidizing or fracturing pressure from above applied to the formation. Conversely, circulating fluid under pressure is positively isolated from the formation below, due to the aforesaid "lock-out" feature

which precludes opening of the tester valve in conjunction with the circulation valve. A further advantage of the circulation mode is the ability to circulate in either direction, so as to be able to spot chemicals or other fluids directly into the testing string bore from the surface, and then open the tester valve to treat the formation therewith. Also, pumping cold fluid through the tool will not prevent it from operating.

In addition to the advantages enumerated above, the present invention includes a novel and unobvious operating mechanism for fluid displacement in the tool which avoids the use of the flow restrictors and check valves of the prior art, such mechanism having utility in a wide variety of downhole tools, which employ pressure changes as a power source, and therefore not being so limited to the tool disclosed herein. Elimination of a fluid metering system greatly reduces tool cycling time and avoids the effects of viscosity changes in the metered fluid, as well as providing enhanced reliability. Another portion of the operating mechanism of the present invention includes a non-rotating ratchet sleeve and a rotating ball follower which enhances the reciprocation of the operating mandrel of the tool as disclosed, but which is also not so limited to that particular tool, having utility in other downhole tools as well.

It should be noted that the tool as disclosed is not limited to the four-mode (drill pipe tester, formation tester, circulation valve, nitrogen displacement valve) operation format. It may be employed in conjunction with another, independently actuated formation tester valve therebelow, and substitute an alternative ratchet slot program to operate in a three-mode (drill pipe tester, circulation valve, nitrogen displacement valve) format, or in a two-mode (circulation valve, nitrogen displacement valve) format.

The present invention will be more fully understood by a review of the following detailed description of a preferred embodiment thereof, in conjunction with the accompanying drawings, wherein:

FIGURE 1 provides a schematic vertically sectioned view of a representative offshore platform from which testing may be conducted and illustrates a formation testing string or tool assembly in a submerged well bore at the lower end of a string of drill pipe which extends upward to the platform.

FIGURES 2A-2H comprise a vertical half-section of the tool of the present invention in a formation testing mode.

FIGURES 3A-3H comprise a vertical half-section of the tool of the present invention in a drill pipe testing mode.

FIGURES 4A-4H comprise a vertical half-section of the tool of the present invention in a nitrogen

displacement mode.

FIGURES 5A-5H comprise a vertical half-section of the tool of the present invention in a circulating mode.

FIGURE 6 comprises a development of the slot design employed in the preferred embodiment of the tool of the present invention.

FIGURES 7 and 7B comprise an enlarged section of an alternative embodiment of the nitrogen displacement valve of the present invention.

FIGURES 8, 9 and 10 comprise alternative slot designs which may be employed to alter the mode-changing sequence in the tool of the present invention.

Referring to Figure 1, the present invention is shown schematically incorporated in a testing string deployed in an offshore oil or gas well. Platform 2 is shown positioned over a submerged oil or gas well bore 4 located in the sea floor 6. Well bore 4 penetrating potential producing formation 8. Well bore 4 is shown to be lined with steel casing 10, which is cemented into place. A subsea conduit 12 extends from the deck 14 of platform 2 into a subsea wellhead 16, which includes blowout preventer 18 therein. Platform 2 carries a derrick 20 thereon, as well as a hoisting apparatus 22, and a pump 24 which communicates with the well bore 4 via control conduit 26, which extends below blowout preventer 18.

A testing string 30 is shown disposed in well bore 4, with blowout preventer 18 closed thereabout. Testing string 30 includes upper drill pipe string 32 which extends downward from platform 2 to wellhead 16, whereat is located hydraulically operated "test tree" 34, below which extends intermediate pipe string 36. Slip joint 38 may be included in string 36 to compensate for vertical motion imparted to platform 2 by wave action; slip joint 38 may be similar to that disclosed in U.S. Patent No. 3,354,950 to Hyde. Below slip joint 38, intermediate string 36 extends downwardly to multi-mode testing tool 50 of the present invention. Below combination tool 50 is lower pipe string 40, extending to tubing seal assembly 42, which stabs into packer 44. When set, packer 44 isolates upper well bore annulus 40 from lower well bore annulus 48. Packer 44 may be any suitable packer well known in the art, such as, for example, a Baker oil Tool Model D packer, an Otis Engineering corporation Type W packer, or Halliburton Services CHAMP®, RTTS or EZ DRILL® SV packers. Tubing seal assembly 42 permits testing string 30 to communicate with lower well bore 48 through perforated tail pipe 52. In this manner, formation fluids from potential producing formation 8 may enter lower well bore 48 through the perforations 54 in casing 10, and be routed into testing string 30.

After packer 44 is set in well bore 4, a formation test controlling the flow of fluid from potential producing formation 8 through testing string 30 may be conducted using variations in pressure effected in upper annulus 46 by pump 24 and control conduit 26, with associated relief valves (not shown). Prior to the actual test, however, the pressure integrity of testing string 30 may be tested with the valve ball of the multi-mode tool closed in the tool's drill pipe tester mode. Tool 50 may be run into well bore 4 in its drill pipe tester mode, or it may be run in its circulation valve mode to automatically fill with fluid, and be cycled to its drill pipe mode thereafter. Formation pressure, temperature and recovery time may be measured during the flow test through the use of instruments incorporated in testing string 30 as known in the art as the ball valve in tool 50 of the present invention is opened and closed in its formation tester valve mode. Such instruments are well known in the art, and include both Bourdon tube-type mechanical gauges, electronic memory gauges, and sensors run on wireline from platform 2 inside testing string 30 prior to the test. If the formation to be tested is suspected to be weak and easily damageable by the hydrostatic head of fluid in testing string 30, tool 50 may be cycled to its displacement mode and nitrogen or other inert gas under pressure employed to displace fluids from the string prior to testing or retesting.

It may also be desirable to treat the formation 8 in conjunction with the testing program while testing string 30 is in place. Such a treating program is conducted by pumping various chemicals and other materials down the interior of testing string 30 at a pressure sufficient to force the chemicals and other materials into the formation, and to possibly fracture the formation. Of course, the chemicals, materials and pressures employed will vary depending on the formation characteristics and the desired changes thought to be effective in enhancing formation productivity. In this manner it is possible to conduct a testing program, treat the formation and a second testing program to determine treatment effectiveness without removal of testing string 30. If desired, treating chemicals may be spotted into testing string 30 from the surface by placing tool 50 in its circulation valve mode, and displacing string fluids into the annulus prior to opening the valve ball in tool 50.

At the end of the testing and treating programs, the circulation valve mode of tool 50 is employed, the circulation valve opened and formation fluids, chemicals and other injected materials in testing string 30 are circulated from the interior of testing string 30 into upper annulus 46 using a clean fluid, packer 44 is released (or tubing seal 42 withdrawn if packer 44 is to remain in place) and testing string

30 withdrawn from well bore 4.

Referring to FIGS. 2A-2H, tool 50 is shown in section, commencing at the top of the tool with upper adapter 100 having threads 102 therein at its upper end, whereby tool 50 is secured to drill pipe in the testing string. Upper adapter 100 is secured to nitrogen valve housing 104 at threaded connection 106, housing 104 containing a valve assembly (not shown), such as is well known in the art, in lateral bore 108 in the wall thereof, from which extends downwardly longitudinal nitrogen charging channel 110.

Valve housing 104 is secured by threaded connection 112 at its outer lower end to tubular pressure case 114, and by threaded connection 116 at its inner lower end to gas chamber mandrel 118, case 114 and mandrel 118 defining pressurized gas chamber 120 and upper oil chamber 122, the two being separated by floating annular piston 124.

The upper end of oil channel coupling 126 extends between case 114 and gas chamber mandrel 118, and is secured to the lower end of case 114 at threaded connection 128. A plurality of longitudinal oil channels 130 (one shown) extend from the upper end of coupling 126 to the lower end thereof. Radially drilled oil fill ports 132 extend from the exterior of tool 50, intersecting channels 130 and are closed with plugs 134. Annular shoulder 136 extends radially inward from inner wall 138 of coupling 126. The lower end of coupling 126, including annular overshoot 127, is secured at threaded connection 140 to the upper end of ratchet case 142, through which oil fill ports 144 extend at annular shoulder 146, being closed by plugs 148. At the lower end of ratchet case 142 are additional oil fill ports 150 closed by plugs 152 and open pressure ports 154.

Ratchet slot mandrel 156 extends upward within the lower end of oil channel coupling 126. Annular ratchet chamber 158 is defined between mandrel 156 and case 142. The upper exterior 160 of mandrel 156 is of substantially uniform diameter, while the lower exterior 162 is of greater diameter so as to provide sufficient wall thickness for ratchet slots 164. There are preferably two such ratchet slots 164 of the configuration shown in FIG. 6 extending about the exterior of ratchet slot mandrel 156.

Ball sleeve assembly 166 surrounds ratchet slot mandrel 156, and comprises upper sleeve 168 including radially outwardly extending annular shoulder 170 having annular piston seat 172 thereon. Below shoulder 170, ratchet piston support surface 173 extends to the lower end of upper sleeve 168, which is overshoot by the upper end of lower sleeve 174 having annular piston seat 176 thereon, and to which it is secured at threaded connection 178. Ball sleeve 180 is disposed at the

bottom of lower sleeve 174, and is secured thereto at swivel bearing race 182 by a plurality of bearings 184. Two ratchet balls 186 each extend into a ball seat 188 on diametrically opposite sides of ball sleeve 180 and into a ratchet slot 164 of semicircular cross-section. Due to this structure when balls 186 follow the path of slots 164, ball sleeve 180 rotates with respect to lower sleeve 174, the remainder of ball sleeve assembly 166 does not rotate, and only longitudinal movement is transmitted to ratchet mandrel 156 by balls 186.

Upper annular ratchet piston 190 and lower annular ratchet piston 192 ride on piston support surface 173 on upper sleeve 168, coil spring 194 being disposed therebetween. Upper ratchet piston 190 carries radial sealing surface 196 on its upper end, while lower ratchet piston 192 carries radial sealing surface 198 on its lower end.

The lower end 200 of ratchet slot mandrel 156 is secured at threaded connection 202 to extension mandrel 204 having relief ports 208 extending therethrough. Annular lower oil chamber 210 is defined by ratchet case 142 and extension mandrel 204. Annular floating piston 212 slidingly seals the bottom of lower oil chamber 210 and divides it from well fluid chamber 214 into which pressure ports 154 open. The lower end of ratchet case 142 is secured at threaded connection 218, to extension case 216, which surrounds extension mandrel 204.

Circulation-displacement housing 220 is threaded at 222 to extension case 216, and possesses a plurality of circumferentially spaced radially extending circulation ports 224 as well as a plurality of nitrogen displacement ports 226 extending through the wall thereof.

Circulation valve sleeve 228 is threaded to extension mandrel 204 at 230. Valve apertures 232 extend through the wall of sleeve 228, and are isolated from circulation ports 224 by annular seal 234, which is disposed in seal recess 236 formed by the junction of circulation valve sleeve 228 with displacement valve sleeve 238, the two being threaded together at 240. The exterior of displacement valve sleeve 238 carries thereon downwardly facing radially extending annular shoulder 242 thereon, against which bears displacement spring 244. The lower exterior of displacement valve sleeve 238 is defined by displacement piston surface 246 upon which sliding annular displacement piston 248 rides. Annular valve surface 250 of piston 248 seats on elastomeric valve seat 254. Nitrogen displacement apertures 256 extend through the wall of displacement valve sleeve 238. Valve seat 254 is pinched between sleeve 238 and shoulder 257 of sleeve 238 and flange 258 of operating mandrel 260, which is secured to sleeve 238 at threaded connection 262.

Seal carrier 264 surrounds mandrel 260 and the junction of mandrel 260 with sleeve 238 and is secured to mandrel 260 at threaded connection 265. Square cross-section annular seal 266 is carried on the exterior of mandrel 260 adjacent flange 258, and is secured in place by the upper end of seal carrier 264.

Below seal carrier 264, mandrel 260 extends downwardly to exterior annular recess 267, which separates annular shoulder 268 from the main body of mandrel 260.

Collet sleeve 270, having collet fingers 272 extending upward therefrom, engages operating mandrel 260 through the accommodation of radially inwardly extending protuberances 274 by annular recess 267. As is readily noted in FIG. 2G, protuberances 274 and the upper portions of fingers 272 are confined between the exterior of mandrel 260 and the interior of circulation-displacement housing 220.

At the lower end of collet sleeve 270, coupling 276 comprising flanges 278 and 280, with exterior annular recess 282 therebetween, grips coupling 284, comprising inwardly extending flanges 286 and 288 with interior recess 290 therebetween, on each of two ball operating arms 292. Couplings 276 and 284 are maintained in engagement by their location in annular recess 296 between ball case 294, which is threaded at 295 to circulation-displacement housing 220, and ball housing 298. Ball housing 298 is of substantially tubular configuration, having an upper smaller diameter portion 300 and a lower, larger diameter portion 302 which has two windows 304 cut through the wall thereof to accommodate the inward protrusion of lugs 306 from each of the two ball operating arms 292. Windows 304 extend from shoulder 311 downward to shoulder 314 adjacent threaded connection 316 with ball support 340. On the exterior of the ball housing 298, two longitudinal channels (location shown by arrow 308) of arcuate cross-section and circumferentially aligned with windows 304, extend from shoulder 310 downward to shoulder 311. Ball operating arms 292, which are of substantially the same arcuate cross-section as channels 308 and lower portion 302 of ball housing 298, lie in channels 308 and across windows 304, and are maintained in place by the interior wall 318 of ball case 294 and the exterior of ball support 340.

The interior of ball housing 298 possesses upper annular seat recess 320, within which annular ball seat 322 is disposed, being biased downwardly against ball 330 by ring spring 324. Surface 326 of upper seat 322 comprises a metal sealing surface, which provides a sliding seal with the exterior 332 of valve ball 330.

Valve ball 330 includes a diametrical bore 334 therethrough, of substantially the same diameter as

bore 328 of ball housing 298. Two lug recesses 336 extend from the exterior 332 of valve ball 330 to bore 334.

The upper end 342 of ball support 340 extends into ball housing 298, and carries lower ball seat recess 344 in which annular lower ball seat 346 is disposed. Lower ball seat 346 possesses arcuate metal sealing surface 348 which slidably seals against the exterior 332 of valve ball 330. When ball housing 298 is made up with ball support 340, upper and lower ball seats 322 and 346 are biased into sealing engagement with valve ball 330 by spring 324.

Exterior annular shoulder 350 on ball support 340 is contacted by the upper ends 352 of splines 354 on the exterior of ball case 294, whereby the assembly of ball housing 294, ball operating arms 292, valve ball 330, ball seats 322 and 346 and spring 324 are maintained in position inside of ball case 294. Splines 354 engage splines 356 on the exterior of ball support 340, and thus rotation of the ball support 340 and ball housing 298 within ball case 294 is prevented.

Lower adapter 360 protrudes at its upper end 362 between ball case 294 and ball support 340, sealing therebetween, when made up with ball support 340 at threaded connection 364. The lower end of lower adapter 360 carries on its exterior threads 366 for making up with portions of a test string below tool 50.

When valve ball 330 is in its open position, as shown in FIG. 2G, a "full open" bore 370 extends throughout tool 50, providing an unimpeded path for formation fluids and/or for perforating guns, wireline instrumentation, etc.

OPERATION OF THE PREFERRED EMBODIMENT OF THE PRESENT INVENTION

Referring to FIGS. 1 through 6, operation of the combination tool 50 of the present invention is described hereafter.

As tool 50 is run into the well in testing string 30, it is normally in its drill pipe tester mode shown in FIGS. 3A-H, with ball 330 in its closed position, with ball bore 334 perpendicular to tool bore 370. In this position, circulation ports 224 are misaligned with circulation apertures 232, seal 234 preventing communication therebetween. In a similar fashion, nitrogen displacement ports 226 are offset from displacement apertures 256 and isolated therefrom by seal 266. With respect to FIG. 6, balls 186 will be in positions "a" in slots 164 as tool 50 is run into the well bore.

As tool 50 travels down to the level of the formation 8 to be tested, at which position packer 44 is set, floating piston 212 moves upward under hydrostatic pressure, pushing ball sleeve assembly

166 upward, and causing balls 186 to move to positions "b", which does not change tool modes or open any valves. A pressure integrity check of the testing string 30 above tool 50 may then be conducted before flow testing the formation.

In order to open valve ball 330 to conduct a flow test of a formation, pressure is increased in annulus 46 by pump 24 via control conduit 26. This increase in pressure is transmitted through pressure ports 154 into well fluid chamber 214, where it acts upon floating piston 212. Piston 212 in turn acts upon a fluid, such as silicone oil, in lower oil chamber 210, which communicates with ratchet chamber 158. In ratchet chamber 158, the pressurized oil pushes against upper ratchet piston 190, the oil being prevented from bypassing piston 190 by the metal to metal seal of sealing surface 196 on piston seat 172. Piston 190 therefore pushes against shoulder 170 on upper sleeve 168, which in turn pulls lower sleeve 174, ball sleeve 180 and balls 186 upward in slots 164. In this manner, balls 186 are moved to positions c, which has no effect on tool operation as balls 186 do not shoulder on the ends of slots 164 in this position. The aforesaid feature is advantageous in that it permits pressuring of the well bore annulus 46 to test the seal of packer 44 across the well bore 4 without opening valve ball 330. By way of elaboration, when piston 190 reaches overshot 127, it is restrained from further upward movement, but fluid continues to act on shoulder 170 of upper sleeve 168, spreading piston seat 172 from sealing surface 196, breaking the seal and dumping fluid past upper sleeve 168 into oil channels 130 and upper oil chamber 122, which equalizes the pressures on both sides of piston 190 and stops the movement of ball sleeve assembly 166 and of balls 186 in slots 164. As the length of the slot is greater than the travel of the ball sleeve assembly, balls 186 stop short of the slot end. As annulus pressure is bled off, the pressurized nitrogen in chamber 120 pushes against floating piston 124, which pressure is transmitted through upper oil chamber 122, channels 130 and ratchet chamber 158 against lower ratchet piston 192. As ratchet piston 192 is biased against piston seat 176, a metal to metal seal is effected between radial sealing surface 198 and seat 176. Ball sleeve assembly 166 is therefore biased downwardly, ratchet balls 186 following the paths of slots 164 to position d₁, where they shoulder on the ends of the slots. Tool 50 is now in its formation tester valve mode as shown in FIGS. 2A-2H, but with valve ball 330 closed. When lower ratchet piston 192 reaches annular shoulder 146 in its downward travel, fluid continues to act on ball sleeve assembly 166, spreading sealing surface 198 from seat 176. Fluid is thus dumped below ball sleeve assembly 166 and is thereby equalized, stopping the travel of ball

sleeve assembly 166, balls 186 and ratchet mandrel 156.

When the well bore annulus is again pressurized, ball sleeve assembly 166 moves upward and balls 186 shoulder in slots 164 at position e₁, moving ratchet mandrel 156 upward, which pulls extension mandrel 204, circulation valve sleeve 228, displacement valve sleeve 238 and operating mandrel 260 upward. Operating mandrel 260 pulls collet sleeve 270 upward, which pulls arms 292 and rotates valve ball 330, aligning ball bore 334 with tool bore 370, permitting the formation to flow into the testing string 30 above tool 50. Tool 50 is now in the tester valve mode shown in FIGS. 2A-2H with valve ball 330 open. When annulus pressure is released, balls 186 shoulder at position d₂, and close valve ball 330, but tool 50 is still in the tester mode of FIGS. 2A-2H. The process of pressuring and releasing pressure may be continued to open and close ball 330 to flow test the formation until balls 186 reach positions d₆.

A subsequent increase in annulus pressure will shoulder balls 186 momentarily on inclined edges 164a before moving further along slots 164 past positions f but valve ball 330 will not open. When pressure is released again, balls 186 move downward and shoulder in positions f, moving ratchet mandrel 156 downward and tool 50 out of its formation tester mode and into the nitrogen displacement mode of FIGS. 4A-H. As can readily be seen in FIG. 4G protuberances 274 on collet sleeve fingers 272 are disengaged from operating mandrel 260 in this mode, preventing rotation and re-opening of ball 330.

A subsequent increase and decrease of annulus pressure causes balls 186 to climb further in slots 164 past positions g, and then to push ratchet mandrel 156 downward, moving tool 50 to its circulation valve mode shown in FIGS. 5A-H. Fluid may be circulated into the testing string 30 from annulus 46 through circulation ports 224, which are aligned with circulation apertures 232, ball valve 330 in its closed position and nitrogen displacement ports 226 offset from apertures 256. Fluid may also be circulated into annulus 46 from the testing string 30, as when it is desired to spot formation treatment chemicals into the string prior to an acidizing or fracturing operation. As may be easily observed in FIG. 5G, operating mandrel 156 has continued to travel downward within collet sleeve 270 but out of engagement with protuberances 274.

Subsequent pressure increases and decreases in the annulus will move balls 186 sequentially to positions h₁, i₁, h₂, i₂, and h₃ without changing tool 50 from its circulation mode, as balls 186 do not shoulder in slots 164. This provides a margin of safety against changing of tool modes due to in-

advertent pressure cycling in the annulus during circulation.

As annulus pressure is decreased after balls 186 reach positions h_3 , they will move downward past positions j , whereupon a subsequent annulus pressure increase will shoulder balls 186 in positions j , moving ratchet mandrel 156 upward and tool 50 back into its nitrogen displacement mode of FIGS. 4A-H. If treatment chemicals have not been spotted in the string, and if it is desired to displace fluid out of the testing string 30 prior to a further test, as where the formation has not flowed initially due to hydrostatic head of fluid in the string, nitrogen may be introduced into the testing string 30 under pressure. In this mode, valve ball 330 is closed and circulation ports 224 offset from apertures 232, but nitrogen displacement ports 226 are aligned with apertures 256. The pressurized nitrogen will act upon displacement piston 248, moving it away from seat 254, and permit fluid in the string to exit into the well bore annulus. When pressure is reduced in the string, annulus pressure outside tool 50 will act upon the upper end of displacement piston 248 through circulation ports 224, and firmly press valve surface 250 against seat 254, preventing re-entry of fluid into the string.

As in the circulation mode, several subsequent increases and decreases in annulus pressure will move balls 186 in slots 164, but will not change the mode of tool 50. As pressure is decreased and increased sequentially when balls are in positions j , they move to positions k_1 , l_1 , k_2 and l_2 . When pressure is again decreased with balls 186 in position l_2 , they will move downward in slots 164 past position m , where a subsequent increase will shoulder balls 186 out on slots 164 in positions m , changing tool mode to the drill pipe tester mode of FIGS. 3A-H, offsetting nitrogen displacement ports and apertures, leaving circulation ports and apertures offset, and leaving valve ball 330 closed. A further decrease in pressure will return balls 186 to positions a , and the operator may begin another cycle of tool 50, such as to treat the formation and retest it after the treatment, or test it with the string unloaded of fluid.

By way of further explanation of the mode changing and operating sequence of tool 50, the reader should note that the tool only changes mode when balls 186 shoulder at specific foreshortened positions on slot 164 during cycling of the tool. For example, tool 50 changes mode at positions d_1 , d_6 , f , g , j and m . Four mode changes are effected by annulus pressure decrease, and two by an increase. The pressure increases which shoulder balls 186 in positions e_1 through e_5 do not produce a mode change because balls 186 travel within a restricted longitudinal range limited by the dumping of the operating fluid in the tool by pis-

tons 190 and 192, and the configuration of the slots 164 from positions e_1 through e_5 does not permit balls 186 to climb in slots 164 to change tool modes.

As has previously been noted, tool 50 of the present invention may be changed to operate in a three-mode sequence as a drill pipe tester, circulation valve and nitrogen displacement valve in conjunction with a separate tester valve therebelow in the string by merely removing ratchet mandrel 156 and inserting another mandrel 156' having a different slot program 164' therein. Such a mandrel slot program 164' is shown in Figure 8. In all respects other than substitution of mandrel 156' for mandrel 156, tool 50 remains structurally the same even though its modes of operation have been altered.

With slot 164', tool 50 is run into the well bore in its drill pipe tester mode with balls 186 in positions a as shown in Figure 8 and tool 50 in the mode shown in FIGS. 3A-H. As tool 50 travels down the well bore, hydrostatic annulus pressure will move balls 186 to position b . As valve ball 330 remains closed, an integrity test of the drill pipe may be conducted. The first increase in annulus pressure subsequent to the drill pipe test will move balls 186 to positions c , which will not change tool mode, and a subsequent decrease and increase will shoulder balls on slot 164' at position d , which will rotate valve ball 330 to an open position, aligning bore 334 with tool bore 370 as shown in FIGS. 2A-2H. This same pressure increase will have opened the ball of the tester valve therebelow, which may be a valve such as are disclosed in U.S. Patents No. 3,964,544, 3,976,136, 4,422,506, 4,429,748, as well as others known in the art. The formation then flows through the tester valve and tool 50 during the test. When annulus pressure is decreased to close the tester valve, the decrease will move balls 186 to positions e_1 , which will not close valve ball 330 because balls 186 do not shoulder on slots 164'. Subsequent pressure increases and decreases to flow test the well via the tester valve will move balls 186 sequentially to positions f_1 , e_2 , f_2 , e_3 , f_3 and e_4 , during which valve ball 330 of tool 50 will remain open. During the next subsequent annulus pressure increase when in position e_4 , balls 186 will climb in slot 164' past positions g , valve ball 330 remaining open. When annulus pressure is relieved, however, balls 186 will shoulder in positions g and move ratchet mandrel 156' downward, closing valve ball 330 and returning tool 50 to its drill pipe tester mode shown in FIGS. 3A-H.

Another increase and decrease in annulus pressure will move balls 186 to shoulder in positions h , changing tool to the nitrogen displacement mode of FIGS. 4A-H. A second increase/decrease

pressure cycle will move balls 186 to positions i and tool 50 to the circulation mode of FIGS. 5A-5H.

Subsequent increases and decreases in annulus pressure will move ratchet balls 186 through positions j₁, i₂, j₂, i₃, j₃, and down past k₁ without changing tool mode, after which an increase will shoulder balls 186 in positions k₁, changing tool 50 to the nitrogen displacement mode of FIGS. 4A-4H.

Further annulus pressure cycling in decrease/increase sequence will move balls 186 to positions l₁, k₂, l₂, k₃ and down past positions m without changing tool mode.

A subsequent pressure increase will shoulder balls 186 in positions m and change tool 50 to its drill pipe tester mode of FIGS. 3A-H. Further pressure cycling of the annulus will begin another tool cycle.

As noted with respect to slot 164, tool 50 only changes mode when balls 186 shoulder in foreshortened paths in the slot. In slot 164' for example, tool mode changes only in ball positions d, g, h, i, k₁, and m. In all other instances, balls 186 merely travel slots 164' with no effect on tool operation.

It is also possible to re-program tool 50 of the present invention to effect modes of operation other than those disclosed with respect to the first and second preferred embodiments.

For example, referring to Figure 9, the program of slot 164" is shown. Using mandrel 156" with slot 164", tool 50 is run into the well bore in its drill pipe tester mode of Figures 3A-3H, with balls 186 in positions a in slots 164. Going downhole, balls 186 will be forced upwards to positions b by hydrostatic pressure in the annulus. A drill pipe integrity test may be conducted when tool 50 reaches the test level in the well bore.

After the packer is set, the formation may be flow tested by raising annulus pressure, lowering it and raising it again, which moves balls up through positions c, down past positions d₁, and up to d₁ whereat balls 186 shoulder and open valve ball 330, tool 50 being in the tester valve mode of FIGS. 2A-H. A subsequent decrease in annulus pressure will move balls 186 to position e₁, which will retain valve ball 330 in an open position. Another increase/decrease cycle will close valve ball 330 due to shouldering of balls 186 in positions f₁ and downward movement of ratchet mandrel 156. Another increase/decrease cycle will result in ball movement to positions g₁, and down past d₂, with valve ball 330 remaining closed. The next increase/decrease opens valve ball 330 when balls 186 shoulder in positions d₂, and leave valve ball 330 open when balls 186 travel to positions e₂. The following increase/decrease shoulders balls 186 in positions f₂ as annulus pressure is relieved, closing valve ball 330. A further increase/decrease moves

balls 186 to position g₂ and back down below d₃, after which the next subsequent increase/decrease shoulders balls 186 in positions d₃, opening valve ball 330 and leaving it open as balls 186 land at position e₃.

To continue the tool cycle, an annulus pressure increase/decrease moves balls 186 to f₃, closing valve ball 330. Balls 186 climb slots 164" with the next increase/decrease to position h, whereat tool 50 is shifted to its nitrogen displacement mode of FIGS. 4A-H, and then to its circulation mode of FIGS. 5A-H when annulus pressure is again cycled and balls 186 shoulder in positions i₁.

The next three increase/decrease cycles in annulus pressure will move balls 186 through positions j₁, i₂, j₂, i₃, j₃ and back down past position k₁. During this travel, balls 186 do not shoulder, and the tool 50 does not change mode. However, the next subsequent increase in pressure will shoulder balls 186 in positions k₁, change tool mode to the nitrogen displacement mode of FIGS. 4A-H.

The next two decrease/increase pressure cycles move balls 186 through positions l₁, k₂, l₂ and k₃ without change in tool mode. During the following decrease/increase cycle, however the tool is moved back to its drill pipe test mode of FIGS. 3A-H when balls 186 move downward below positions m on the decrease and then shoulder as pressure is increased. When annulus pressure is next decreased, balls 186 move back to positions a for commencement of a new tool cycle.

As was noted with respect to the previous operating mandrels 156 and 156' mandrel 156" does not move longitudinally to operate valve ball 330 and to change tool modes unless balls 186 shoulder in foreshortened legs of slots 164". In slots 164", only positions d₁, f₃, h, i₁, k₁, and m produce a change of mode. Positions d₁, f₁, d₂, f₂, d₃ and f₃, however, all serve to open and close, respectively valve ball 330.

With the slot program employed in slot 164", the test operator must positively pressure the annulus and then relieve pressure for valve ball 330 to move from a closed to an open position and vice-versa, which feature prevents a shutoff in the middle of a flow test if annulus pressure is reduced inadvertently. Furthermore, valve ball 330 may be left open after the formation test and circulation, to let testing string 30 drain of fluid as it is removed from well bore 4.

Another embodiment of the present invention may be effected utilizing yet another slot program, illustrated in FIG. 10 as slot 164''' on mandrel 156'''. With slots 164''', tool 50 is restricted to a two-mode operation, circulation valve, which would be preferred in some areas of the world which do not conduct drill pipe tests prior to flow testing the well, and which use a separate tester valve below

tool 50.

With slots 164"', ratchet balls 186 commence in positions a, and move to b as tool 50 travels down the well bore. Valve ball 330 is open. A first annulus pressure increase after packer 44 is set will result in ball movement to positions c₁, and subsequent decrease/increase cycling will move balls 186 through positions d₁, c₂, d₂ and c₃ to d₃. The next three increase/decrease pressure cycles will result in balls 186 climbing slots 164"' to positions e, which closes valve ball 330; positions f, which places tool 50 in its displacement valve mode; and position g₁, which places tool 50 in its circulation valve mode. The next three increase/decrease pressure cycles will result in free ball movement through positions h₁, g₂, h₂, g₃ and h₃ past i₁, without moving tool 50 from its circulation valve mode. However, a subsequent increase will change tool mode to displacement valve, as balls 186 shoulder in positions i₁. This mode is maintained through the next two decrease/increase cycles with free ball travel. The next decrease/increase cycle then moves balls 186 to shoulder in positions k, which offsets both displacement ports 226 from displacement apertures 256 and circulation ports 224 from circulation apertures 232 while leaving valve ball 330 closed. The next subsequent decrease/increase cycle will again open valve ball 330 with balls 186 in positions l, and an annulus pressure decrease will place balls back in positions a for another tool cycle. In slots 164"', balls 186 shoulder in positions e, f, g₁, i₁, k and l.

ALTERNATIVE EMBODIMENT OF THE DISPLACEMENT VALVE OF THE PRESENT INVENTION

FIGS. 7A and 7B illustrate an alternative construction for a nitrogen displacement valve assembly which may be employed in tool 50. Valve assembly 400 includes an outer circulation-displacement housing 220' with slightly longer spacing between circulation ports 224 and displacement apertures 226 than in standard housing 220. At its upper end, housing 220' is secured at threaded connection 222 to extension case 216, while at its lower end (not shown) it is secured to ball case 294. Within tool 50, extension mandrel 204 is secured at threaded connection 230 to circulation valve sleeve 228, through which circulation apertures 232 extend. Sleeve 228 is threaded to displacement valve sleeve 238', seal 226 being maintained in an annular recess 236 therebetween to isolate circulation apertures 232 from circulation ports 224.

On the exterior of displacement valve sleeve 238' lie annular marker grooves 420 (three

grooves), 422 (two grooves) and 424 (one groove), the purpose of which will be explained hereafter. Below the marker grooves displacement apertures 256 extend through the wall of sleeve 238' adjacent obliquely inclined annular wall 416, which is a part of displacement assembly 400.

Flapper mandrel 406 slides on the exterior of sleeve 238' below wall 416, and is restricted in its longitudinal travel by the abutment of elastomeric seal 414 against wall 416 at its upper extent, and by the abutment of shoulder 408 against stop 404 extending upward from shoulder 402 on operating mandrel 260'. Stops 404 prevent pressure locking of shoulder 408 to shoulder 402. Seal 266 is maintained in a recess between annular shoulder 258' on mandrel 260' and seal carrier 264, which surrounds threaded connection 262 between sleeve 238' and operating mandrel 260', and is itself secured to operating mandrel 260' at threaded connection 265.

Flapper mandrel 406 carries thereon a plurality of frustoconical valve flappers 412, which are bonded to mandrel 406 adjacent annular shoulders 410.

Displacement assembly 400 is placed in its operative mode in the same fashion as the displacement mode of tool 50 in FIGS. 2-5, that is by longitudinally moving the internal assembly connected to ratchet mandrel 156 through the interaction of balls 186 in slots 164. However, unlike displacement piston 248 which is spring-biased toward a closed position against seat 254 (FIGS. 2E-F, 3E-F) and is moved therefrom by nitrogen flowing under pressure through apertures 256 (FIGS. 4E-F), mandrel 406 operates when placed adjacent displacement ports 226 (FIGS. 7A-B) through downward movement against stops 404 followed by collapse of flappers 412 against mandrel 406 to permit exit through ports 226 of the fluid in the string and the pressurized nitrogen impelling it into the well bore annulus.

If pressure is removed from the bore 370 of tool 50, the hydrostatic head (and pressure) in the annulus will expand flappers 412 against circulation-displacement housing 220' and move mandrel 406 upward against wall 416, whereon elastomeric seal 414 will seat, preventing re-entry of annulus fluids into bore 370.

An added feature of assembly 400 is the ease of identification of tool mode through the use of marker grooves 420, 422 and 424. For example, when tool 50 is in its circulation mode, circulation ports 224 will be aligned with circulation apertures 232 and no grooves will be visible. When tool 50 is in its displacement mode (FIGS. 7A-B), grooves 420 will be visible. When valve ball 330 is closed, grooves 422 will be visible, and when valve ball 330 is open, groove 420 will be visible. With knowl-

edge of which ratchet mandrel is employed in tool 50 and the initial portion desired, the tool will then be easily able to ensure placement of tool 50 in its proper mode for running into the well bore.

It is thus apparent that a novel and unobvious multi-mode testing tool has been developed, which further includes a novel and unobvious operating mechanism and valves therein. It will be readily apparent to one of ordinary skill in the art that numerous additions, deletions and modifications may be made to the invention as disclosed in its preferred and alternative embodiments as disclosed herein. For example, tool 50 might employ an all-oil operating biasing mechanism such as is disclosed in U.S. Patents No. 4,109,724, 4,109,725 and U.S. Applications Serial No. 354,529 and 417,947; the nitrogen displacement valve might be placed above the circulation valve in the tool; alternative pressure-responsive check valve designs might be employed as displacement valves; Belleville or other springs might be substituted for the coil springs shown in tool 50; the operating mechanism of the tool, including nitrogen and/or oil chambers, the ratchet mandrel and the ball sleeve assembly could be placed at the bottom of the tool or between the ends thereof; the ratchet balls could be seated in recesses on a mandrel and a rotating ratchet sleeve with slots cut on the interior thereof might be employed therearound and joined by swivel means to a sleeve assembly carrying annular pistons 190 and 192 thereon; a ratchet sleeve might be rotatably mounted about a separate mandrel and ratchet balls mounted in a non-rotating sleeve assembly thereabout; a sleeve-type valve such as is disclosed in U.S. Patent RE 29,562 might be utilized to close bore 370 through tool 50 in lieu of a ball valve; an annular sample chamber might be added to tool 50 such as is also disclosed in the aforesaid U.S. Patent RE 29,562; a second valve ball might be included longitudinally spaced from valve ball 330 and secured to operating mandrel 260 to form a ball-type sampler having a mechanism similar to those disclosed in U.S. Patents No. 4,064,937, 4,270,610 and 4,311,197; the valve ball 330 could be placed at the top of the tool and employed for drill pipe test purposes only with another tester valve run below the tool, as has been heretofore suggested; an annular piston having a longitudinal channel therein with a resiliently biased check valve closure member and valve seats at each end thereof may be substituted for the piston sleeve and pistons of the preferred embodiment, using for stop means a pin or rod adapted to push the check valve closure member back from its seat at each limit of piston travel to dump fluid therepast.

Preferred features of the apparatus defined in claims 17 are as follows:

(1) The apparatus of claim 17, wherein one of said elements has operating means associated therewith adapted to initiate said longitudinal movement.

(2) The apparatus of (1) above, wherein said slot means includes a plurality of longitudinally disposed legs, and said ratchet assembly only effects said relative movement when said ball means shoulders at the end of a said leg.

(3) The apparatus of (2) above, wherein said longitudinally disposed legs include extended ends and foreshortened ends, and said ball means only shoulders in said foreshortened ends.

(4) The apparatus of (3) above, wherein said slot means further includes oblique transfer channels between laterally adjacent legs, adapted to guide said ball means from one leg to another.

(5) The apparatus of (4) above, wherein at least some of said legs having foreshortened ends are longitudinally offset from legs laterally adjacent thereto, the combination of said offset legs, said foreshortened ends and said transfer channels being adapted to enable said ball means to travel longitudinally beyond the extent of a single leg and to thereby effect relative longitudinal movement between said elements beyond the extent of a single leg.

(6) The apparatus of (5) above, wherein at least one of said foreshortened legs includes a foreshortened end extending in a first longitudinal direction, and another of said legs includes a foreshortened end extending in a second, opposite direction, whereby said relative longitudinal movement can be effected in both directions.

(7) The apparatus of (5) above, wherein said slot means further includes at least two laterally adjacent legs having longitudinally opposed extended ends, said legs being linked by a transfer channel, whereby said ball means is enabled to move sequentially in opposite longitudinal directions without effecting said relative longitudinal movement.

(8) The apparatus of (4) above, wherein said slot means comprises at least one continuous slot of semicircular cross-section; and said ball means comprises at least one substantially spherical ball of lesser diameter than the wall of said slot.

(9) The apparatus of (8) above, wherein said swivel means comprises a plurality of bearings in a bearing race.

Preferred features of the apparatus defined in claim 18 are as follows:

(1) The apparatus of claim 18, wherein said piston sleeve means further includes first and second piston seats on said first and second shoulder means, said first piston includes a first

sealing surface sealingly engageable with said first piston seat and said second piston includes a second sealing surface sealingly engageable with said second piston seat.

(2) The apparatus of (1) above, wherein said chamber is of annular configuration; said pressure transfer means communicates pressure from the exterior of said tool; the top of said chamber comprises the inner wall of the housing of said downhole tool, and the bottom of said chamber comprises the outer wall of a substantially cylindrical element within said tool.

(3) The apparatus of (2) above, wherein said piston sleeve means comprises a tubular sleeve slidably sealingly disposed about said cylindrical tool element; said shoulder means comprise radially outward extending annular shoulders; said piston seats comprise a radially oriented surface on each of said annular shoulders at each end of said piston support surface; said pistons comprise annular pistons disposed about said piston sleeve in slidably sealing engagement with said inner wall of said tool housing; said sealing surfaces comprise radially oriented surfaces on the outer ends of said pistons; said piston stop means comprise inward protuberances from said inner wall of said tool housing; and said piston biasing means comprises a spring.

(4) The apparatus of (3) above, wherein each of said piston stop means is adapted to limit longitudinal movement of said piston sleeve in one direction by contacting its associated piston and spreading said piston from its associated shoulder on said piston sleeve, thereby permitting equalization of chamber fluid pressure on both sides of said piston.

(5) The apparatus of (3) above, wherein one of said pistons is adapted to sealingly engage its associated shoulder responsive to a positive pressure differential across said piston sleeve in one longitudinal direction, and the other of said pistons is adapted to sealingly engage its associated shoulder responsive to a positive pressure differential across said piston sleeve in the opposite longitudinal direction.

Preferred features of the apparatus defined in claim 19 are as follows:

(1) The apparatus of claim 19, wherein said pressure responsive double-acting piston means further includes a fluid-filled chamber; a piston sleeve connected to said ball and slot means; first and second shoulders on said piston sleeve; and first and second pistons disposed on said piston sleeve; and biasing means disposed between said first and second pistons.

(2) The apparatus of item (1), wherein said first piston is adapted to seat on said first shoulder, said second piston is adapted to seat on said

second shoulder, and said indexing assembly further includes first and second longitudinally spaced piston stop means respectively associated with said first and second pistons and adapted to prevent said seating when in contact with their associated pistons.

(3) The apparatus of item (2), wherein said ball and slot ratchet means includes a ball received in a ball seat means and extending into a slot associated with mandrel means, and swivel means permitting substantially unimpeded relative rotational movement between said ball seat means and said mandrel means.

(4) The apparatus of item (3), wherein said swivel means is disposed between said double-acting piston means and said ball seat means, and said slot is a continuous slot disposed on the exterior of said mandrel means.

(5) The apparatus of item (4), wherein said slot includes a plurality of longitudinally disposed legs connected by oblique laterally disposed transfer channels.

(6) The apparatus of item (5), wherein said legs include extended ends and foreshortened ends, and said piston means moves said mandrel means through shouldering of said ball in said foreshortened ends.

(7) The apparatus of item (6), further including at least two laterally adjacent oppositely longitudinally oriented legs having extended ends, whereby said ball is permitted to move sequentially at least twice in opposite longitudinal directions without movement of said mandrel means.

(8) The apparatus of item (6), wherein said slot includes longitudinally offset legs including foreshortened ends connected by transfer channels, whereby said ball is enabled to travel longitudinally in said slot and move said mandrel means a distance greater than that of a single leg.

(9) The apparatus of claim 18, wherein said ball and slot ratchet means includes a ball received in a ball seat means and extending into a slot associated with mandrel means, and swivel means permitting substantially unimpeded relative rotational movement between said ball seat means and said mandrel means.

(10) The apparatus of item (9), wherein said swivel means is disposed between said double-acting piston means and said ball seat means, and said slot is a continuous slot disposed on the exterior of said mandrel means.

(11) The apparatus of item (10), wherein said slot includes a plurality of longitudinally disposed legs connected by oblique laterally disposed transfer channels.

(12) The apparatus of item (11), wherein said legs include extended ends and foreshortened ends, and said piston means moves said man-

drel means through shouldering of said ball in said foreshortened ends.

(13) The apparatus of item (12), further including at least two laterally adjacent oppositely longitudinally oriented legs having extended ends, whereby said ball is permitted to move sequentially at least twice in opposite longitudinal directions without movement of said mandrel means.

(14) The apparatus of item (12), wherein said slot includes longitudinally offset legs having foreshortened ends connected by transfer channels, whereby said ball is enabled to travel longitudinally in said slot and move said mandrel means a distance greater than that of a single leg.

Preferred features of the apparatus defined in claim 20 are as follows:

(1) The apparatus of claim 20, wherein said check valve comprises a sliding annular piston biased against a valve seat by spring means therebehind.

(2) The apparatus of claim 20, further including biasing port means disposed through said housing wall, said annular piston being disposed between said biasing port means and said displacement port means.

(3) The apparatus of claim 20, wherein said displacement port means and said displacement aperture means are longitudinally offset, said check valve means includes a sliding flapper mandrel disposed on said mandrel means between said port means and said aperture means, said flapper mandrel

Preferred features of the apparatus of claim 22 are as follows:

(1) The apparatus of claim 22, wherein said check valve members comprise pistons and said biasing means comprises spring means.

(2) The apparatus of item (1), wherein said pistons are associated with a piston sleeve and positioned between the ends thereof, said valve seats comprise metal surfaces on shoulders fluid bypass channel comprises a path from one longitudinal fluid bypass channel comprises a path from one shoulder, past said first valve seat, between said pistons, and said sleeve and past said second valve seat to said second shoulder.

(3) The apparatus of item (2), wherein said chamber is defined between a mandrel and a tubular housing of said tool and said piston sleeve, said shoulders and said pistons are annular in configuration.

(4) The apparatus of item (3), wherein said stop means comprises radially inward extending protuberances from the inner wall of said housing.

(5) The apparatus of item (4), wherein said pressure transfer means is adapted to communicate

well bore pressure outside said tool to said fluid.

Claims

- 5 1. A multi-mode downhole tool (50) for use in a testing string (30) disposed in a well bore (4), comprising: tubular housing means (100,104,114,126,142,216, 220,294,360) defining a longitudinal tool bore (370); valve means (166,174,190,192,228,330) disposed in said housing means including a tool bore closure valve (330), said valve means being operable in at least a circulation valve mode and a second valve mode; and operating means (156,180,186, 260) adapted to change said valve means between valve modes responsive to changes in pressure proximate said tool in said well bore; characterised in that said tool further comprises means (224,226,232,248,256) for fluid displacement, said valve means further includes a sleeve valve (228), said second valve mode is a displacement valve mode, and said operating means comprises a mandrel means (156) and a ball and slot ratchet means (164,180,186,188) associated with said mandrel means, the ratchet slot (164) being defined on said mandrel means, wherein said ratchet slot is formed by a continuous closed loop having a number of operating regions, each region corresponding to one of said valve modes and comprising a number of rest positions such that said ratchet means hold said valve means in the corresponding one of said valve modes for a predetermined number of pressure changes.
- 20 2. A tool according to Claim 1, wherein said operating means is arranged to change valve modes through longitudinal movement of said mandrel means (156) in said tool.
- 25 3. A tool according to Claim 1 or 2, wherein said valve means additionally comprises a check valve (166,174, 190,192).
- 30 4. A tool according to Claims 1, 2 or 3, wherein said operating means further includes double-acting piston means (190,192) associated with said ball and slot ratchet means.
- 35 5. A tool according to any preceding claim, wherein said valve means is further operable in a drill pipe tester valve mode, or a formation tester valve mode.
- 40 6. A tool according to claim 1 wherein said housing means has circulation ports (224) and dis-



drel means through shouldering of said ball in said foreshortened ends.

(13) The apparatus of item (12), further including at least two laterally adjacent oppositely longitudinally oriented legs having extended ends, whereby said ball is permitted to move sequentially at least twice in opposite longitudinal directions without movement of said mandrel means.

(14) The apparatus of item (12), wherein said slot includes longitudinally offset legs having foreshortened ends connected by transfer channels, whereby said ball is enabled to travel longitudinally in said slot and move said mandrel means a distance greater than that of a single leg.

Preferred features of the apparatus defined in claim 20 are as follows:

(1) The apparatus of claim 20, wherein said check valve comprises a sliding annular piston biased against a valve seat by spring means therebehind.

(2) The apparatus of claim 20, further including biasing port means disposed through said housing wall, said annular piston being disposed between said biasing port means and said displacement port means.

(3) The apparatus of claim 20, wherein said displacement port means and said displacement aperture means are longitudinally offset, said check valve means includes a sliding flapper mandrel disposed on said mandrel means between said port means and said aperture means, said flapper mandrel

Preferred features of the apparatus of claim 22 are as follows:

(1) The apparatus of claim 22, wherein said check valve members comprise pistons and said biasing means comprises spring means.

(2) The apparatus of item (1), wherein said pistons are associated with a piston sleeve and positioned between the ends thereof, said valve seats comprise metal surfaces on shoulders fluid bypass channel comprises a path from one longitudinal fluid bypass channel comprises a path from one shoulder, past said first valve seat, between said pistons, and said sleeve and past said second valve seat to said second shoulder.

(3) The apparatus of item (2), wherein said chamber is defined between a mandrel and a tubular housing of said tool and said piston sleeve, said shoulders and said pistons are annular in configuration.

(4) The apparatus of item (3), wherein said stop means comprises radially inward extending protuberances from the inner wall of said housing.

(5) The apparatus of item (4), wherein said pressure transfer means is adapted to communicate

well bore pressure outside said tool to said fluid.

Claims

- 5 1. A multi-mode downhole tool (50) for use in a testing string (30) disposed in a well bore (4), comprising: tubular housing means (100,104,114,126,142,216, 220,294,360) defining a longitudinal tool bore (370); valve means (166,174,190,192,228,330) disposed in said housing means including a tool bore closure valve (330), said valve means being operable in at least a circulation valve mode and a second valve mode; and operating means (156,180,186, 260) adapted to change said valve means between valve modes responsive to changes in pressure proximate said tool in said well bore; characterised in that said tool further comprises means (224,226,232,248,256) for fluid displacement, said valve means further includes a sleeve valve (228), said second valve mode is a displacement valve mode, and said operating means comprises a mandrel means (156) and a ball and slot ratchet means (164,180,186,188) associated with said mandrel means, the ratchet slot (164) being defined on said mandrel means, wherein said ratchet slot is formed by a continuous closed loop having a number of operating regions, each region corresponding to one of said valve modes and comprising a number of rest positions such that said ratchet means hold said valve means in the corresponding one of said valve modes for a predetermined number of pressure changes.
- 20 2. A tool according to Claim 1, wherein said operating means is arranged to change valve modes through longitudinal movement of said mandrel means (156) in said tool.
- 25 3. A tool according to Claim 1 or 2, wherein said valve means additionally comprises a check valve (166,174, 190,192).
- 30 4. A tool according to Claims 1, 2 or 3, wherein said operating means further includes double-acting piston means (190,192) associated with said ball and slot ratchet means.
- 35 5. A tool according to any preceding claim, wherein said valve means is further operable in a drill pipe tester valve mode, or a formation tester valve mode.
- 40 6. A tool according to claim 1 wherein said housing means has circulation ports (224) and dis-



- placement ports (226) extending through the wall thereof; wherein said mandrel means (156,204,228,238,260) is slidably disposed in said housing means and has circulation apertures (232) and displacement apertures (256) extending through the wall thereof and alignable, respectively, with said circulation ports (224) and displacement ports (226) through longitudinal movement of said mandrel means in said housing means; check valve means (166,174,190,192) between said housing means and said mandrel means associated with said displacement ports and apertures; and wherein said operating means is adapted to effect said longitudinal mandrel means movement in response to pressure changes in said well bore.
7. A tool according to claim 6, wherein said ball and slot ratchet means (164,180,186,188) is adapted to control said longitudinal mandrel means movement.
 8. A tool according to claim 7, wherein said operating means further includes an operating fluid (122,210) disposed between said housing means and said mandrel means in communication with pressure in said well bore, and double-acting piston means (190,192) disposed in said operating fluid and adapted to longitudinally move said mandrel means in response to pressure differentials across said double-acting piston means initiated by said well bore pressure changes.
 9. A tool according to claim 8, wherein said double-acting piston means further includes operating fluid dump means (127) adapted to limit the travel of said piston means.
 10. A tool according to Claim 6, 7, 8 or 9, wherein said tool bore closure valve (330) is adapted to block said tool bore responsive to said longitudinal mandrel means movement, said tool bore closure valve preferably comprising a valve ball (330) rotatable to block said tool bore responsive to said longitudinal mandrel means movement.
 11. A tool according to Claim 10, further including lost motion means (267,272,274) to selectively disconnect said tool bore closure valve from said mandrel means.
 12. A tool according to Claim 11, wherein said lost motion means includes an annular recess (267) on the exterior of said mandrel means (260) and collet fingers (272) associated with said tool bore closure valve, said collet fingers adapted to grip said mandrel means recess when radially inwardly biased, and to release said mandrel means when said inward bias is removed.
 13. A tool according to Claim 10, 11 or 12, further including mode identification means (420,422,424) adapted to identify the position of said mandrel means with respect to said housing means and to thereby enable the operator of said tool to determine relative positioning of said circulation ports with circulation apertures, displacement ports with displacement apertures, and the position of said tool bore closure valve.
 14. A tool according to Claim 13, wherein said mode identification means comprises markings (420,422,424) on said mandrel means which are observable through said circulation ports (224).
 15. A method of operating a multi-mode downhole tool (50) having a longitudinal bore (370) extending therethrough, comprising: running said tool into a well bore (4) on a pipe string (30); changing said tool between at least two operating modes selected from the group of drill pipe tester mode, formation tester mode, displacement mode and circulation mode through sequential changes of pressure in said well bore; and opening and closing a closure valve (330) disposed in the bore (370) of said tool a plurality of times while said tool is in said formation tester mode responsive to changes in well bore pressure, without changing said tool to a different operating mode.
 16. A method according to claim 15, further comprising displacing fluid out of said pipe string and into said well bore by introducing gas under pressure into said pipe string from the surface while said tool is in said displacement mode.
 17. A method according to claim 15, further including circulating fluid between said pipe string and said well bore while said tool is in said circulation mode.
 18. A method according to claim 17, further comprising pressure-testing the integrity of said pipe string while said tool is in its drill pipe tester mode.
 19. An operating assembly in connection with a downhole tool according to claim 1, the operat-

ing assembly comprising: a chamber (210) filled with fluid; pressure transfer means (212) acting on said fluid; double-acting piston means disposed in said chamber between the ends thereof; a longitudinal fluid bypass channel associated with said piston means and extending between the ends thereof; first and second check valve members (190,192) associated with said fluid bypass channel; first and second valve seats (172,198) respectively associated with said first and second check valve members; means (194) adapted to bias each of said check valve members against its associated valve seat; and longitudinally spaced first and second stop means (127,146) adapted to respectively push upon contact therewith said first and second check valve members away from their respective valve seats.

20. An assembly according to Claim 19, wherein said check valve members comprise pistons and said biasing means comprises spring means.
21. An assembly according to Claim 20, wherein said pistons are associated with a piston sleeve (168) and positioned between the ends thereof, said valve seats comprise metal surfaces on shoulders (170,174), the fluid bypass channel comprises a path from one shoulder, past said first valve seat, between said pistons and said sleeve, and past said second valve seat to the second shoulder.
22. A tool according to Claim 2, wherein the operating means is adapted to selectively open and close said tool bore closure valve (330) in response to sequential changes in pressure proximate said tool in said well bore; and said ratchet means (164,180,186) and said mandrel means (156) control said selective opening and closure of said tool bore closure valve pursuant to a program.
23. A tool according to Claim 22, wherein said ratchet means program is defined by the configuration of said continuous closed loop (164) and said loop includes at least one program position (f) therefor in said loop configuration whereby said tool bore closure valve is disconnected from said mandrel means and subsequently reconnected thereto.
24. A tool according to Claim 23, wherein said tool bore closure valve is disconnected in its open position from said mandrel means, whereby said well bore pressure can be changed at least two times prior to said reconnection.

25. A tool according to Claim 22, wherein said tool bore closure valve comprises a ball valve (330) rotatable to block said tool bore responsive to movement of said mandrel means.

26. A tool according to Claim 1, wherein said mandrel means (156) is slidably disposed in said tool bore (370), said tool bore closure valve (330) being adapted to block said tool bore responsive to longitudinal movement of said mandrel means; and wherein said operating means is adapted to effect said longitudinal mandrel means movement in response to pressure changes in said well bore (4), said ratchet means comprising lost motion means (180,186,267, 272,274) adapted to selectively disconnect said tool bore closure valve from and reconnect said tool bore closure valve to said mandrel means.

27. A tool according to Claim 26, wherein the configuration of said continuous closed loop defines a program for the operation of said tool bore closure valve and said disconnection and reconnection of said tool bore closure valve from and to said mandrel means.

28. A tool according to Claim 27, wherein said program is adapted to disconnect said tool bore closure valve from said mandrel means after said tool bore closure valve is placed in an open position, and to reconnect said tool bore closure valve to said mandrel means after a sequence of not less than two pressure changes in said well bore.

29. A tool according to claim 26, wherein said tool bore closure valve comprises a ball valve rotatable to block said tool bore responsive to movement of said mandrel means.

30. A method according to claim 16, wherein said operating modes are selected by opening said closure valve (330) responsive to an increase in pressure in said well bore; reducing said well bore pressure without closing said closure valve; increasing said well bore pressure a second time; reducing said well bore pressure a second time; and closing said closure valve in response to said second reduction in well bore pressure.

Patentansprüche

1. Bohrlochwerkzeug (50) für mehrere Betriebsarten zur Verwendung mit einem Prüfstrang (30) in einem Bohrloch (4), enthaltend: rohrförmige Gehäusemittel (100, 104, 114, 126, 142, 216,



220, 294, 360), die eine längsverlaufende Werkzeugbohrung (370) bestimmen; in den Gehäusemitteln angeordnete Ventilmittel (166, 174, 190, 192, 228, 330) mit einem Schließventil (330) für die Werkzeugbohrung, die wenigstens in der Betriebsart eines Zirkulationsventils und einer zweiten Ventilbetriebsart betreibbar sind; und Betriebsmittel (156, 180, 186, 260) zum Wechsel der Ventilmittel zwischen den Ventilbetriebsarten unter Ansprechen auf Druckänderungen unmittelbar an dem Werkzeug im Bohrloch,

dadurch gekennzeichnet, daß das Werkzeug weiter Mittel (224, 226, 232, 248, 256) zur Fluidverdrängung enthält, daß die Ventilmittel ferner ein Hülsenschieberventil (228) enthalten, daß die zweite Ventilbetriebsart die eines Verdrängerventils ist und daß die Betriebsmittel Dornmittel (156) und den Dornmitteln zugeordnete Kugel- und -schlitz-Ratschenmittel (164, 180, 186, 188) aufweisen, wobei der Ratschenschlitz (164) an den Dornmitteln bestimmt ist, und daß der Ratschenschlitz durch eine endlose, in sich geschlossene Bahn mit einer Anzahl von Betriebsbereichen gebildet ist, die jeweils einer der Ventilbetriebsarten entsprechen und eine Anzahl von Ruhestellungen aufweist, derart, daß die Ratschenmittel die Ventilmittel über eine vorgegebene Anzahl von Druckänderungen in der entsprechenden Ventilbetriebsart halten.

2. Werkzeug nach Anspruch 1, dadurch gekennzeichnet, daß die Betriebsmittel zu einem Wechsel der Ventilbetriebsarten durch Längsbewegung der Dornmittel (156) in dem Werkzeug angeordnet sind.
3. Werkzeug nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Ventilmittel zusätzlich ein Rückschlagventil (166, 174, 190, 192) aufweisen.
4. Werkzeug nach Ansprüchen 1, 2 oder 3, dadurch gekennzeichnet, daß die Betriebsmittel ferner doppelt wirkende Kolbenmittel (190, 192) enthalten, die den Kugel- und -schlitz-Ratschenmitteln zugeordnet sind.
5. Werkzeug nach einem vorstehenden Anspruch, dadurch gekennzeichnet, daß die Ventilmittel ferner in der Betriebsart eines Bohrgestängeprüfventils oder eines Formationsprüfventils betreibbar sind.
6. Werkzeug nach Anspruch 1, dadurch gekennzeichnet, daß die Gehäusemittel Zirkulations-

öffnungen (224) und Verdrängungsöffnungen (226) enthalten, die durch deren Wandung verlaufen; daß die Dornmittel (156, 204, 228, 238, 260) gleitbar in den Gehäusemitteln angeordnet sind und Zirkulationsdurchbrüche (232) und Verdrängungsdurchbrüche (256) enthalten, die durch deren Wandung verlaufen und durch Längsbewegung der Dornmittel in den Gehäusemitteln zu den Zirkulationsöffnungen (224) bzw. Verdrängungsöffnungen (226) ausrichtbar sind; wobei zwischen den Gehäusemitteln und den Dornmitteln befindliche Rückschlagventilmittel (166, 174, 190, 192) den Verdrängungsöffnungen und -durchbrüchen zugeordnet sind; und daß die Betriebsmittel zur Bewirkung der Längsverstellung der Dornmittel unter Ansprechen auf Druckänderungen in dem Bohrloch eingerichtet sind.

7. Werkzeug nach Anspruch 6, dadurch gekennzeichnet, daß die Kugel- und -schlitz-Ratschenmittel (164, 180, 186, 188) zur Steuerung der Längsbewegung der Dornmittel eingerichtet sind.
8. Werkzeug nach Anspruch 7, dadurch gekennzeichnet, daß die Betriebsmittel weiterhin ein Betriebsfluid (122, 210) enthalten, das zwischen den Gehäusemitteln und den Dornmitteln angeordnet ist und mit dem Druck in dem Bohrloch in Verbindung steht, und in dem Betriebsfluid doppelt wirkende Kolbenmittel (190, 192) angeordnet und eingerichtet sind, um die Dornmittel unter Ansprechen auf Druckdifferenzen an den doppelt wirkenden Kolbenmitteln, die durch Druckänderungen im Bohrloch ausgelöst sind, in Längsrichtung zu verstellen.
9. Werkzeug nach Anspruch 8, dadurch gekennzeichnet, daß die doppelt wirkenden Kolbenmittel ferner Ablassmittel (127) für das Betriebsfluid enthalten, die zur Begrenzung der Verstellung der Kolbenmittel eingerichtet sind.
10. Werkzeug nach Anspruch 6, 7, 8 oder 9, dadurch gekennzeichnet, daß das Schließventil (330) der Werkzeugbohrung zum Absperren der Werkzeugbohrung unter Ansprechen auf die Längsverstellung der Dornmittel eingerichtet ist und vorzugsweise eine Ventilkugel (330) aufweist, die unter Ansprechen auf die Längsbewegung der Dornmittel drehbar ist, um die Werkzeugbohrung abzusperren.
11. Werkzeug nach Anspruch 10, ferner gekennzeichnet durch Mittel (267, 272, 274) mit totem Gang, um das Schließventil für die Werkzeugbohrung wahlweise von den Dornmitteln zu



trennen.

12. Werkzeug nach Anspruch 11, dadurch gekennzeichnet, daß die Mittel mit totem Gang eine ringförmige Ausnehmung (267) am Äußeren der Dornmittel (260) und Ringfinger (272) aufweisen, die dem Schließventil für die Werkzeugbohrung zugeordnet und eingerichtet sind, um bei radial einwärts gerichteter Vorspannung in die Ausnehmung der Dornmittel einzugreifen und bei Aufhebung der einwärts gerichteten Vorspannung die Dornmittel freizugeben. 5
13. Werkzeug nach Anspruch 10, 11 oder 12, weiter gekennzeichnet durch Identifizierungsmittel (420, 422, 424) für die Betriebsart, die zur Identifizierung der Stellung der Dornmittel gegenüber den Gehäusemitteln eingerichtet sind, um der Bedienungsperson des Werkzeugs dadurch die Bestimmung der Relativstellung der Zirkulationsöffnungen zu den Zirkulationsdurchbrüchen, der Verdrängungsöffnungen zu den Verdrängungsdurchbrüchen und der Stellung des Schließventils für die Werkzeugbohrung zu ermöglichen. 10 20 25
14. Werkzeug nach Anspruch 13, dadurch gekennzeichnet, daß die Identifikationsmittel für die Betriebsart Markierungen (420, 422, 424) an den Dornmitteln aufweisen, die durch die Zirkulationsöffnungen (224) beobachtbar sind. 30
15. Verfahren zum Betrieb eines Bohrlochwerkzeugs (50) für mehrere Betriebsarten mit einer durchgehenden Längsbohrung (370) mit den folgenden Verfahrensschritten: Einfahren des Werkzeugs in ein Bohrloch (4) an einem Rohrstrang (30); Wechsel des Werkzeugs zwischen wenigstens zwei Betriebsarten, die aus der Gruppe der Betriebsarten für die Bohrgestängeprüfung, Formationsprüfung, Verdrängung und Zirkulation durch eine Folge von Änderungen des Drucks in dem Bohrloch ausgewählt werden; mehrmaliges Öffnen und Schließen eines Schließventils (330), das in der Bohrung (370) des Werkzeugs angeordnet ist, während sich das Werkzeug in der Betriebsart der Formationsprüfung befindet, unter Ansprechen auf Änderungen im Bohrlochdruck, ohne das Werkzeug auf eine andere Betriebsart umzuschalten. 35 40 45 50
16. Verfahren nach Anspruch 15, weiter gekennzeichnet durch das Verdrängen von Fluid aus dem Rohrstrang in das Bohrloch durch Einbringen von Gas unter Druck in den Rohrstrang von der Oberfläche her, während das Werkzeug in der Verdrängungs-Betriebsart ist. 55
17. Verfahren nach Anspruch 15, weiter gekennzeichnet durch Zirkulieren von Fluid zwischen dem Rohrstrang und dem Bohrloch, während das Werkzeug in der Zirkulations-Betriebsart ist.
18. Verfahren nach Anspruch 17, weiter gekennzeichnet durch Druckprüfen der Unversehrtheit des Rohrstrangs, während das Werkzeug in der Betriebsart der Bohrgestängeprüfung ist.
19. Betätigungsanordnung in Verbindung mit einem Bohrlochwerkzeug nach Anspruch 1, gekennzeichnet durch: eine fluidgefüllte Kammer (210); auf das Fluid einwirkende Druckübertragungsmittel (212); doppelt wirkende Kolbenmittel, die in der Kammer zwischen deren Enden angeordnet sind; einen längsverlaufenden Fluidumgehungskanal, der den Kolbenmitteln zugeordnet ist und zwischen dessen Enden verläuft; erste und zweite Rückschlagventilglieder (190, 192), die dem Fluidumgehungskanal zugeordnet sind; erste und zweite Ventilsitze (172, 198), die den ersten und zweiten Rückschlagventilgliedern zugeordnet sind; Mittel (194), die zum Vorspannen jedes der Rückschlagventilglieder gegen seinen zugeordneten Ventilsitz eingerichtet sind; und im Längsabstand befindliche erste und zweite Anschlagmittel (127, 146), die bei Berührung zum Abstoßen der ersten und zweiten Rückschlagventilglieder von ihren jeweiligen Ventilsitzen eingerichtet sind.
20. Anordnung nach Anspruch 19, dadurch gekennzeichnet, daß die Rückschlagventilglieder Kolben und die Vorspannmittel Federmittel aufweisen.
21. Anordnung nach Anspruch 20, dadurch gekennzeichnet, daß die Kolben einer Kolbenhülse (168) zugeordnet und zwischen deren Enden angeordnet sind, daß die Ventilsitze an Schultern (170, 174) Metallflächen aufweisen und der Fluidumgehungskanal einen Weg von einer Schulter vorbei an dem ersten Ventilsitz zwischen den Kolben und der Hülse und vorbei an dem zweiten Ventilsitz zu der zweiten Schulter aufweist.
22. Werkzeug nach Anspruch 2, dadurch gekennzeichnet, daß die Betriebsmittel zum wahlweisen Öffnen und Schließen des Schließventils (330) der Werkzeugbohrung unter Ansprechen auf eine Folge von Änderungen des Drucks unmittelbar an dem Werkzeug in dem Bohrloch eingerichtet sind; und daß die Ratschenmittel (164, 180, 186) und die Dornmittel (156)



die wahlweise Öffnung und Schließung des Schließventils für die Werkzeugbohrung nach einem Programm steuern.

23. Werkzeug nach Anspruch 22, dadurch gekennzeichnet, daß das Ratschenmittel-Programm durch die Ausbildung der endlosen, in sich geschlossenen Bahn (164) bestimmt ist und die Bahn wenigstens eine Programmstellung (f) in der Ausbildung der Bahn dafür enthält, wodurch das Schließventil für die Werkzeugbohrung von den Dornmitteln getrennt und danach wieder damit verbunden wird. 5
24. Werkzeug nach Anspruch 23, dadurch gekennzeichnet, daß das Schließventil für die Werkzeugbohrung in seiner Offenstellung von den Dornmitteln getrennt ist, wodurch der Bohrlochdruck wenigstens zweimal vor der Wiederverbindung geändert werden kann. 10 15
25. Werkzeug nach Anspruch 22, dadurch gekennzeichnet, daß das Schließventil für die Werkzeugbohrung ein Kugelventil (330) aufweist, das unter Ansprechen auf die Verstellung der Dornmittel zum Absperren der Werkzeugbohrung drehbar ist. 20 25
26. Werkzeug nach Anspruch 1, dadurch gekennzeichnet, daß die Dornmittel (156) gleitbar in der Werkzeugbohrung (370) angeordnet sind und das Schließventil (330) für die Werkzeugbohrung zur Abspernung der Werkzeugbohrung unter Ansprechen auf Längsverstellung der Dornmittel eingerichtet ist; und daß die Betriebsmittel zur Bewirkung der Längsverstellung der Dornmittel unter Ansprechen auf Druckänderungen in dem Bohrloch (4) eingerichtet sind, wobei die Ratschenmittel Mittel (180, 186, 267, 272, 274) mit totem Gang aufweisen, die zur wahlweisen Trennung des Schließventils für die Werkzeugbohrung von den Dornmitteln und Wiederverbindung des Schließventils für die Werkzeugbohrung mit den Dornmitteln eingerichtet sind. 30 35 40 45
27. Werkzeug nach Anspruch 26, dadurch gekennzeichnet, daß die Ausbildung der endlosen, in sich geschlossenen Bahn ein Programm für die Betätigung des Schließventils für die Werkzeugbohrung und die Trennung und Wiederverbindung des Schließventils für die Werkzeugbohrung von und mit den Dornmitteln bestimmt. 50
28. Werkzeug nach Anspruch 27, dadurch gekennzeichnet, daß das Programm zur Trennung des Schließventils für die Werkzeugbohrung von 55

den Dornmitteln eingerichtet ist, nachdem das Schließventil für die Werkzeugbohrung in eine Offenstellung gebracht worden ist, und zur Wiederverbindung des Schließventils für die Werkzeugbohrung mit den Dornmitteln nach einer Folge von nicht weniger als zwei Druckänderungen in dem Bohrloch.

29. Werkzeug nach Anspruch 26, dadurch gekennzeichnet, daß das Schließventil für das Bohrloch ein Kugelventil aufweist, das unter Ansprechen auf eine Verstellung der Dornmittel zum Absperren der Werkzeugbohrung drehbar ist.
30. Verfahren nach Anspruch 16, dadurch gekennzeichnet, daß die Betriebsarten durch Öffnen des Schließventils (330) unter Ansprechen auf eine Druckerhöhung im Bohrloch ausgewählt werden; Verringern des Bohrlochdrucks ohne Schließen des Schließventils; eine zweite Druckerhöhung des Bohrlochdrucks; eine zweite Verringerung des Bohrlochdrucks; und Schließen des Schließventils unter Ansprechen auf die zweite Verringerung des Bohrlochdrucks.

Revendications

1. Outillage de fond de trou multimode (50), destiné à être utilisé dans un train de tiges d'essai (30) disposé dans un puits de forage (4), comprenant une enveloppe tubulaire (100, 104, 114, 126, 142, 216, 220, 294, 360), délimitant un passage central longitudinal d'outillage (370), un ensemble à fonction de soupape (166, 174, 190, 192, 228, 330), disposé dans l'enveloppe et comprenant une soupape de fermeture de passage d'outillage (330), cet ensemble à fonction de soupape étant agencé de façon qu'on puisse le faire fonctionner au moins dans un mode de soupape de circulation et dans un mode de seconde soupape, et des moyens d'actionnement (156, 180, 186, 260) agencés de façon à faire passer l'ensemble à fonction de soupape d'un mode de soupape à l'autre sous l'effet de variations se présentant dans la pression à proximité de l'outillage dans le puits de forage, caractérisé en ce qu'il comprend en outre des moyens (224, 226, 232, 248, 256) permettant un refoulement de fluide, en ce que l'ensemble à fonction de soupape comprend en outre une soupape à manchon (228), en ce que le mode de seconde soupape est un mode de soupape de refoulement et en ce que les moyens d'actionnement comprennent un fourreau (156) et des moyens d'encliquetage à bille et fente (164, 30 35 40 45 50 55



180, 186, 188) associés à ce fourreau, la fente d'encliquetage (164) étant ménagée dans le fourreau et étant formée par une boucle fermée continue comportant un certain nombre de zones actives, chaque zone correspondant à l'un des modes de soupape et comprenant un certain nombre de positions de repos telles que, pour chacune, les moyens d'encliquetage maintiennent l'ensemble à fonction de soupape dans le mode de soupape correspondant pendant un nombre prédéterminé de changements de pression.

2. Outillage suivant la revendication 1, dans lequel les moyens de commande sont agencés de façon à permettre le passage d'un mode de soupape à l'autre par déplacement longitudinal du fourreau (156) dans l'outillage.
3. Outillage suivant la revendication 1 ou 2, dans lequel les moyens à fonction de soupape comprennent en outre un clapet antiretour (166, 174, 190, 192).
4. Outillage suivant l'une quelconque des revendications 1 à 3, dans lequel les moyens de commande comprennent en outre des moyens à piston à double effet (190, 192) associés aux moyens d'encliquetage à bille et fente.
5. Outillage suivant l'une quelconque des revendications précédentes, dans lequel les moyens à fonction de soupape sont en outre agencés de façon à pouvoir être commandés dans un mode de soupape de tester de tiges de forage ou dans un mode de soupape de tester de formation.
6. Outillage suivant la revendication 1, dans lequel l'enveloppe comporte des orifices de circulation (224) et des orifices de refoulement (226) traversant sa paroi, le fourreau (156, 204, 228, 238, 260) est disposé de manière coulissante dans l'enveloppe et comporte des ouvertures de circulation (232) et des ouvertures de refoulement (256) traversant sa paroi et pouvant être amenées dans l'alignement respectivement des orifices de circulation (224) et des orifices de refoulement (226) par déplacement longitudinal du fourreau dans l'enveloppe, un clapet antiretour (166, 174, 190, 192) étant disposé entre l'enveloppe et le fourreau et étant associé aux orifices et ouvertures de refoulement, et les moyens de commande sont agencés de façon à provoquer le mouvement longitudinal du fourreau sous l'effet de variations de pression dans le puits de forage.

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7. Outillage suivant la revendication 6, dans lequel les moyens d'encliquetage à bille et fente (164, 180, 186, 188) sont agencés de façon à commander le mouvement longitudinal du fourreau.

8. Outillage suivant la revendication 7, dans lequel les moyens de commande comprennent en outre un fluide de commande (122, 210), disposé entre l'enveloppe et le fourreau et communiquant avec la pression régnant dans le puits de forage, et des moyens à piston à double effet (190, 192) disposés dans ce fluide de commande et agencés de façon à déplacer longitudinalement le fourreau sous l'effet de différences de pression de part et d'autre des moyens à piston à double action qui sont déclenchées par lesdites variations de pression du puits de forage.

9. Outillage suivant la revendication 8, dans lequel les moyens à piston à double effet comprennent en outre des moyens de déplacement de fluide de commande (127) agencés de façon à limiter le déplacement desdits moyens à piston.

10. Outillage suivant l'une quelconque des revendications 6 à 9, dans lequel la soupape (330) d'obturation du passage central de l'outillage est agencée de façon à bloquer ce passage central de l'outillage sous l'effet dudit mouvement longitudinal du fourreau, cette soupape d'obturation du passage central de l'outillage comprenant de préférence un obturateur sphérique de soupape (330) agencé de façon à pouvoir tourner de manière à bloquer le passage central de l'outillage sous l'effet dudit mouvement longitudinal du fourreau.

11. Outillage suivant la revendication 10, comprenant en outre des moyens à course perdue (267, 272, 274) permettant de déconnecter du fourreau la soupape d'obturation du passage central de l'outillage.

12. Outillage suivant la revendication 11, dans lequel les moyens à course perdue comprennent un logement annulaire (267) situé sur la surface extérieure du fourreau (260) et des doigts de serrage (272) associés à la soupape d'obturation du passage central de l'outillage, ces doigts de serrage étant agencés de façon à s'accrocher sur le logement du fourreau lorsqu'ils sont soumis à une sollicitation radiale vers l'intérieur et à libérer ce fourreau lorsque la sollicitation vers l'intérieur est supprimée.



13. Outillage suivant l'une quelconque des revendications 10 à 12, comprenant en outre des moyens d'identification de mode (420, 422, 424) agencés de façon à identifier la position du fourreau vis-à-vis de l'enveloppe et à permettre ainsi à l'opérateur de l'outillage de déterminer le positionnement relatif des orifices de circulation vis-à-vis d'ouvertures de circulation, le positionnement relatif d'orifices de refoulement vis-à-vis d'ouvertures de refoulement et la position de la soupape d'obturation du passage central de l'outillage.
14. Outillage suivant la revendication 13, dans lequel les moyens d'identification de mode comprennent des repères (420, 422, 424) situés sur le fourreau et qui sont observables par les orifices de circulation(224).
15. Procédé de commande d'un outillage de fond de trou multimode (50) comportant un passage central longitudinal (370) qui le traverse, ce procédé consistant à faire descendre l'outillage dans un puits de forage (4) sur un train de tiges (30), à faire passer l'outillage entre au moins deux modes de fonctionnement sélectionnés dans le groupe constitué par un mode de tester de tiges de forage, un mode de tester de formation, un mode de refoulement et un mode de circulation, à l'aide de variations successives de la pression dans le puits de forage, et à ouvrir et fermer plusieurs fois une soupape d'obturation (330) disposée dans le passage central (370) de l'outillage pendant que ce dernier est dans le mode de tester de formation, sous l'effet de variations de la pression du puits de forage, sans faire passer l'outillage dans un mode différent de fonctionnement.
16. Procédé selon la revendication 15, consistant en outre à refouler du fluide hors du train de tiges et dans le puits de forage, en introduisant un gaz sous pression dans le train de tiges à partir de la surface pendant que l'outillage est dans le mode de refoulement.
17. Procédé selon la revendication 15, consistant en outre à faire circuler un fluide entre le train de tiges et le puits de forage pendant que l'outillage est dans le mode de circulation.
18. Procédé selon la revendication 17, consistant en outre à procéder à un essai d'intégrité du train de tiges en ce qui concerne la pression pendant que l'outillage est dans son mode de tester de tiges de forage.
19. Ensemble de commande, en liaison avec un outillage de fond de trou suivant la revendication 1, cet ensemble de commande comprenant une chambre (210) remplie de fluide, des moyens de transfert de pression (212) agissant sur ce fluide, des moyens à piston à double effet disposés dans la chambre entre les extrémités de cette dernière, un conduit longitudinal de dérivation de fluide associé à ces moyens à piston et s'étendant entre les extrémités de ces derniers, des premier et second éléments de clapet antiretour (190, 192) associés au conduit de dérivation de fluide, des premier et second sièges de clapet (172, 198) associés respectivement aux premier et second éléments de clapet antiretour, des moyens (194) agencés de façon à repousser chacun des éléments de clapet antiretour en appui contre le siège de clapet qui lui est associé, et des premier et second moyens de butée (127, 146) espacés longitudinalement et agencés de façon à repousser respectivement les premier et second éléments de clapet antiretour de leurs sièges de clapet respectifs lors d'une venue en contact avec eux.
20. Ensemble suivant la revendication 19, dans lequel les éléments de clapet antiretour sont constitués par des pistons et les moyens de sollicitation sont constitués par des moyens élastiques.
21. Ensemble suivant la revendication 20, dans lequel les pistons sont associés à un manchon à pistons (168) et sont disposés entre les extrémités de ce dernier, les sièges de clapet sont constitués par des surfaces métalliques situées sur des parties en surépaisseur (170, 174), le conduit de dérivation de fluide est constitué d'un chemin partant d'une partie en surépaisseur, passant devant le premier siège de clapet, entre les pistons et le manchon et devant le second siège de clapet pour parvenir à la seconde partie en surépaisseur.
22. Outillage suivant la revendication 2, dans lequel les moyens de commande sont agencés de façon à ouvrir et fermer de manière sélective la soupape (330) d'obturation du passage central de l'outillage sous l'effet de variations successives de la pression à proximité de l'outillage dans le puits de forage, et les moyens d'encliquetage (164, 180, 186) et le fourreau (156) commandent l'ouverture et la fermeture sélectives de la soupape d'obturation du passage central de l'outillage en conformité avec un programme.



23. Outillage suivant la revendication 22, dans lequel le programme des moyens d'encliquetage est défini par la configuration de la bouche fermée continue (164) et cette boucle comprend à cet effet, dans la configuration de boucle, au moins une position de programme (f) telle que la soupape d'obturation du passage central de l'outillage est déconnectée du fourreau et lui est ensuite reconnectée.

24. Outillage suivant la revendication 23, dans lequel la soupape d'obturation du passage central de l'outillage est déconnectée du fourreau dans sa position ouverte, de sorte qu'on peut faire varier au moins deux fois la pression du puits de forage avant ladite reconnexion.

25. Outillage suivant la revendication 22, dans lequel la soupape d'obturation du passage central de l'outillage comprend un obturateur sphérique de soupape (330) agencé de façon à pouvoir être déplacé en rotation de manière à bloquer le passage central de l'outillage sous l'effet d'un mouvement du fourreau.

26. Outillage suivant la revendication 1, dans lequel le fourreau (156) est disposé de manière coulissante dans le passage central (370) de l'outillage, la soupape (330) d'obturation de ce passage central de l'outillage étant agencée de façon à bloquer ce passage central sous l'effet d'un mouvement longitudinal du fourreau, et dans lequel les moyens de commande sont agencés de façon à provoquer ledit mouvement longitudinal du fourreau sous l'effet de variations de pression dans le puits de forage (4), les moyens d'encliquetage comprenant des moyens à course perdue (180, 186, 267, 272, 274) agencés de façon à pouvoir, d'une manière sélective, déconnecter du fourreau la soupape d'obturation du passage central de l'outillage et la reconnecter sur ce fourreau.

27. Outillage suivant la revendication 26, dans lequel la configuration de la boucle fermée continue définit un programme permettant le fonctionnement de la soupape d'obturation du passage central de l'outillage et la déconnexion de cette soupape d'obturation par rapport au fourreau et sa reconnexion sur ce fourreau.

28. Outillage suivant la revendication 27, dans lequel le programme est agencé de façon à déconnecter du mandrin la soupape d'obturation du passage central de l'outillage après que cette dernière ait été placée dans une position ouverte et à reconnecter cette soupape sur ce fourreau après une séquence qui

n'est pas inférieure à deux variations de pression dans le puits de forage.

29. Outillage suivant la revendication 26, dans lequel la soupape d'obturation du passage central de l'outillage comprend un obturateur sphérique de soupape agencé de façon à pouvoir être déplacé en rotation de manière à bloquer le passage central de l'outillage sous l'effet d'un mouvement du fourreau.

30. Procédé suivant la revendication 16, selon lequel les modes de fonctionnement sont sélectionnés en ouvrant la soupape d'obturation (330) sous l'effet d'une augmentation de pression dans le puits de forage, en réduisant cette pression du puits de forage sans fermer la soupape d'obturation, en augmentant cette pression du puits de forage une seconde fois, en réduisant cette pression du puits de forage une seconde fois et en fermant la soupape d'obturation sous l'effet de cette seconde réduction de la pression du puits de forage.

