US 20090056952A1

(19) United States
(12) Patent Application Publication
Churchill
(10) Pub. No.: US 2009/0056952 A1
(43) Pub. Date: Mar. 5, 2009

(54) **DOWNHOLE TOOL**

(76) Inventor: **Andrew Philip Churchill**, Aberdeen (GB)

Correspondence Address:
**The McBride Law Firm, P.C.**
**406 Bynre, Suite A**
**Houston, TX 77009**

(21) Appl. No.: **12/094,988**

(22) PCT Filed: **Nov. 24, 2006**

(86) PCT No.: **PCT/GB06/04400**

§ 371 (c)(1),
(2), (4) Date: **Oct. 14, 2008**

(30) **Foreign Application Priority Data**

Nov. 24, 2005 (GB) ................................ 0523841.5
Apr. 13, 2006 (GB) ................................ 0607412.4

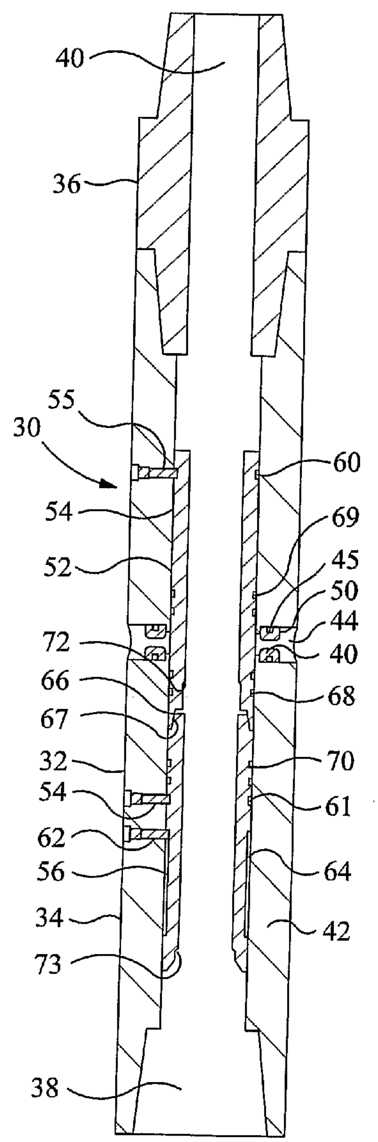
**Publication Classification**

(51) **Int. Cl.**
*E21B 34/06* (2006.01)
*E21B 33/12* (2006.01)

(52) **U.S. Cl.** ........................................ **166/373**; 166/386

(57) **ABSTRACT**

A method of actuating a tool in a downhole string comprises utilising a flow restriction, such as a non-return valve, which provides less restriction to fluid flow in the normal direction to induce a reverse fluid pressure differential to permit actuation of the tool.



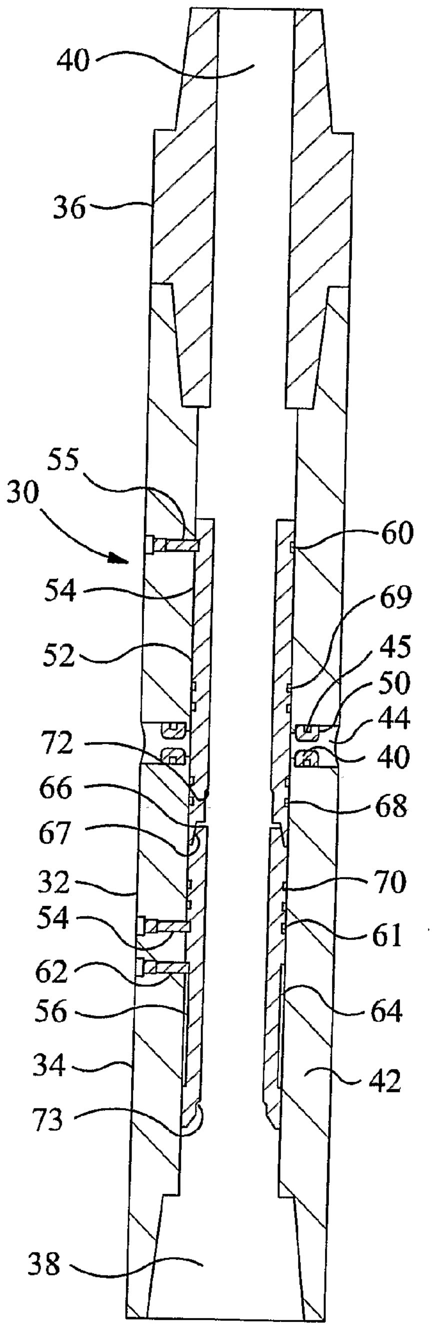

40
36
55
30
54
52
72
66
67
32
54
62
56
34
73
38
60
69
45
50
44
40
68
70
61
64
42

FIG 1

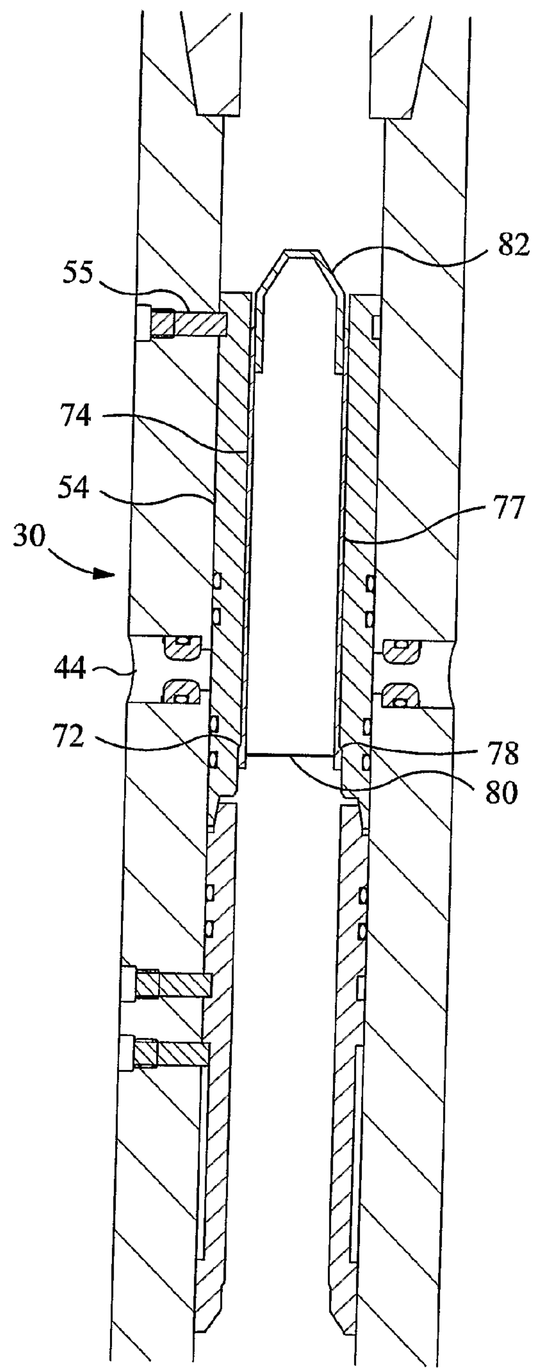

55
74
54
30
44
72
82
77
78
80

FIG 2

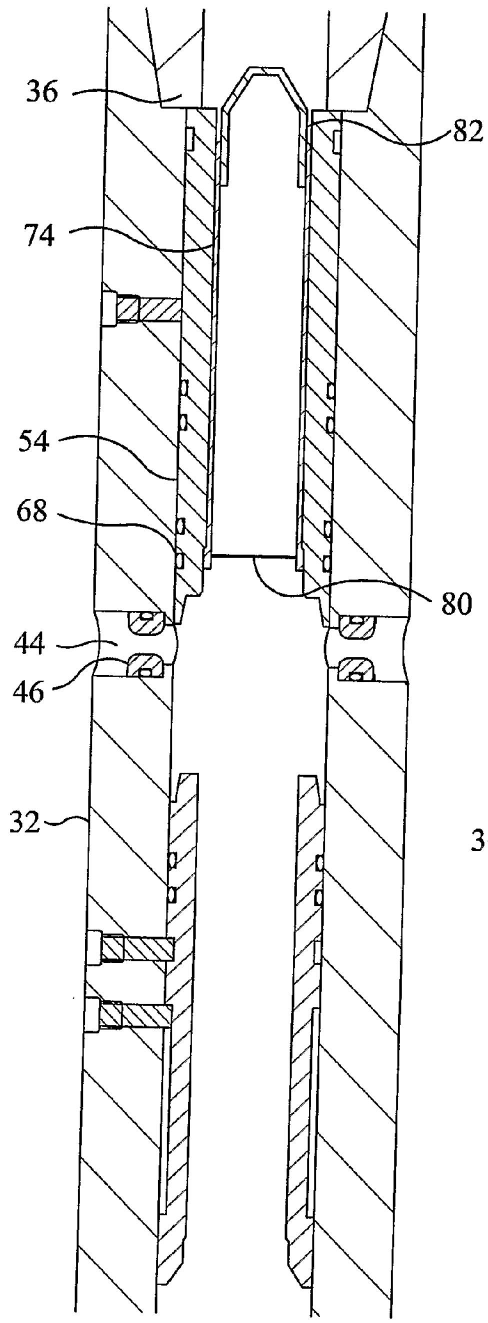



FIG 3

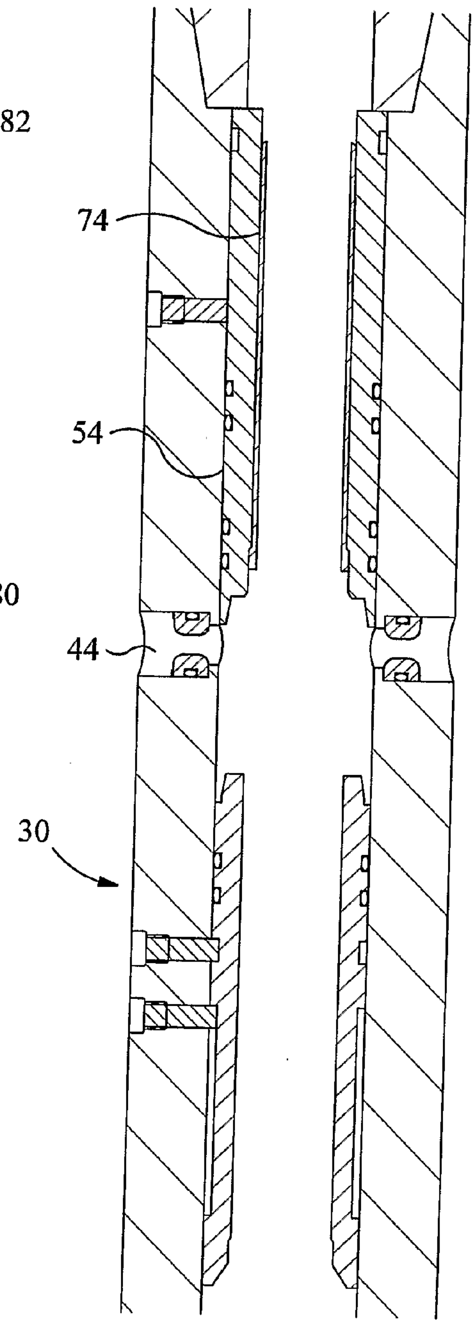



FIG 4

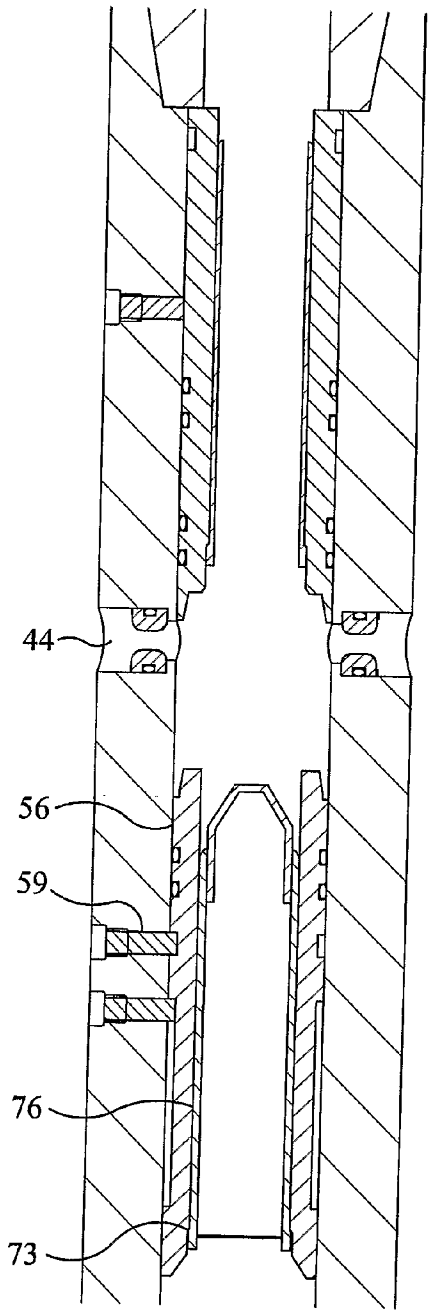



FIG 5

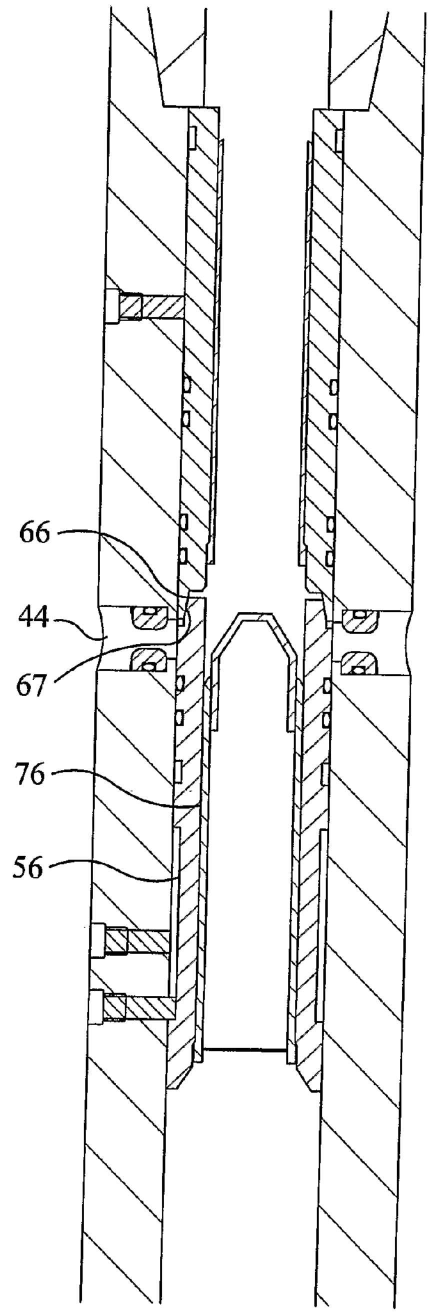



FIG 6

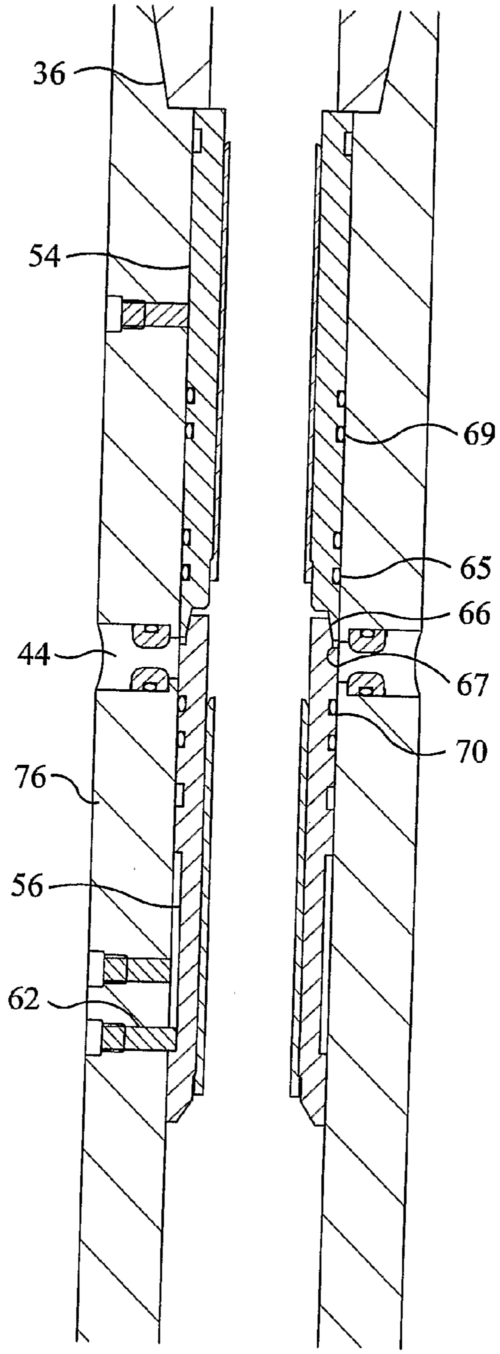



FIG 7

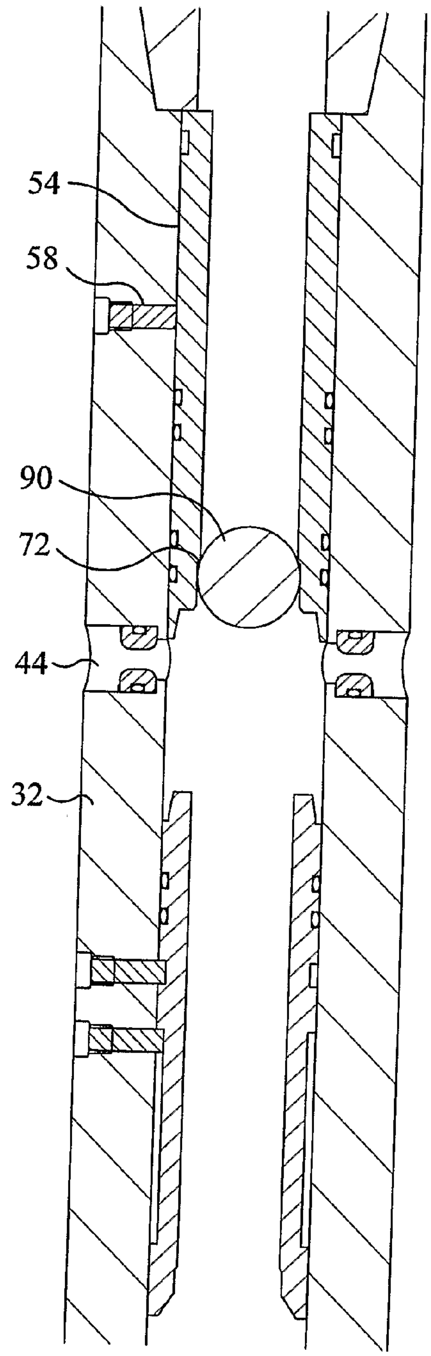



FIG 8

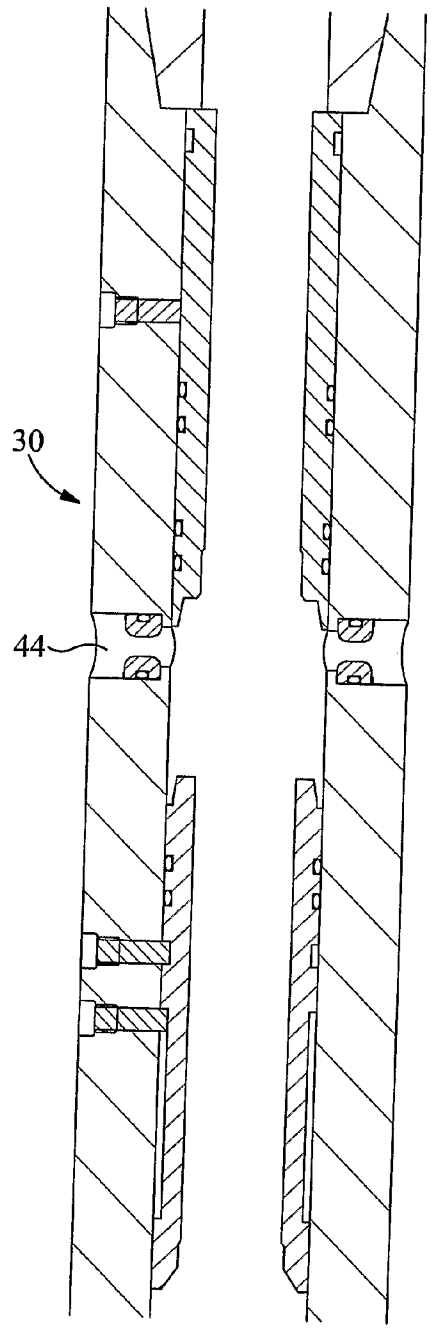



FIG 9

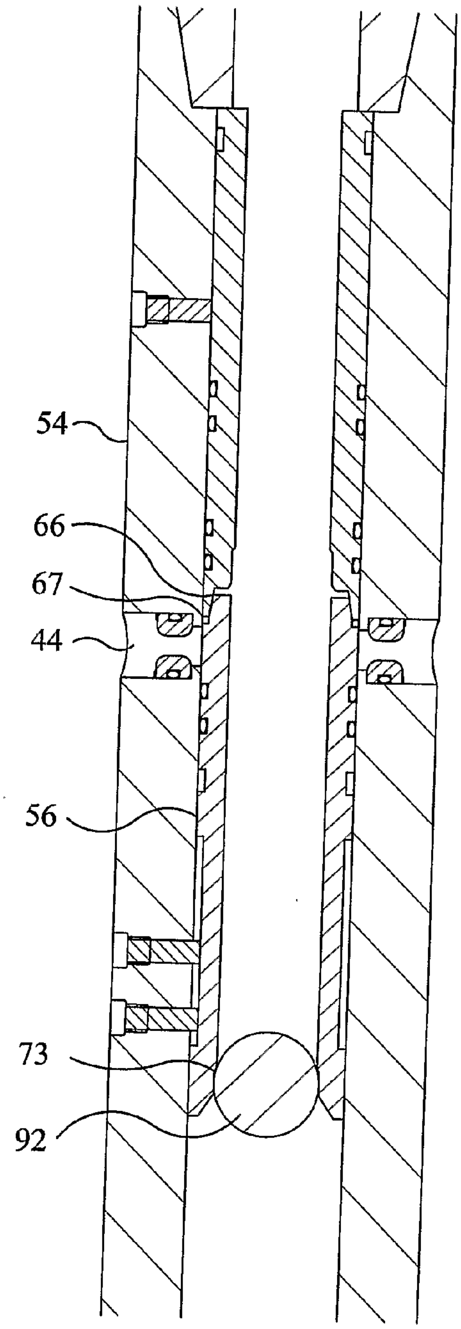



FIG 10

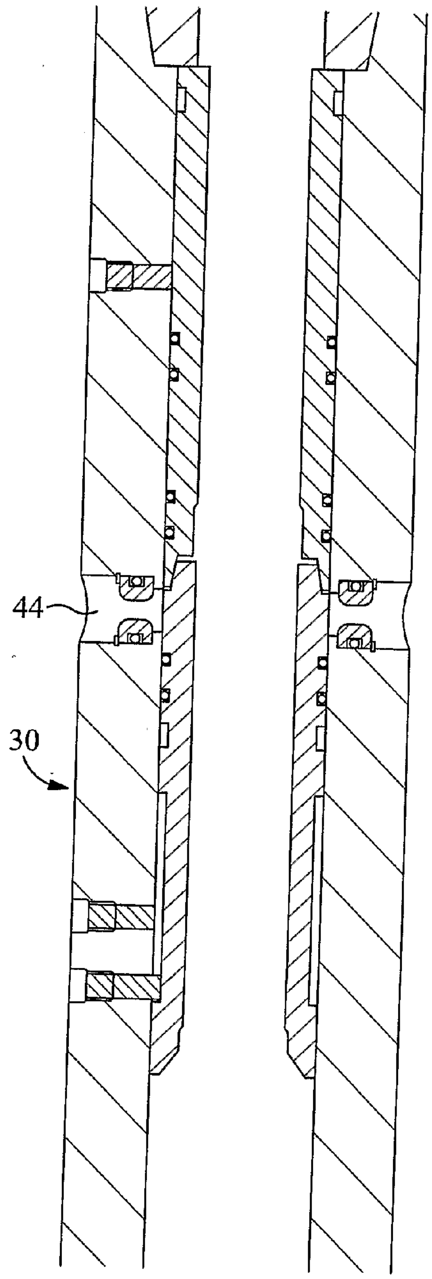



FIG 11

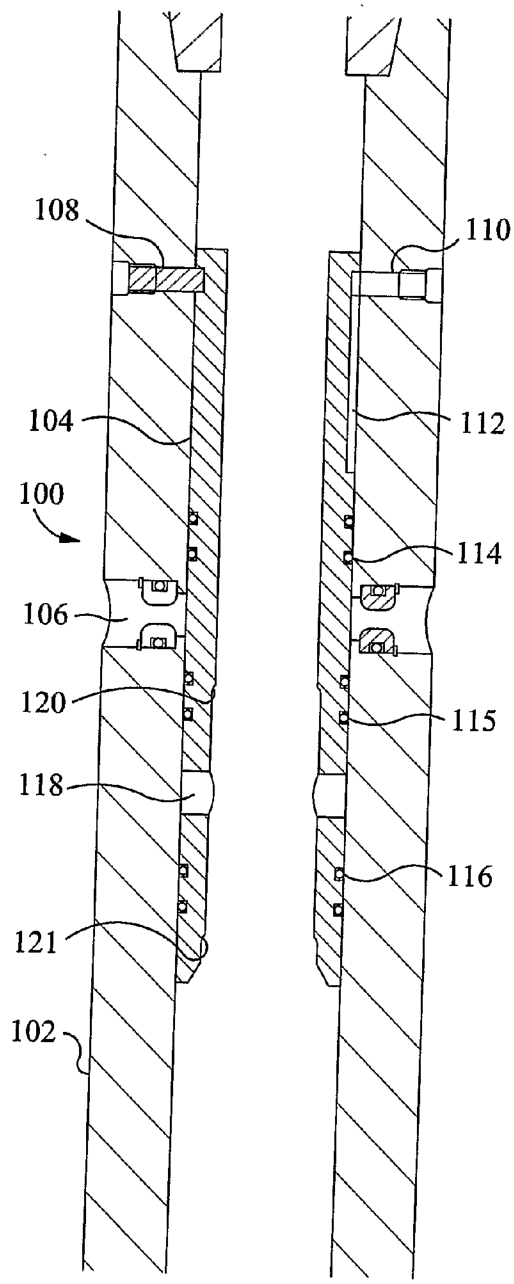



FIG 12

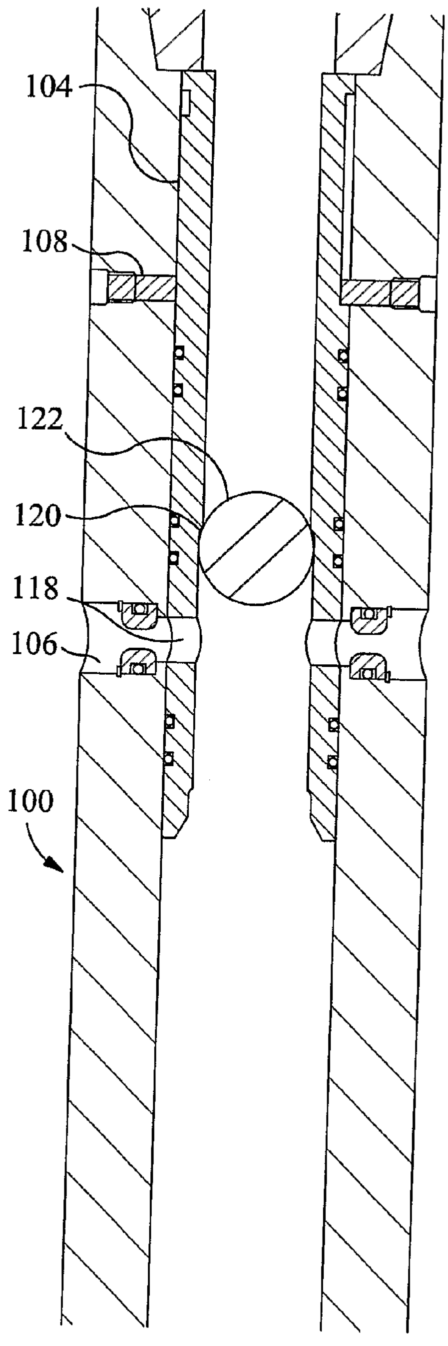



FIG 13

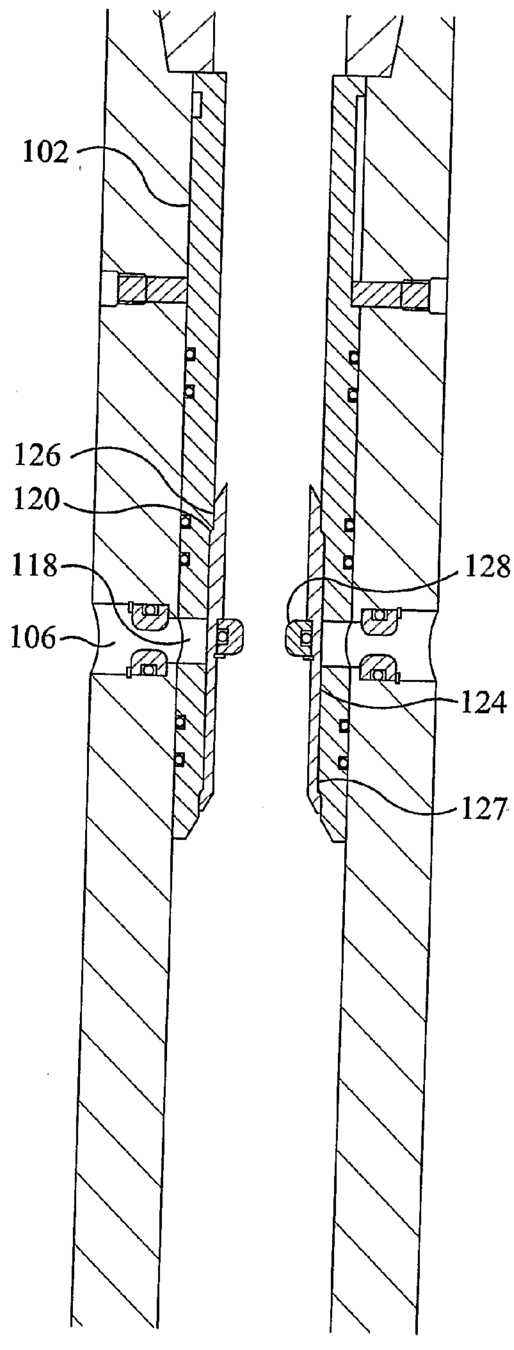



FIG 14

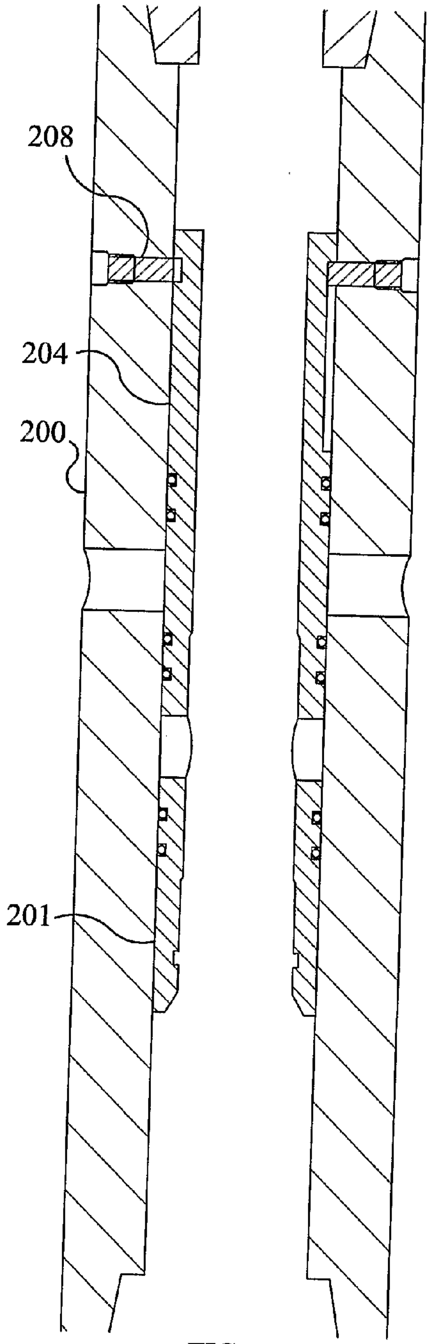



FIG 15

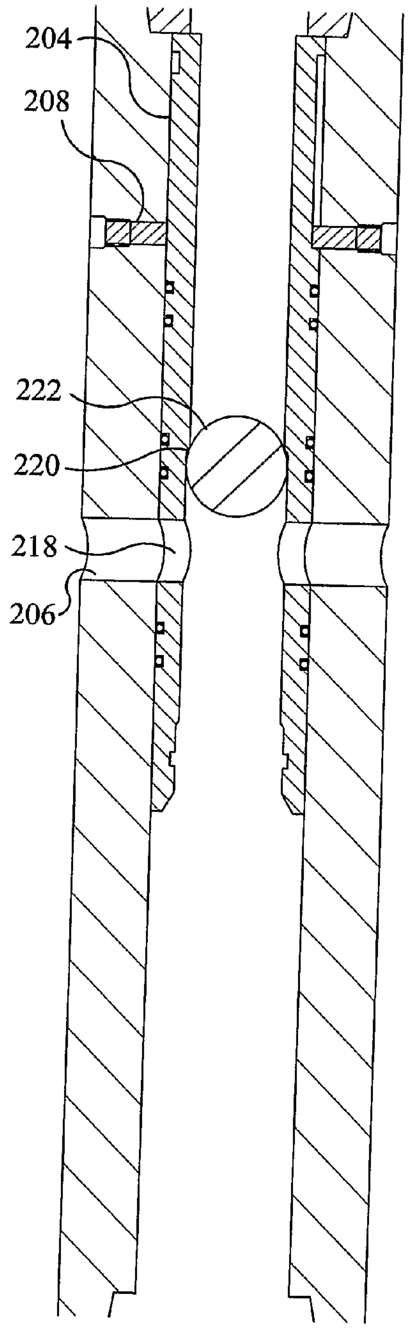



FIG 16

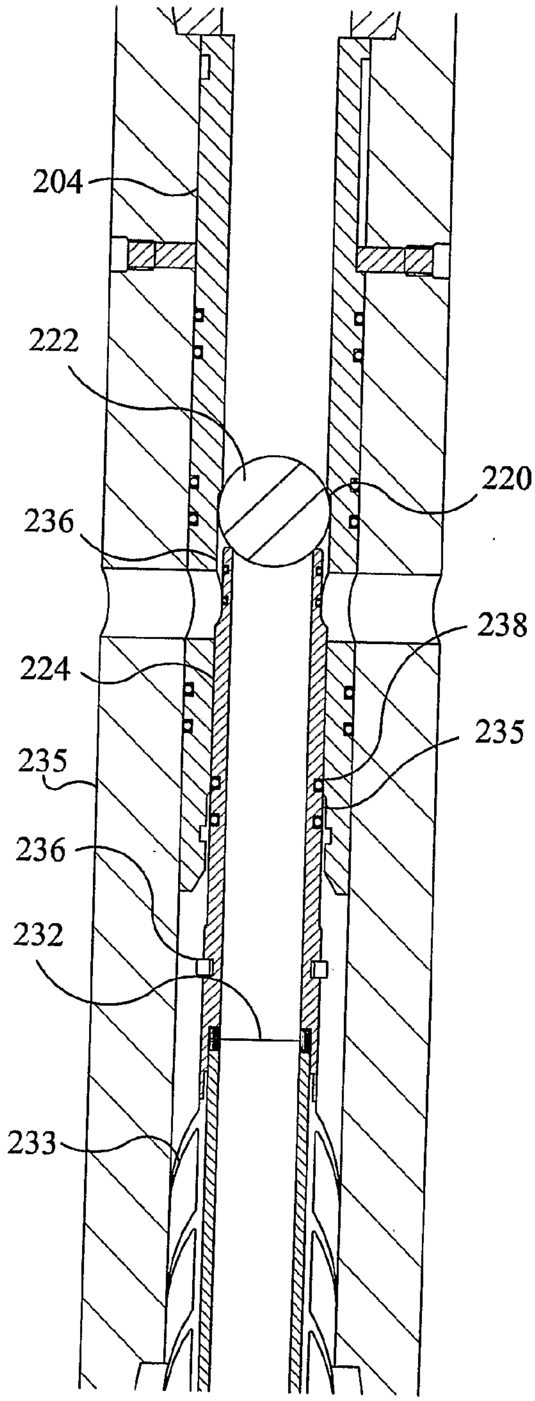

204
222
220
236
238
224
235
235
236
232
233

FIG 17

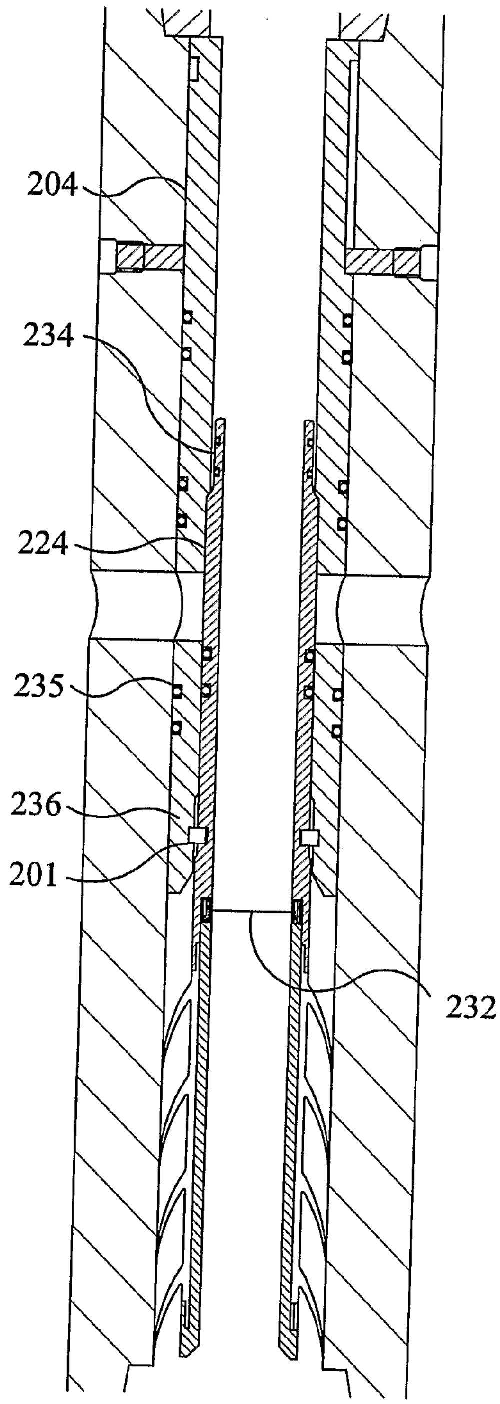

204
234
224
235
236
201
232

FIG 18

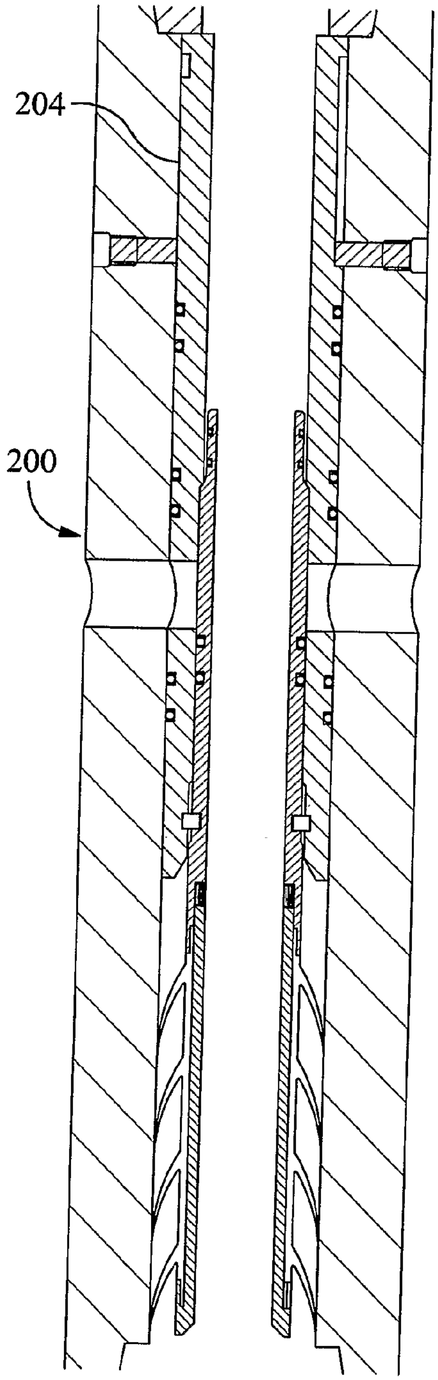



FIG 19

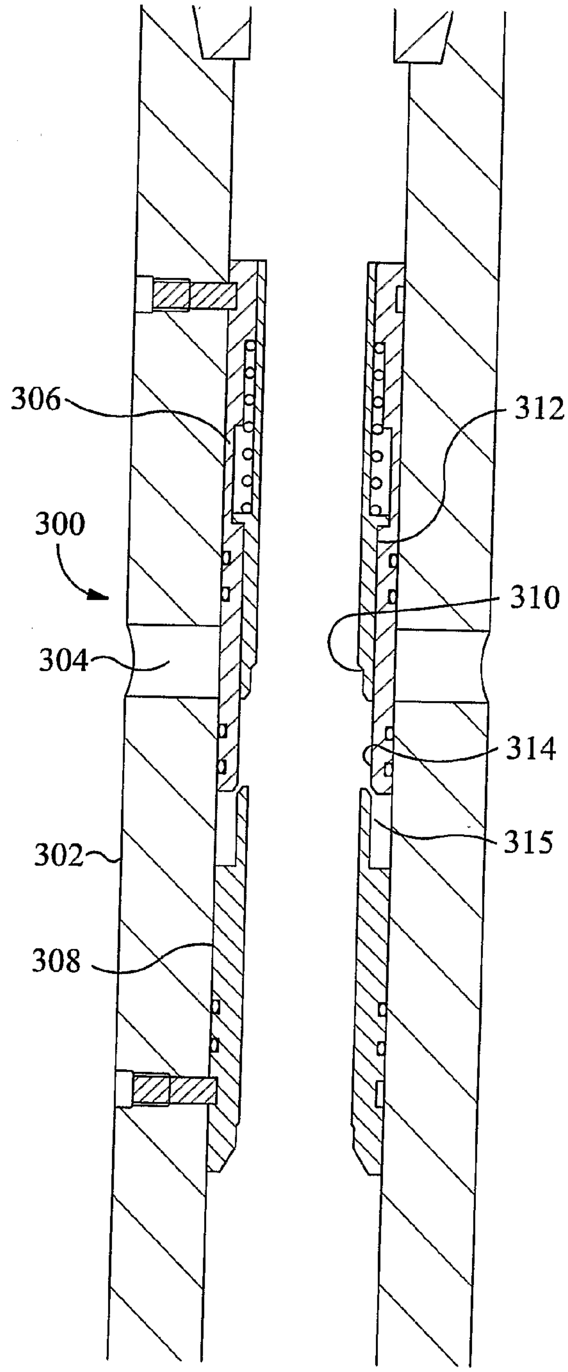



FIG 20

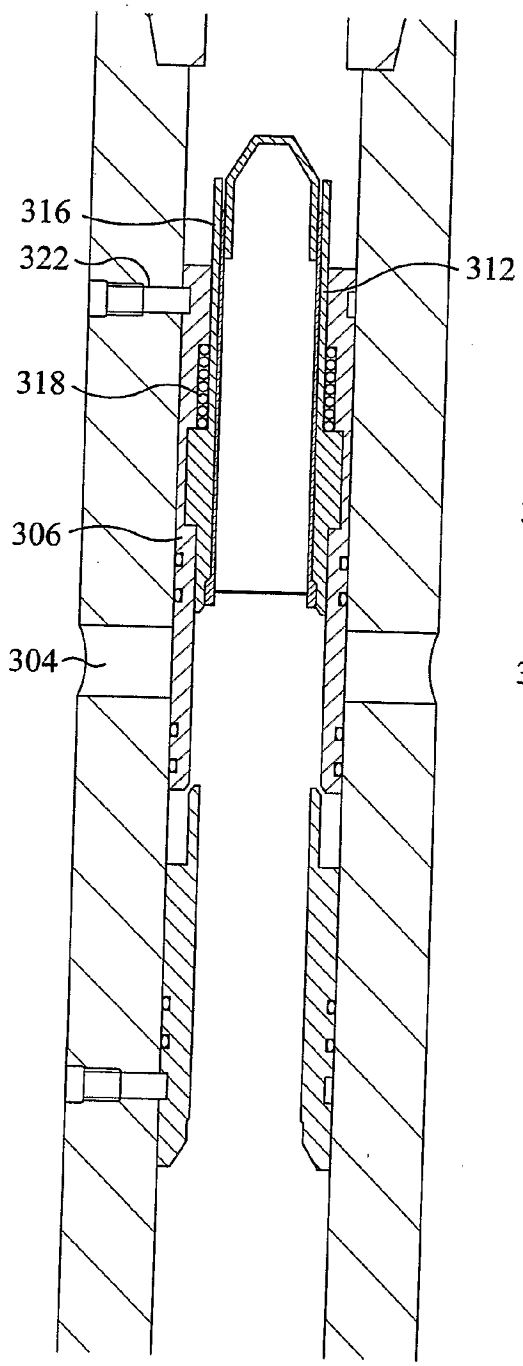



FIG 21

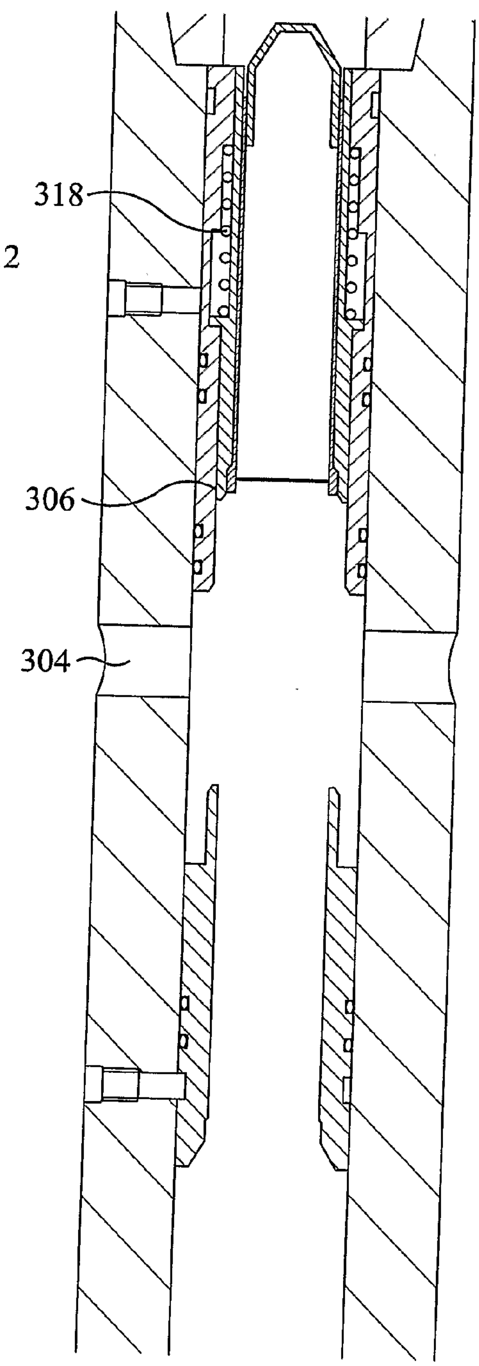



FIG 22

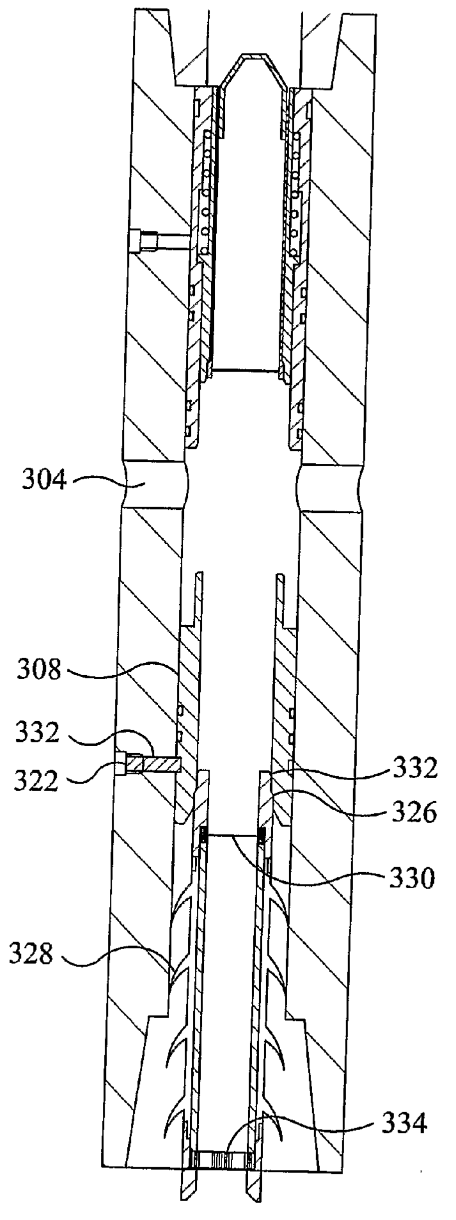

304
308
332
322
332
326
330
328
334

FIG 23

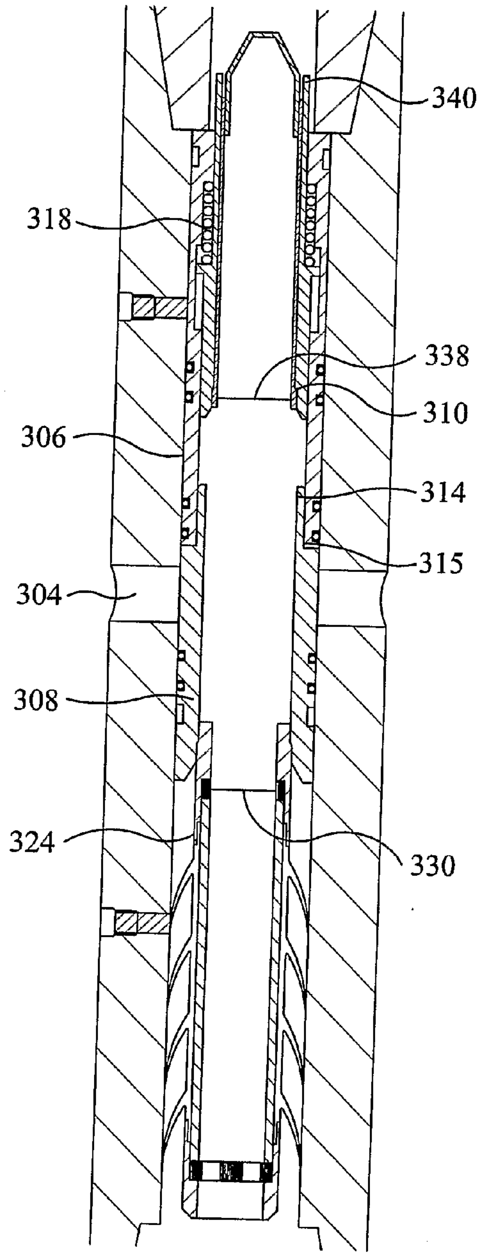

340
318
338
310
306
314
315
304
308
324
330

FIG 24

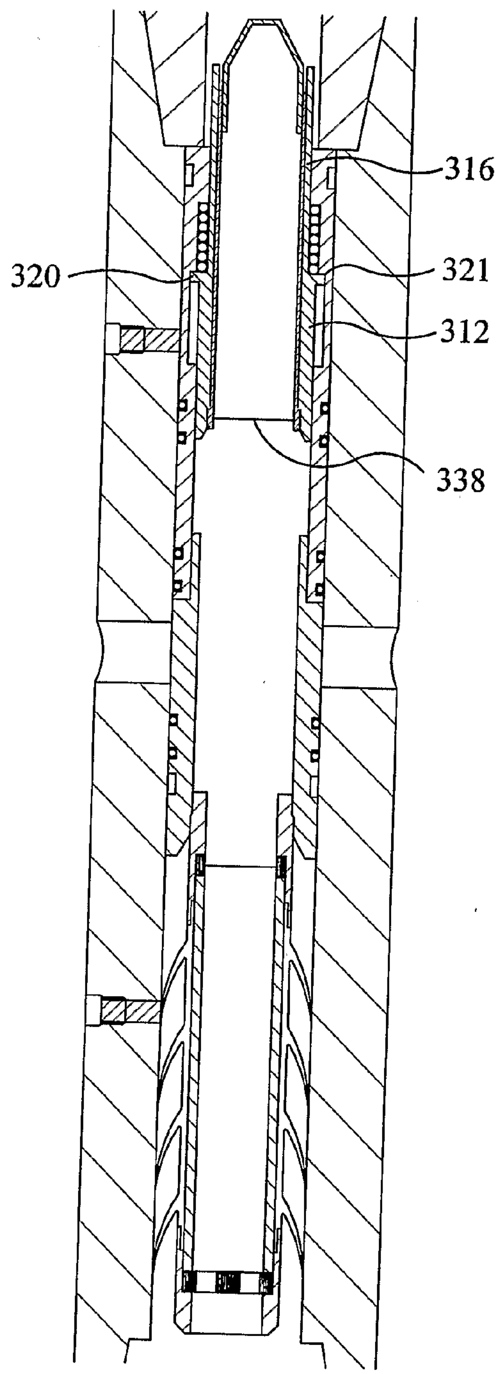



FIG 25

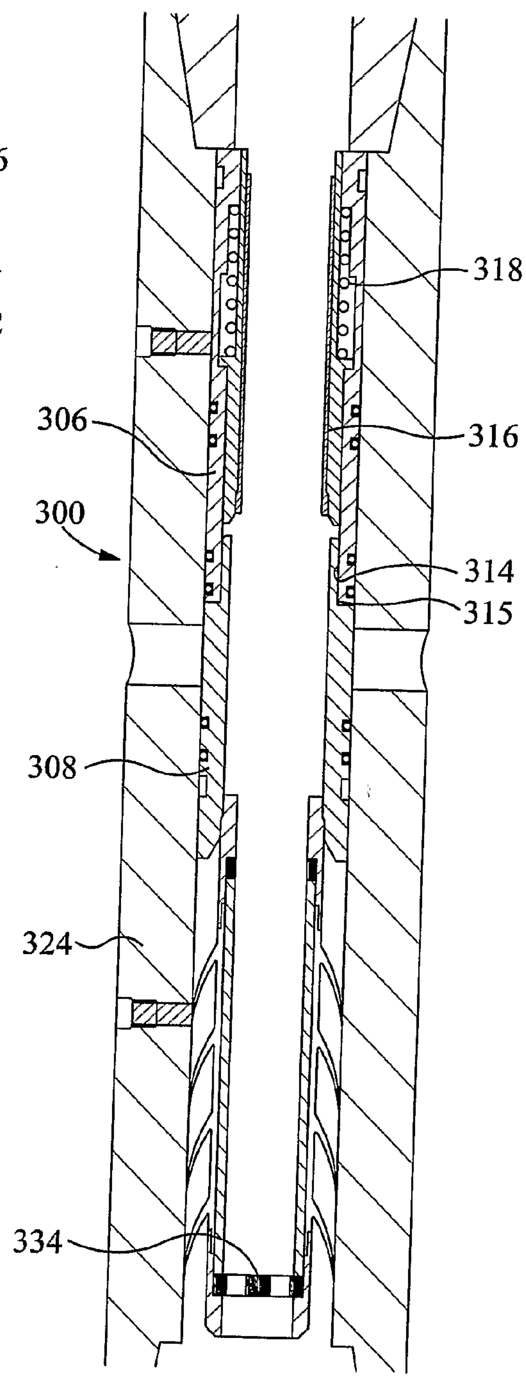



FIG 26

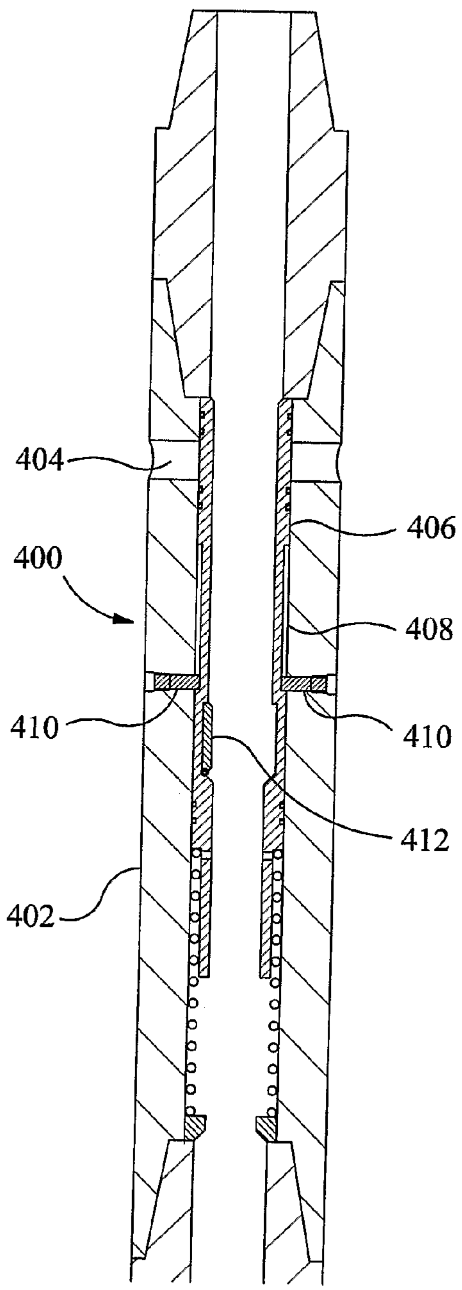



FIG 27

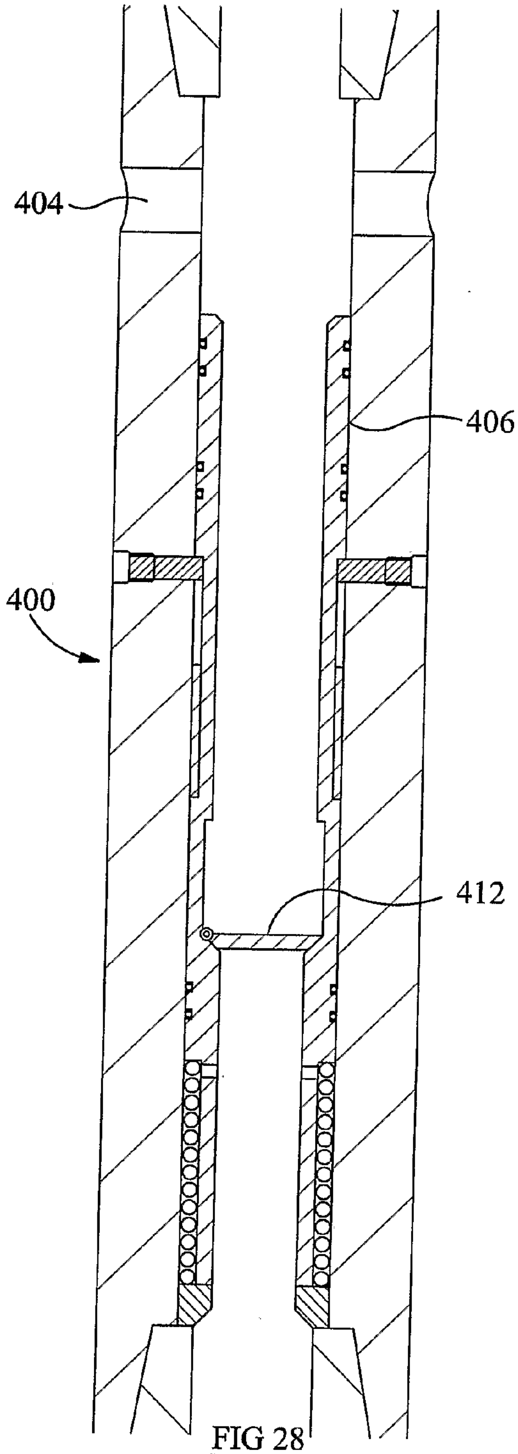



FIG 28

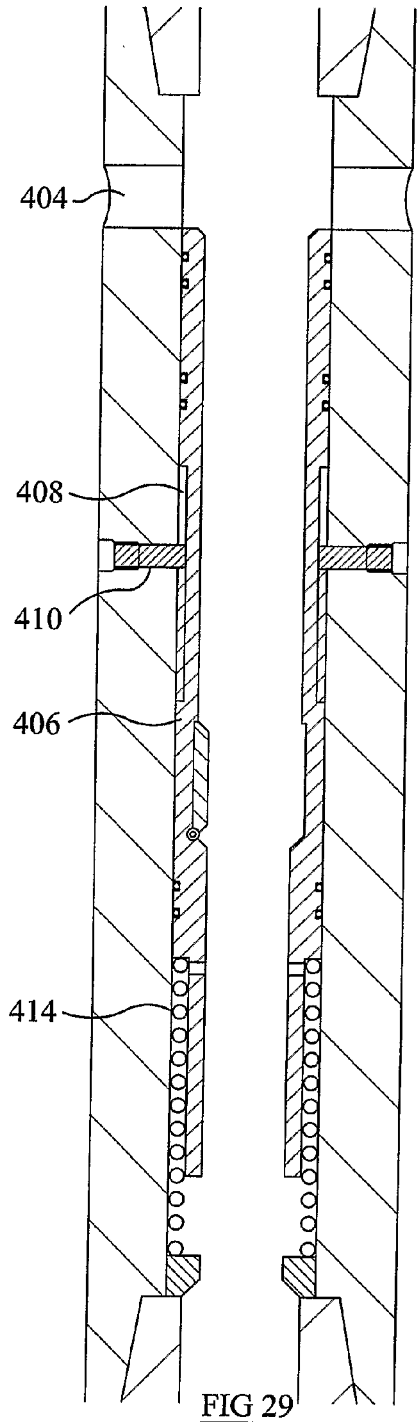



FIG 29

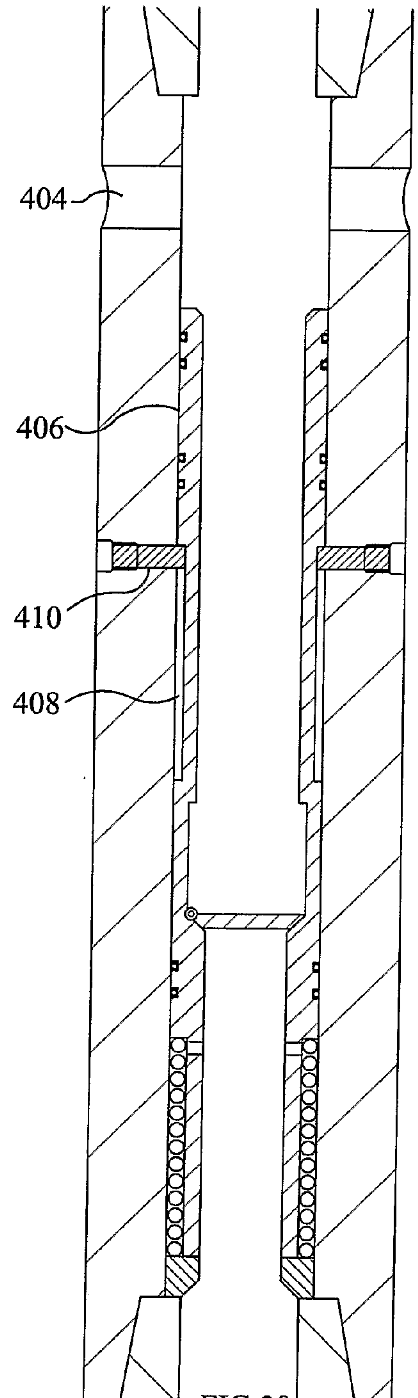



FIG 30

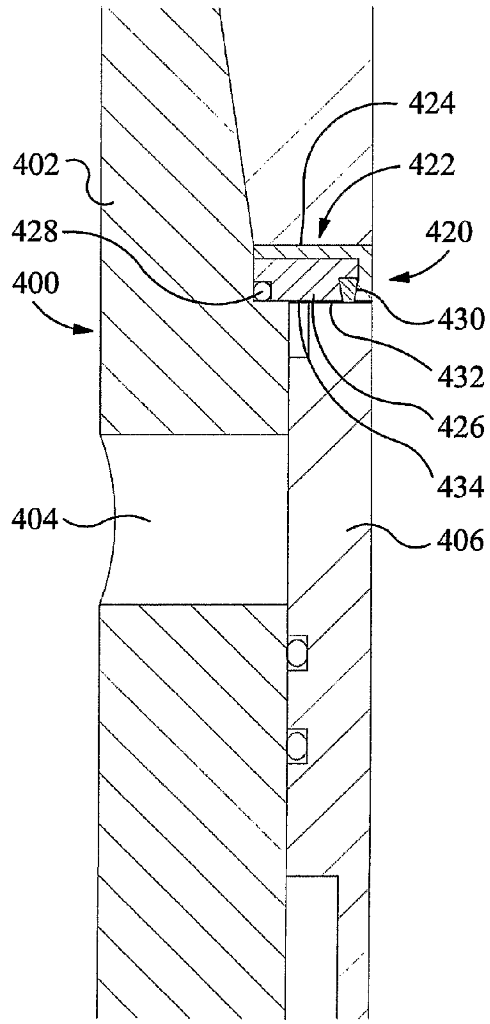

424
402
422
428
420
400
430
432
426
434
404
406

FIG 31

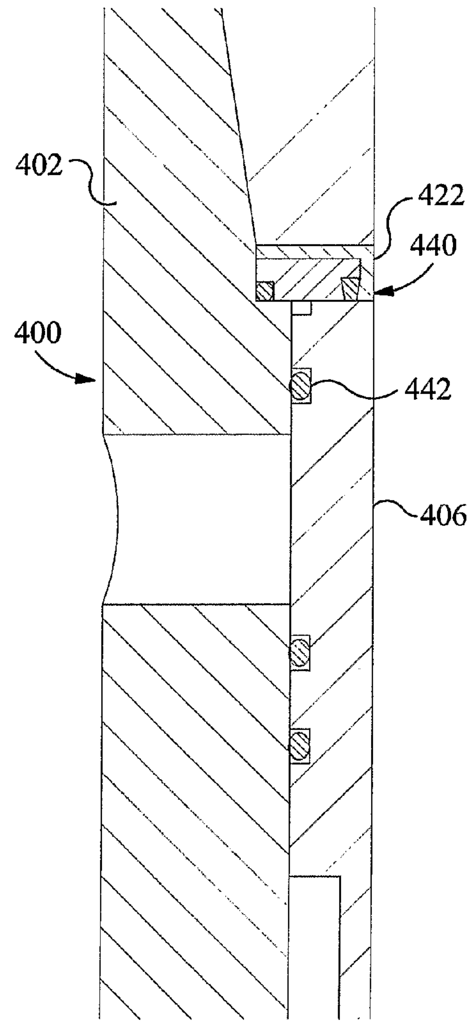

402
422
440
400
442
406

FIG 32

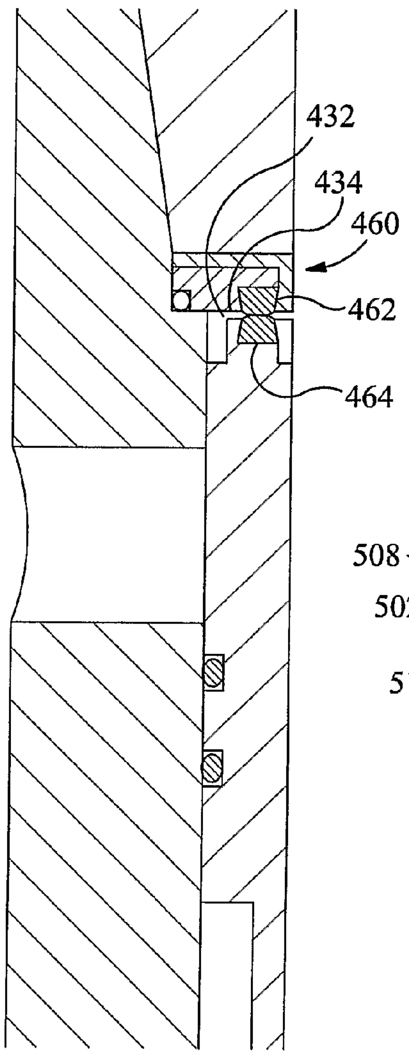



FIG 33

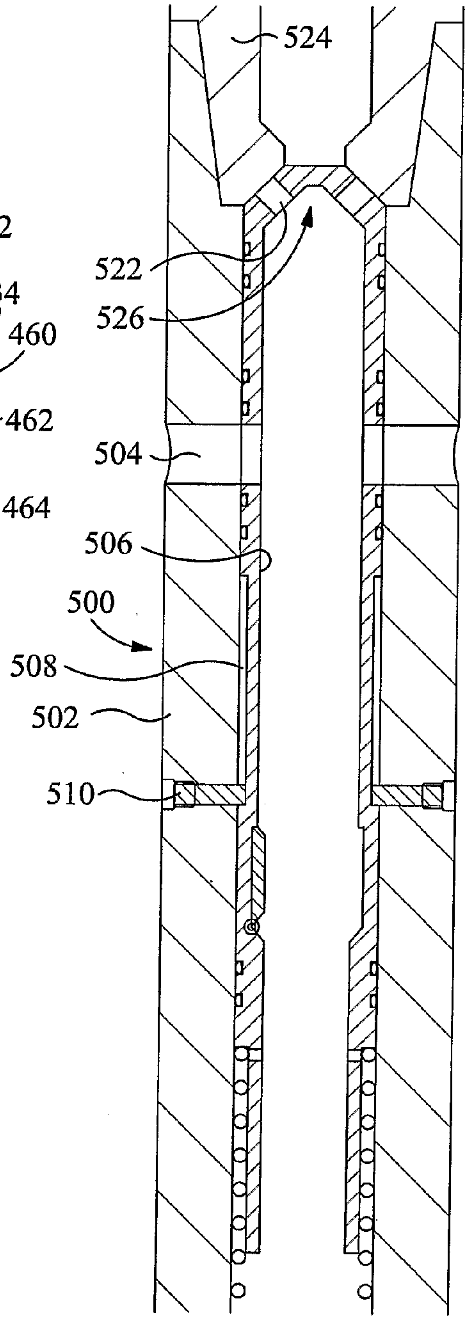



FIG 34

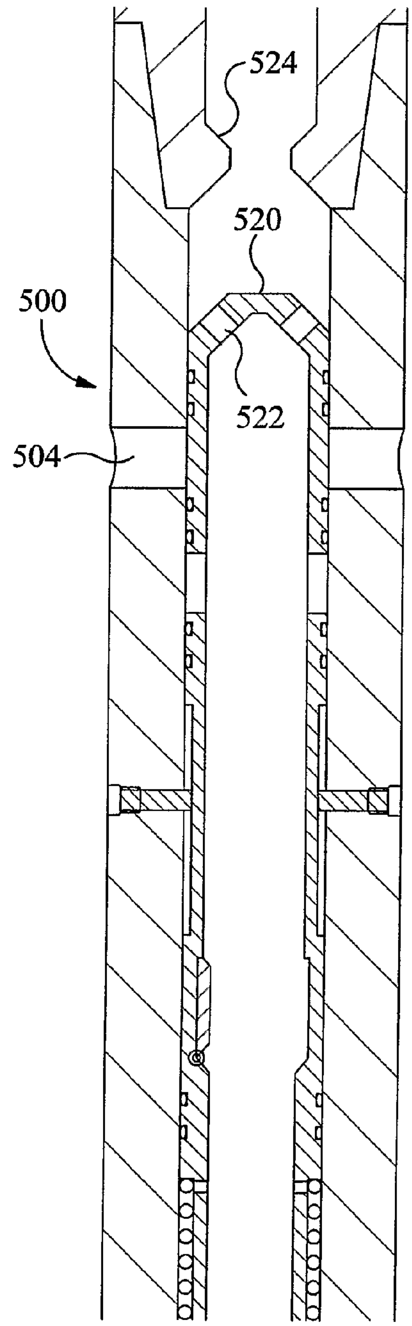



FIG 35

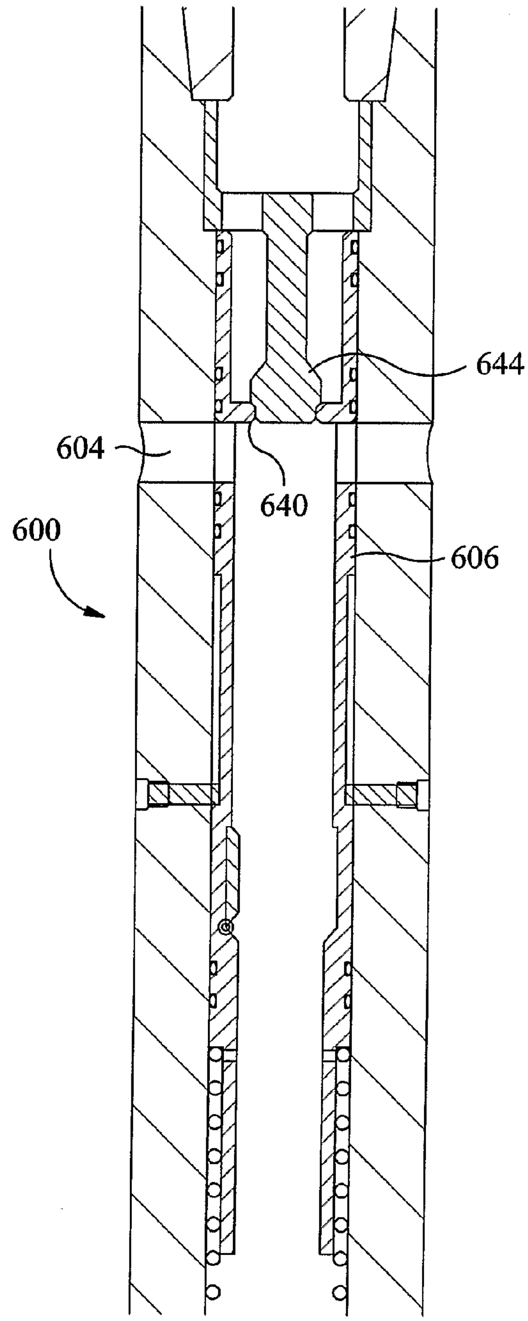



FIG 36

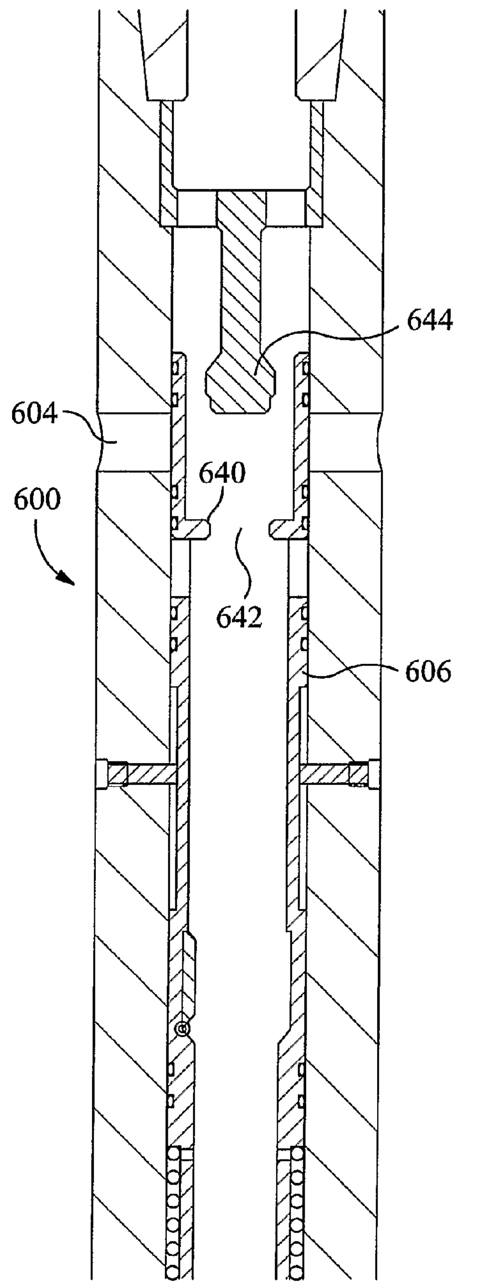



FIG 37

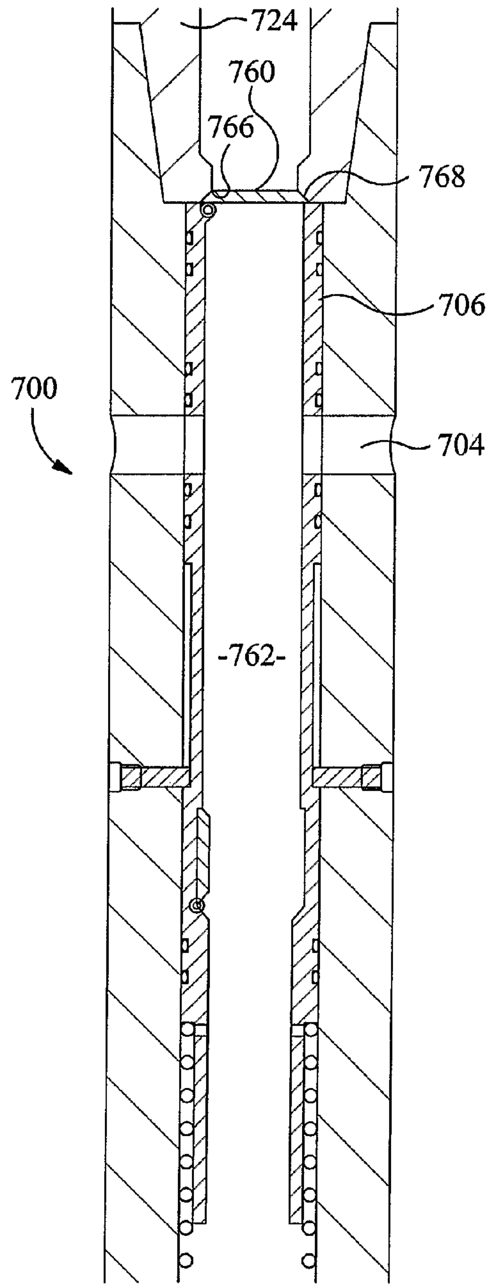



FIG 38

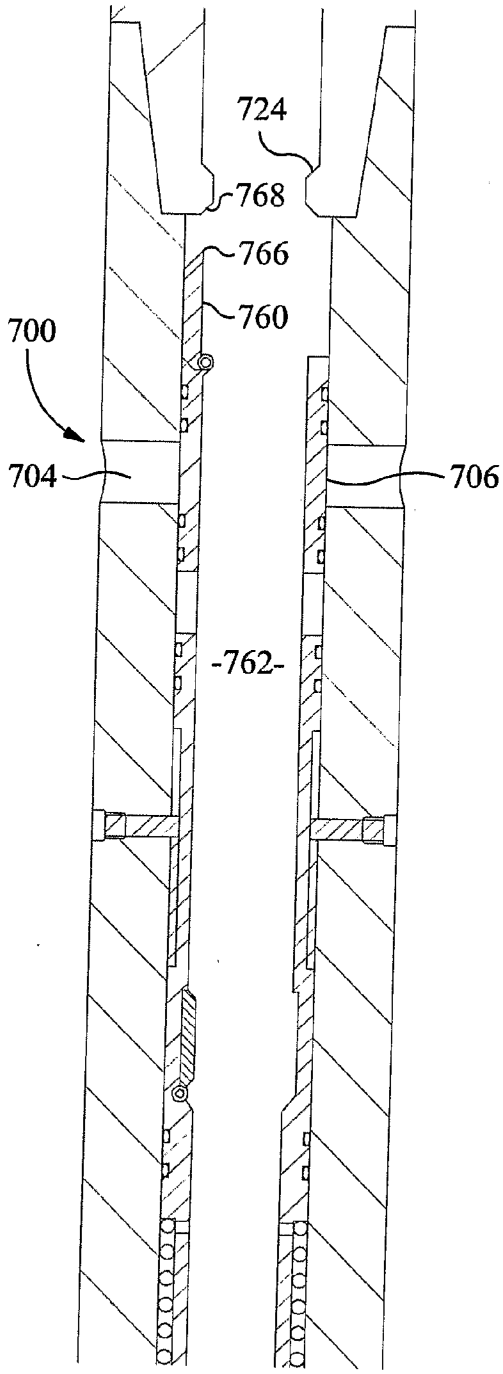

724
768
766
760
700
704
706
-762-

FIG 39

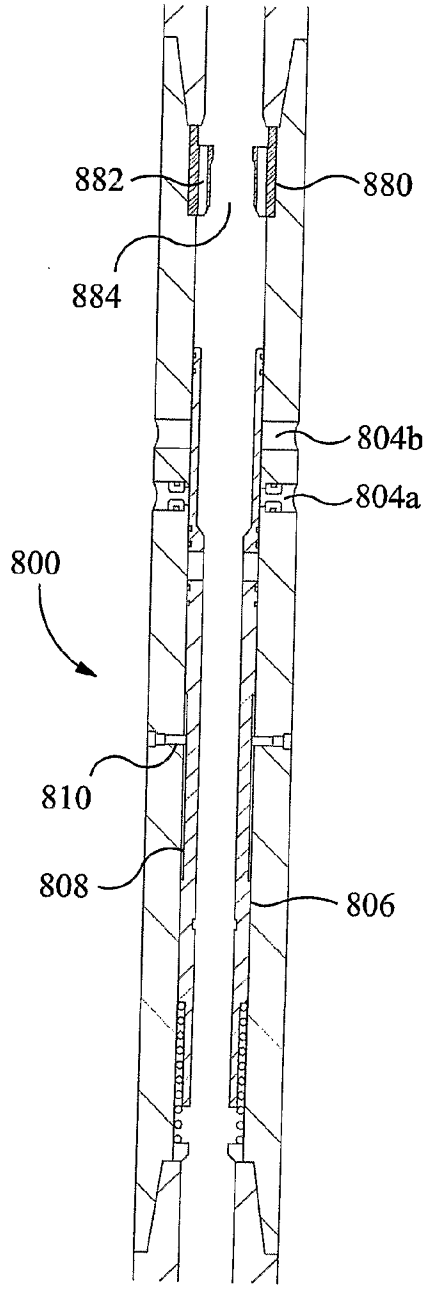

882
880
884
804b
804a
800
810
808
806

FIG 40

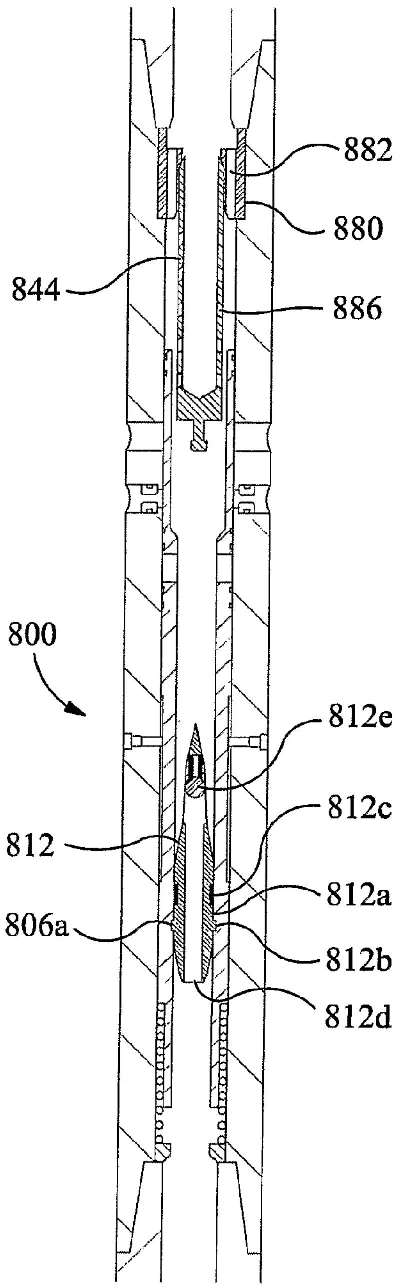

882
880
844
886
800
812e
812c
812
812a
806a
812b
812d

FIG 41

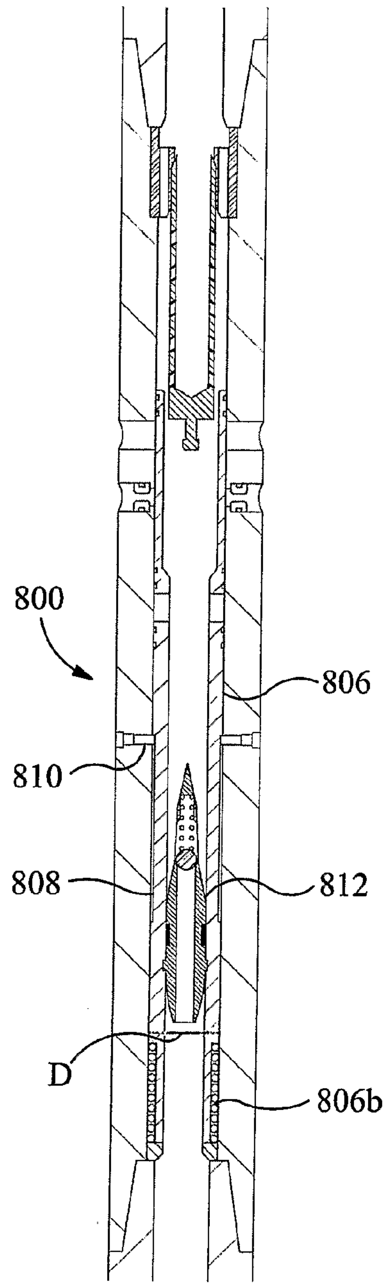

800
806
810
808
812
D
806b

FIG 42

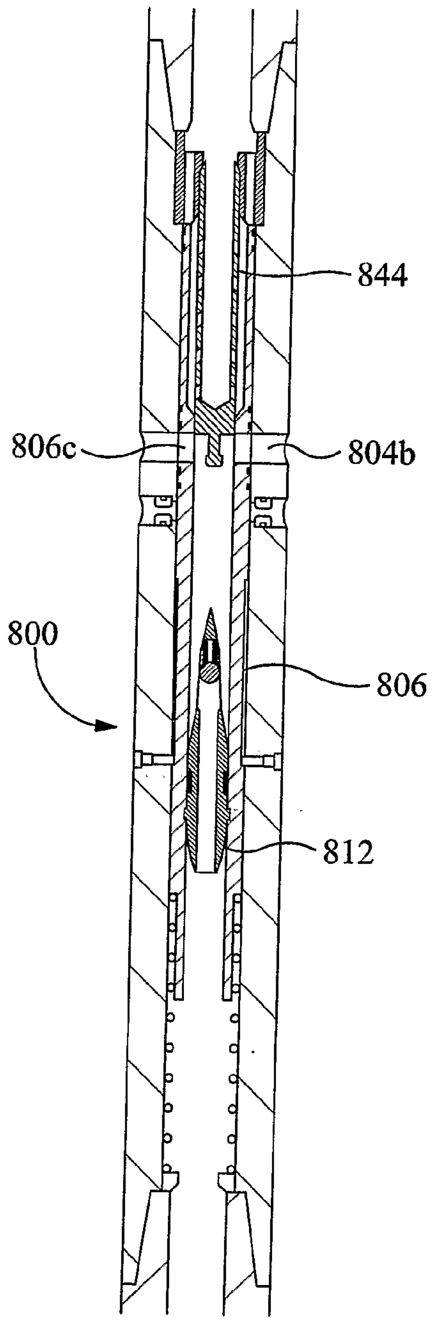



FIG 43

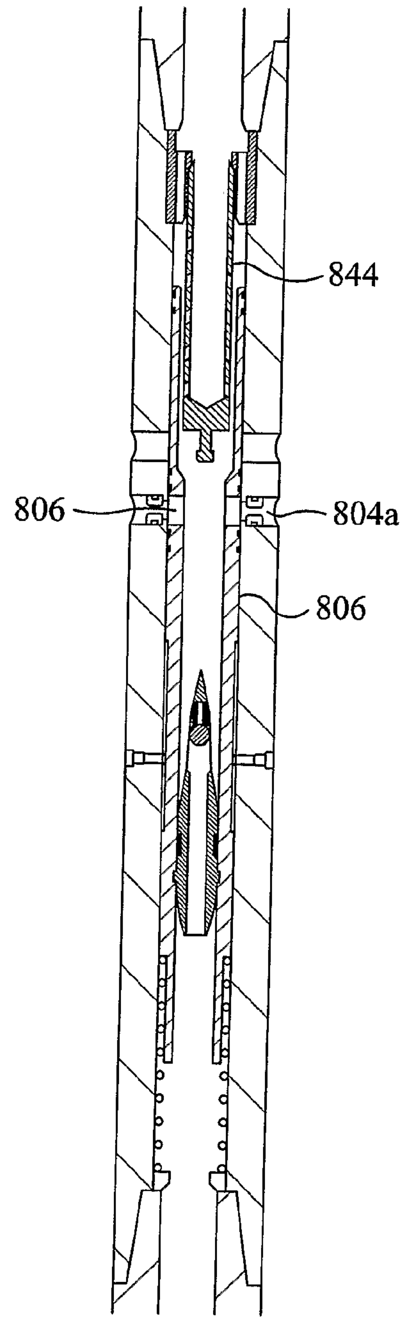



FIG 44

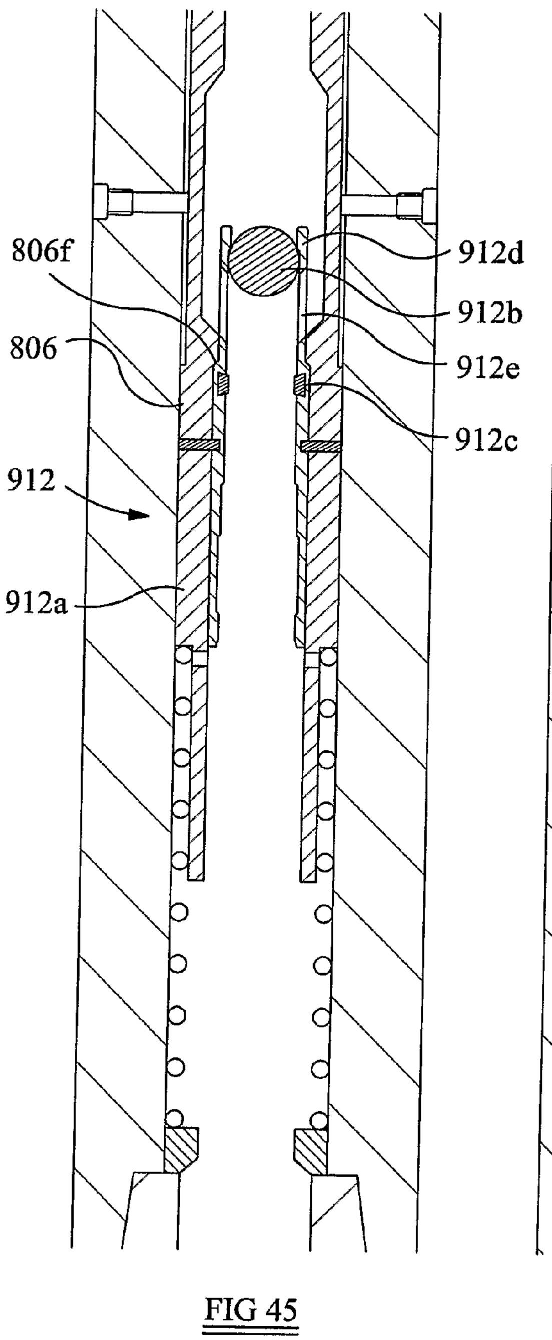



FIG 45

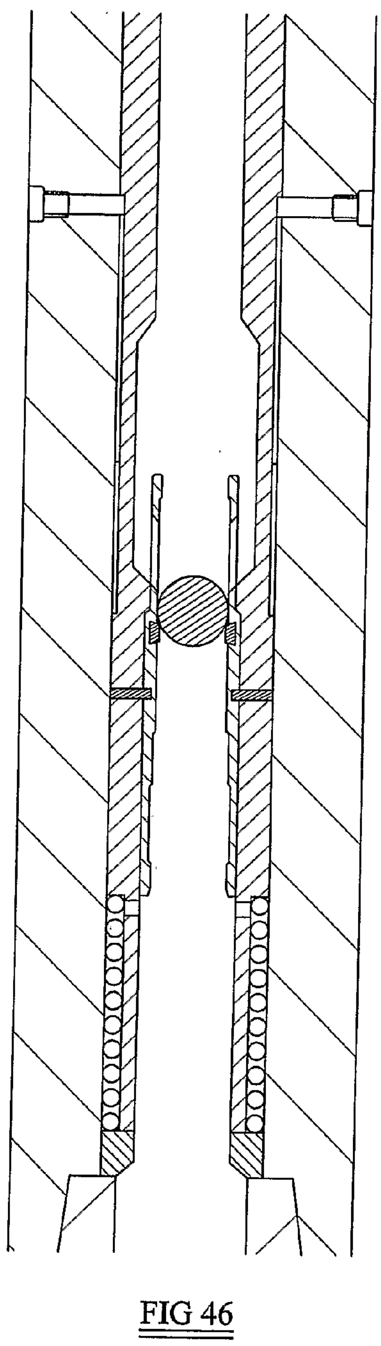


FIG 46

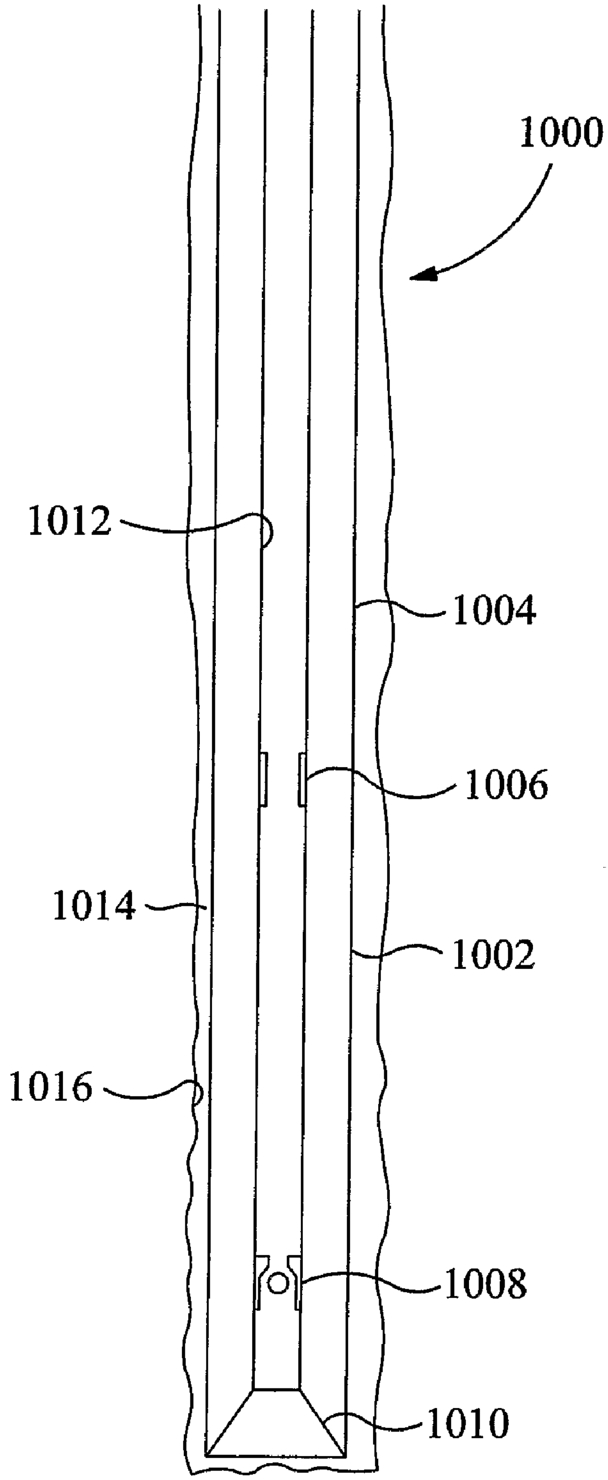



FIG 47

# DOWNHOLE TOOL

## FIELD OF THE INVENTION

[0001] This invention relates to a downhole tool, and to features of downhole tools. One embodiment of the invention relates to a downhole bypass tool for incorporation in a tubular string and which may be used to allow fluid to flow directly from the string into a surrounding annulus without having to pass through a bottom hole assembly (BHA). Other embodiments of the invention relate to methods of operating downhole tools.

## BACKGROUND OF THE INVENTION

[0002] In the oil and gas exploration and production industry long strings of pipe sections or other tubulars may be used to, for example, support and transmit force to a drill bit from a surface rig. The "drill string" is also used to carry drilling fluid pumped from the rig to jetting nozzles in the drill bit. On exiting the nozzles, the fluid passes back to surface via the annulus between the string and the bore wall. However, there are occasions when it is desirable to pass fluid from the tubular string directly into the annulus, without having to pass the fluid through the drill bit and other apparatus mounted on the end of the drill string, known as the bottom hole assembly (BHA). Such a fluid bypass may be desirable to, for example, provide a greater flow rate of fluid to facilitate clearing of drill cuttings from the annulus.

[0003] Conventional flow bypass devices, typically known as circulating tools or subs, feature a tubular body to be incorporated in the string and defining one or more radial flow ports. A sleeve held in place by one or more shear pins normally closes the flow ports. When it is desired for the drilling fluid to bypass the string below the sub a ball is dropped into the string and travels down through the string to land on top of the sleeve. This allows fluid pressure to be applied to the sleeve, shearing the pins and moving the sleeve downwards to allow flow through the side ports. Such tools have been in use for many years, and are relatively inexpensive and reliable. However, once such a device has been actuated, flow cannot be re-established to the string below the device, and the string has to be retrieved to remove the ball and reset the device.

[0004] There are a number of bypass tools currently available which avoid this disadvantage, in that the side port may be closed and fluid flow below the tool re-established.

[0005] U.S. Pat. No. 6,253,861 (Carmichael et al) discloses an arrangement in which a sleeve-shaped valve member may be moved to close or open a bypass port by dropping an actuating ball onto the valve member. An embodiment is described in which a bypass port is initially closed, then opened, and then closed once more, this process requiring the use of two differently sized actuation balls. Once the bypass ports are closed, the tool is arranged to provide a fluid bypass path around the balls, which remain within the tool.

[0006] International patent application publication No WO88/00275 (Bode) describes a valve in which side ports are opened by dropping a ball, and the ports are then subsequently closed by dropping and pumping a wiper dart. Bode describes a similar operating sequence to Carmichael et al and also provides for a flow path around the ball and wiper dart once the bypass port has been closed.

[0007] Carmichael et al and Bode describe relatively simple, single use tools, that is the tools offer an operator the opportunity to open and close the bypass ports just once. Such tools are also generally reliable and relatively inexpensive.

[0008] There are a number of other tools available which can be opened and closed a number of times. One of these tools is described in U.S. Pat. No. 4,889,199 (Lee). This tool utilises a plastic ball to open the ports, and a smaller steel ball to close the ports and allow the larger ball to be forced downwardly through the valve sleeve into a ball catcher provided in the lower part of the tool.

[0009] In U.S. Pat. No. 5,564,500 (Rogers et al) a sleeve may be moved to open bypass ports by dropping an actuating plug. If desired, a fishing tool can be lowered into the drill string to retrieve the actuating plug and to move the sleeve back into its initial position, closing the bypass ports.

[0010] The applicant has also proposed various arrangements as described in U.S. Pat. Nos. 6,820,697 and 6,378,612 and International Patent publications WO0549900 and WO05049959.

[0011] These tools provide the operator with the opportunity to open and close the bypass ports two or more times. However, these tools tend to be more expensive than single use tools, and the risks of tool failure are generally greater.

## SUMMARY OF THE INVENTION

[0012] According to a first aspect of the present invention there is provided a downhole tool comprising:

[0013] a fluid transmitting tubular body having an inlet and first and second outlets;

[0014] a sleeve defining a throughbore located in the body and initially closing the second outlet, the sleeve being axially moveable in one direction to open the second outlet and then permanently close the second outlet; and

[0015] an actuating device adapted to land on the sleeve and cause the sleeve to permanently close the second outlet and wherein, following closure of the second outlet, the actuating device is configurable to permit flow between the inlet and the first outlet through the sleeve, said flow through the sleeve being substantially confined to said sleeve throughbore.

[0016] According to another aspect of the present invention there is provided a method of controlling flow in a downhole tubular comprising a tubular body having an inlet and first and second outlets, the second outlet being initially closed by a sleeve defining a throughbore, the method comprising:

[0017] translating the sleeve in a first direction to open the second outlet;

[0018] directing fluid from the body inlet through the second outlet;

[0019] locating an actuating device in the body and operatively associating the actuating device with the sleeve;

[0020] translating the sleeve in said first direction to permanently close the second outlet; and

[0021] directing the fluid from the body inlet through the first outlet, the fluid passing through the sleeve and being substantially confined to said sleeve throughbore.

[0022] As used herein, the term "permanently closed" is used to indicate an arrangement in which the sleeve is arranged such that it is not normally possible or intended to re-open the second outlet once the outlet has been closed by the sleeve and flow is established or re-established between the inlet and the first outlet. This allows embodiments of the invention to be of relatively simple construction when compared to multiple use tools, that is tools intended to be opened and then closed on two or more occasions. Accordingly, embodiment of the invention may be relatively inexpensive and the simplicity of the tools facilitates provision of more reliable tools.

**[0023]** Substantially confining the flow to the sleeve throughbore offers a number of advantages and contrasts with existing arrangements in which a valve sleeve remains obstructed by an actuation ball such that a serpentine ball bypass flow path must be provided through the sleeve wall or around the sleeve. Such a serpentine flow path is likely to increase the risk of erosion to parts of the tool, limiting the applications of such tools or requiring use of expensive materials capable of operating in such conditions.

**[0024]** The flow between the inlet and the first outlet following closure of the second outlet may be through the actuating device.

**[0025]** The sleeve may define a substantially axial flow path, thus retaining the ability to drop, pump and run tools and devices through the tool after the sleeve has closed the second outlet.

**[0026]** The body inlet and first outlet may be axially aligned, and may be aligned with a throughbore extending through the body. Typically, the body throughbore and the sleeve throughbore are coaxial.

**[0027]** The second outlet may extend generally transversely or radially from the body through bore, and if desired may be arranged to direct fluid substantially perpendicular from the body, upwards or downwards relative to the body, or tangentially relative to the body. Only a single second outlet may be provided, but it is more likely that a plurality of second outlets will be provided in the body.

**[0028]** The body may have conventional pin and box end connections to allow the body to be mounted in an otherwise conventional string. Alternatively, the tool may comprise a main body section having box connections at both ends, for use in conjunction with a body section, which may be in the form of a saver sub, having pin connections at both ends. This facilitates the accurate machining of the inside of the main body section from either end.

**[0029]** The second outlet may simply be a bore or port in the body wall. Alternatively, the second outlet may be lined or may incorporate a nozzle or other flow restricting or controlling arrangement. In one embodiment, each second outlet is provided with a tungsten carbide nozzle.

**[0030]** The sleeve may be in one or more parts, and if formed from two or more parts, the parts may be axially moveable relative to one another. One part of the sleeve may be moveable to open the second outlet and another part of the sleeve may be moveable to close the second outlet.

**[0031]** The sleeve may be axially movable relative to the body. The sleeve may be adapted to be axially movable in the direction of normal fluid flow through the body.

**[0032]** The sleeve may be initially located in the body, or may be adapted to be passed into the body. In certain embodiments, one or more parts of the sleeve may be initially provided within the body, and then one or more other parts of the sleeve may be moved into the body, for example by pumping or dropping from surface.

**[0033]** Parts of the sleeve may be retained in initial positions by releasable retainers such as shear pins.

**[0034]** The movement of parts of the sleeve may be controlled or restricted by the provision of appropriate shoulders, ledges or the like, or by providing body-mounted pins to engage formations on the sleeve parts or vice versa.

**[0035]** In particular embodiments the tool may be adapted to permit the second outlet to be subsequently reopened in selected circumstances, typically in circumstances which are beyond the normal operating conditions or parameters encountered during an operation in which the tool is employed, for example a drilling operation, which is the application for a preferred embodiment of the invention. In one embodiment, the valve member may be adapted to reopen the second outlet in response to a selected reverse differential pressure, that is, when the pressure in the annulus surrounding the string containing the tool is higher than the pressure within the tool. This effect may be achieved by reverse circulation of drilling fluid, that is, by pumping fluid into the annulus at surface and circulating the fluid out of the hole via the drill string. However, operators will normally take all available measures to avoid creation of a reverse pressure differential, or reverse circulation, during drilling operations, due to the risk of drill cuttings and the like being circulated into the string and damaging or blocking sensitive equipment, and to protect exposed formations from elevated fluid pressure. However, as described below, a further aspect of the present invention seeks to overcome both of these problems. Thus, during normal operations with drilling and other fluids being circulated in the hole in the conventional manner, the operator may treat the second outlet as permanently closed.

**[0036]** The second outlet may be closed by the sleeve forming a seal between a surface of the sleeve and an opposing surface of the body, or by providing a seal between parts of the sleeve. The seal may be provided by conventional sealing arrangements such as elastomer O-rings or chevron seals. Alternatively, metal-to-metal seals or other non-elastomeric seals may be provided in which a seal is formed by, for example, metal elements of sleeve parts or metal elements of a sleeve part and the body being brought into contact. The sealing surfaces may be tapered or inclined to the direction of relative movement of the sealing parts or may be parallel or perpendicular. One advantage of tapered or inclined surfaces is that, by appropriate selection of taper angles, it may be possible to create a seal which will resist separation of the parts. As used herein, the term "metal-to-metal" is intended to encompass seals formed between metal surfaces provided with, for example, a non-metallic protective coating or a non-metallic low friction coating. Other non-elastomeric seals include seals of ceramic materials.

**[0037]** The sleeve may define one or more ports or holes which may be aligned with the second outlet to open the outlet, and which ports may be misaligned with the second outlet to close the outlet. Alternatively, or in addition, a sleeve or sleeve part may be axially spaced from the second outlet when the outlet is opened and may extend across the outlet to close the outlet.

**[0038]** In certain embodiments, a sleeve part may act as an actuating device. Such a sleeve part may incorporate a flow restriction, to facilitate pumping of the sleeve part into the body. The flow restriction may completely occlude the sleeve part and may be, for example, a burst disc or a plug of extrudable or soluble material. In other embodiments, the flow restriction may only partially occlude the sleeve part, and may be in the form of a nozzle, which nozzle may be adapted to be eroded by subsequent flow through the sleeve part. The provision of a nozzle allows the sleeve part to be pumped into bore relatively quickly, as the hydraulic shock experienced when the nozzled sleeve lands is less than that which would be experienced by an occluded sleeve or occluding ball. The erode-able nozzle may be achieved by forming the nozzle from a relatively soft material, and may simply take the form of a thick aluminium or aluminium alloy washer. Thus, once the second outlet has been closed, the nozzle will erode such that the remains of the sleeve will present little if any restriction to flow through the tool.

**[0039]** The sleeve may be adapted to be retained in a second outlet-closing configuration. The sleeve and body may be configured such that differential pressure tends to retain the sleeve closed. Surfaces of the sleeve may be arranged such that the sleeve is maintained in the closed configuration by friction or interference fit. Retaining members, such as sprung pins or snap rings, may be provided to lock the sleeve in the closed configuration.

**[0040]** The actuating device may take any appropriate form, including a plug, ball, sleeve, dart or the like.

**[0041]** Depending upon the tool functionality, more than one actuating device may be provided, and in such a case the actuating devices may take a similar or different form. A first actuating device may be utilised to open the second outlet and the second actuating device may then be utilised to close the second outlet.

**[0042]** The actuating device may be configured to restrict fluid flow through the sleeve to allow pressure to be built up across the sleeve, and thus reconfigure the sleeve. The actuating device may then be reconfigured to substantially reinstate the flow path through the sleeve. The actuating device may comprise an erodable element, such that flow of fluid through the device will cause the flow area through the device to increase. The actuating device may include an element which is displaceable or disruptable by a selected fluid pressure, for example a burst disk or a plug or portion of material which may be displaced from the sleeve. The actuating device may include a soluble material which is adapted to dissolve, disintegrate or otherwise change its characteristics on exposure to selected fluids. The actuating device may be a ball or some other form which is adapted to be extruded or otherwise displaced through the sleeve.

**[0043]** The actuating device may be adapted to be reconfigured to reinstate the sleeve flow path merely by application of fluid pressure thereto. Alternatively, the actuating device may be adapted to be reconfigured by another member, for example, a further actuating device.

**[0044]** The actuating device may be adapted to travel towards the sleeve under the influence of gravity, that is the actuating device may be configured to have a density greater than the fluid in which the device will operate. Alternatively, the density of the actuating device may be selected to be closer to the surrounding fluid. This requires the actuating device to be pumped through the string, but facilitates negotiation of inclined, horizontal or uphill bore sections.

**[0045]** A first actuating device may be configured to at least partially occlude the sleeve, such that flow from the body inlet to the first outlet is prevented or at least restricted, and a significant proportion of flow is directed from the body inlet to the second outlet.

**[0046]** It will be apparent to those of skill in the art that many of the above features have utility separately of the particular aspects of the invention identified above, and may indeed provide separate and distinct aspects of the invention. These various features may also be provided in combination with the further aspects of the invention set out below.

**[0047]** According to a further aspect of the invention there is provided a downhole tool comprising:

**[0048]** a fluid transmitting tubular body having a first inlet and first and second outlets;

**[0049]** a valve member configurable to close the second outlet; and

**[0050]** a seal arrangement operatively associated with the valve member and comprising first and second sealing surfaces relatively movable from a spaced apart non-sealing configuration to a contacting sealing configuration in which a seal is formed between contacting hard portions of the surfaces.

**[0051]** The invention further relates to a method of controlling fluid flow downhole through a tubular body having an inlet and first and second outlets, the method comprising:

**[0052]** directing fluid from the body inlet through the second outlet; and

**[0053]** translating a valve member to close the second outlet and form a seal between first and second sealing surfaces of a tough material.

**[0054]** The use of hard or tough materials in embodiments of the invention to form the sealing surfaces reduces the likelihood of the sealing surfaces suffering damage, wear or erosion. Thus, the hard or tough sealing surfaces may, if desired, be provided in more exposed locations, where the surfaces may be exposed to fluid flow. This offers that advantage that fluid flowing over the surfaces will tend to maintain the surfaces clean, such that the contacting surfaces are more likely to provide the desired seal. Conventional elastomeric bypass tool seals typically extend across small annular gaps provided between hard cylindrical surfaces with at least one port in each surface. To open the ports one sleeve will slide inside the other and a port will cross a seal until the ports align. To close, the port will move back across the seal so the ports do not align. The seal will only be exposed briefly as it moves from between open and closed. To protect the seals, the tool will normally be arranged such that there is no flow in the gap. However, where the working fluid contains small particulates, as is the case with drilling operations, it is not unusual for such gaps to fill with material over time or with use, which may restrict the subsequent movement of parts of the tool resulting in an expensive failure.

**[0055]** The sealing surfaces may form a metal-to-metal seal, for example the surfaces may feature a tungsten carbide coating which has been ground and polished. The metal surfaces may feature a coating of non-metallic material, such as PTFE or a ceramic. Alternatively, the sealing surfaces may be formed of ceramic material, an elastomeric material, or a combination of different materials.

**[0056]** The sealing surfaces may be formed of rigid materials.

**[0057]** Preferably, the tool is configured to permit translation of the valve member in response to a fluid pressure-induced force. The force may be induced by a pressure differential across a flow restriction or by a fluid pressure differential between the interior and exterior of the tool. In other embodiments the tool may be configured to operate in response to a mechanical force or a gravity-induced force.

**[0058]** A flow restriction may be provided in the tool. The restriction may form an integral part of the tool, or may be provided by a restriction member or actuating member which is located or placed in the tool, typically by dropping or pumping the member into the tool, which member may land on a seat, profile or restriction in the tool.

[0059] The tool may be configured to lock or otherwise retain the first and second surfaces in the sealing configuration. Thus, in certain embodiments, the valve member may permanently close the second outlet such that it will not reopen in normal operating circumstances. In other embodiments the valve member may be subsequently movable to open the second outlet, for example by cycling the pressure experienced by the tool.

[0060] The movement of the valve member may be controlled by an indexing arrangement, for example a cam and follower. The valve member may be biased towards one of the open or closed configurations by a spring or other arrangement.

[0061] The first and second surfaces may be configured to provide a locking engagement therebetween. The surfaces may be configured to form an interference fit therebetween. The surfaces may define locking profiles, for example ratchet threads.

[0062] The tool may be configured such that the sealing surface may be brought into contact with a force sufficient to provide locking engagement therebetween. The force may be produced by moving the valve member at a relatively high speed to create sufficient momentum to provide the locking engagement or by applying a high magnitude force directly to the valve member.

[0063] The sealing surfaces may be energised, that is maintained in sealing contact, by any appropriate arrangement, for example a spring, by applied weight, or by a mechanical force. In particular embodiments pressure may be utilised to energise the seal, for example by utilising a differential piston.

[0064] The valve member may comprise a sleeve.

[0065] The first and second surfaces may be inclined relative to the direction of movement of the valve member, which may be parallel to the body axis. Alternatively, the surfaces may be parallel or perpendicular to the direction of valve member movement.

[0066] The valve member may be in one or more parts. The sealing surfaces may be on co-operating parts of the valve member. Alternatively, one sealing surface may be on the valve member and the other sealing surface on the body or some other part of the tool.

[0067] The tool may also feature other forms of sealing arrangement between parts of the valve member and other elements of the tool. In some embodiments elastomer seals may be provided between parts of the valve member and the body, or between cooperating parts of the valve member.

[0068] According to a still further aspect of the invention there is provided a downhole tool comprising:

[0069] a fluid transmitting tubular body having a side port;

[0070] a valve member configurable to close the side port; and

[0071] a seal arrangement operatively associated with the valve member and comprising first and second sealing surfaces relatively movable from a spaced apart non-sealing configuration to a contacting sealing configuration in which a seal is formed between contacting hard portions of the surfaces.

[0072] The invention further relates to a method of controlling fluid flow downhole through a tubular body having a side port, the method comprising:

[0073] directing fluid through the side port; and

[0074] translating a valve member to close the side port and form a seal between first and second sealing surfaces of a rigid material.

[0075] According to another aspect of the present invention there is provided a downhole tool comprising:

[0076] a fluid-transmitting body; and

[0077] a tool function member adapted for actuation in response to application of fluid pressure tending to circulate fluid in a reverse direction.

[0078] The invention also relates to a method of actuating a downhole tool, the method comprising reverse circulating fluid or inducing a reverse fluid pressure differential, to actuate the tool.

[0079] The reverse fluid pressure may act on or across a partial or complete flow restriction within the string, which restriction provides less restriction to flow in the normal direction.

[0080] This aspect of the invention utilises reverse circulation of fluid, or creation of a reverse fluid pressure differential, to actuate a tool. In conventional fluid-actuated downhole tools, actuation is achieved by circulating fluid from surface down through a drill string or other hollow member, the fluid then returning to surface via the annulus between the string and the surrounding bore wall, which may be formed by, for example, an unlined bore, or by casing or liner. Actuation of such a conventional tool may be achieved by locating a restriction in the string bore, for example an occluding ball or dart, or a nozzle, such that a differential pressure may be created across the restriction. Alternatively, a conventional fluid-actuated tool may comprise a differential piston having an area exposed to higher internal tool pressure and an opposing area exposed to lower annulus pressure. Many conventional fluid-actuated tools will cycle between different configurations every time the fluid flow in the string is cycled, typically every time the fluid pumps on surface are switched on and off, as will occur many times in a typical downhole operation. The operator must thus always take care to ensure that the tool is in the appropriate configuration, and the continual cycling of the tool may induce wear and damage. Such tools will also typically rely on the operation of return springs, which springs tend to be relatively weak in comparison to the hydraulic forces experienced by the tool. Thus, in the event of the spring failing to return properly, the tool will fail.

[0081] Embodiments of the invention avoid many of these problems by utilising reverse circulation or other mechanisms or methods to create a reverse pressure differential, which pressure differential can readily be utilised to create an actuating force acting in an opposite direction to that created by conventional flow or pressure regimes. Accordingly, the tool may be configured such that variations in flow in normal usage do not affect the tool configuration.

[0082] Reverse circulation may be achieved by reconfiguring fluid control valves at surface and, closing the BOPs or otherwise sealing the annulus, such that fluid from the surface pumps is directed into the annulus rather than into the string, and fluid may flow from the top of the string. If the well has been cased off with metal casing, then reverse pressure differentials of 5000 psi may be achieved, resulting in massive actuation pressure forces being available to actuate the tool. However, if the bore is at least partially unlined, and the formation is exposed, the reverse pressure differential available before the formation is damaged may be only 50-500 psi, depending on the strength of the formation. It has previously been proposed to operate tools by pressuring up the annulus, which tools typically rely on a differential piston effect between the outside and the inside of the pipe or tubing. However, such tools require a packer to be set lower down the bore, below the tool, to block off the annulus. Accordingly, such arrangements are normally only provided in combination with a completion or testing string, which is not subject to movement in the well. Clearly, such arrangements would not be suitable for use in combination with a drill string or well-bore clean-out string, were the string is subject to movement. Alternatively, in some cases the presence of different fluids in different parts of the bore may be utilised to achieve a similar effect. For example, if the annulus is filled with heavy or dense drilling fluid, and the string in the bore is filled with water, as is common in well-bore clean-outs, simply shutting down the circulating pumps and opening appropriate valves will allow the heavier fluid in the annulus to reverse circulate to displace the lighter fluid in the string. Thus, the normally undesirable "U-tube" effect may be utilised to the operator's advantage. A similar effect may be created by draining fluid from the upper end of the string. This may be achieved by bleeding-off pressure from the sting bore and annulus, lifting the string from the bore and then cracking or loosening the coupling between the two uppermost drill pipe stands such that the fluid in the uppermost stand may drain from the stand, and be caught in an appropriate mud bucket. The coupling is re-tightened and the uppermost stand, which is now filled with air, is run back into the bore. The resulting difference between the height of a column of typical drilling fluid within the string and the height of the column of drilling fluid in the annulus (approximately 95 feet) creates a reverse pressure differential between the annulus and the drill string of around 40 to 80 psi, depending on the liquid density. This pressure acting on a 15 square inch piston will produce a force of 600-1200 lbs or 0.27-0.55 tons. A larger reverse pressure differential, of the order of 100 psi, can be created simply by draining fluid from two pipe stands, or by running in the string without top-filling; two air-filled drill pipe stands may be utilised to create a pressure differential of approximately 100 psi with regular drilling "mud" and three stands would create 150 psi, four 200 psi and so on. This method of obtaining a reverse pressure differential also offers the advantage that the annulus only experiences hydrostatic pressure and does not exert any extra pressure on the formation.

**[0083]** The tool-actuating flow restriction may be provided below the tool or within the tool. The tool may comprise an actuation arrangement or mechanism. The arrangement may include a differential piston adapted to apply an actuating force in response to a pressure differential between the annulus and the tool interior. The tool may be configured such that a reverse pressure directly actuates the tool or a part of the tool, for example to retract or extend blades, cutters or pistons, for example a cutter on an under reamer or a piston of a variable gauge stabiliser. In other embodiments the reverse pressure may be utilised to configure the tool such that, on equalisation or bleeding off pressure, the tool is actuated or assumes a desired operating configuration, or is configured such that a conventional pressure differential will actuate the tool. As noted above, the restriction is configured to provide a greater restriction to reverse flow than normal flow. For example, the restriction may be normally closed, or lightly biased towards a closed or restricted flow configuration, but will open or open up in response to normal flow, and thus not significantly restrict normal flow. The restriction may thus be configured to create little if any pressure loss in normal flow, and to create little if any restriction in the bore to the passage of tools or other devices from surface. However, the restriction will maintain or assume a restricted flow configuration in the absence of flow or in response to reverse flow or pressure. In one embodiment the restriction may be a lightly biased flapper valve, which opens in response to normal flow. However, the flapper remains closed in no flow or reverse flow conditions, and the closed flapper provides a large area piston. In other embodiments other forms of non-return valves may be used to similar effect. The non-return valve may be configured such that the valve may be blown out or otherwise removed or retrieved from the string. The non-return valve may be located in the tool as the tool is run in, or may be dropped or pumped into the tool. The former arrangement would prevent the string from self-filling, thus requiring top-filling as the string was run in to the bore. The need for top-filling could be alleviated by providing a bleed hole or valve or the like on the non-return valve, however this would increase the volume of fluid which would be required to be reverse circulated to actuate the tool, and it is considered desirable to minimise the reverse flow volume.

**[0084]** With the provision of an arrangement as described above only a small reverse differential pressure across the valve will provide a very significant force. This allows actuation of the tool with only a relatively low reverse flow rate or pressure: in some situations, for example when operating in an open or unlined bore, it may be desired to maintain the pressure in the annulus at a relatively low level, to avoid damaging the formation. As noted above, a sufficient actuating pressure may be achieved simply by draining fluid from a limited length of the upper end of the drill string, and utilising the hydrostatic pressure created by the fluid columns in the annulus and the string seeking to equalise to create the reverse pressure differential.

**[0085]** As noted above, where a non-return valve is provided in the string, the string may require top-filling as it is being run into the bore. Alternatively, the valve may be lowered or pumped into the string once the string is in place.

**[0086]** The tool may be a single use tool, or the tool may be capable of multiple actuations such that, for example, the tool configuration may be cycled or modified a number of times. This may be achieved simply by raising and lowering the string to provide a u-tube effect, as described above.

**[0087]** The tool may comprise a cam mechanism that controls the movement of elements of the tool, for example the tool function member may comprise a pin which follows a cam slot in a tool body element, or vice versa.

**[0088]** The tool may be releasably retained in an initial configuration, for example by a shear pin or other releasable retainer.

**[0089]** The tool may comprise a return spring or other arrangement configured to resist forces created by reverse circulation of fluid.

**[0090]** The tool may be initially configured in a dormant or inactive configuration. The tool may be activated by any appropriate means, for example a signal from surface. Alternatively, an activating member may be dropped or pumped from surface to activate the tool. In one embodiment a sleeve pumped or dropped from surface may land on the tool and release locking keys or dogs. In another embodiment the activating member may incorporate a flow restriction, for example the member may be a nozzled sleeve, a non-return valve, which may be provided in a drop-in dart, or a ball which will land in the tool to create a non-return valve. As described above, the restriction may be configured to open or open up in response to normal flow, but remain closed or close up in response to no flow or reverse flow. The flow restriction may be retrievable, for example using a wireline fishing tool. Alternatively, or in addition, the flow restriction may be selectively configured to remain in an open or fully open position, for example a hold-open sleeve may be pumped into the string and retain the restriction open.

**[0091]** The tool may comprise a body having a side port and a valve member configurable to close the side port. The side port may be useful in providing fluid bypass, that is the tool may be a bypass sub. The valve member may be adapted to be actuated by reverse pressure or circulation to open or close the port. In such an embodiment a restriction may be provided in the tool above the side port. A non-return valve or other flow control arrangement may be provided below the port. Such an arrangement may be utilised to prevent flow of fluid from the annulus or the string into the string below the tool. This would be useful in preventing drill cuttings, lost circulation material (LCM) and other material passing into a bottom hole assembly (BHA) and possibly damaging the assembly.

**[0092]** The valve member may define a flow port which is adapted to be aligned with a body side port. In some embodiments, one or both of the valve member or body may define two or more sets of ports. By aligning different flow ports it is possible to achieve different flow characteristics. For example, one set of ports may be nozzled.

**[0093]** According to a yet further aspect of the present invention there is provided a device adapted for passing into a downhole tubular to engage a downhole apparatus and permit the creation of an actuating fluid pressure differential, the device defining an erode-able flow restriction.

**[0094]** This aspect of the invention allows an operator to locate a fluid-flow restriction in a downhole apparatus to, for example, facilitate actuation of an apparatus by application of a fluid pressure actuating force. However, following actuation, continued pumping of fluid through the restriction will cause the restriction to erode and ultimately substantially remove the restriction. Thus, the pressure losses and bore restriction created by the restriction are only temporary.

**[0095]** The device may comprise a sleeve, with the restriction provided within the sleeve.

**[0096]** The restriction may comprise a relatively soft material, such as aluminium or aluminium alloy, or may comprise a material which degrades in contact with selected fluids.

**[0097]** It will be apparent to those of skill in the art that many of the features identified and described above have utility separately of the various aspects of the invention. Indeed, many of these features may form individual, separate and distinct aspects of the invention. These various features may also be provided in combination with aspects of the invention other than the particular aspect which the features follow.

**[0098]** According to a still further aspect of the present invention there is provided a method of actuating a downhole tool, the method comprising:

**[0099]** providing a fluid column in a string;

**[0100]** providing a fluid column in an annulus surrounding the string;

**[0101]** creating a hydrostatic pressure differential between the fluid columns; and

**[0102]** utilising the hydrostatic pressure differential to actuate a downhole tool.

**[0103]** The hydrostatic pressure may be higher in the annulus, to create a reverse pressure differential. In other embodiments a positive pressure differential may be created.

**[0104]** A portion of the string may be filled with lower density fluid, such as water, brine, or air.

**[0105]** An upper portion of the string may be filled with air by raising an upper portion of the string from the bore, draining liquid from the upper portion of the string, and then lowering the air-filled upper portion of the string into the bore. Alternatively, air may be pumped into the string, or air may be supplied to the string from a compressed air source.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0106]** These and other aspects of the present invention will now be described, by way of example with reference to the accompanying drawings, in which:

**[0107]** FIG. **1** is a schematic sectional view of a bypass tool made in accordance with an embodiment of the present invention;

**[0108]** FIGS. **2** through **7** are enlarged sectional views of the bypass tool of FIG. **1** in various different configurations, and showing sleeve-form actuating members;

**[0109]** FIGS. **8** through **11** are enlarged sectional views of the tool of FIG. **1** in various configurations, and showing actuating devices in the form of balls;

**[0110]** FIGS. **12**, **13** and **14** show a bypass tool in accordance with a further embodiment of the present invention;

**[0111]** FIGS. **15** through **19** illustrate a bypass tool in accordance with a still further embodiment of the present invention;

**[0112]** FIGS. **20** through **26** illustrate a bypass tool in accordance with a yet further embodiment of the present invention;

**[0113]** FIGS. **27** through **30** illustrate a reverse circulation actuated bypass tool in accordance with an alternative embodiment of the present invention;

**[0114]** FIG. **31** shows an enlarged view of an alternative sealing arrangement according to another embodiment of the present invention;

**[0115]** FIG. **32** shows an enlarged view of a further alternative sealing arrangement according to another embodiment of the present invention;

**[0116]** FIG. **33** shows an enlarged view of a further alternative sealing arrangement according to another embodiment of the present invention;

**[0117]** FIGS. **34** and **35** illustrate a reverse circulation actuated bypass tool in accordance with another embodiment of the present invention;

**[0118]** FIGS. **36** and **37** illustrate a reverse circulation actuated bypass tool in accordance with another embodiment of the present invention;

**[0119]** FIGS. **38** and **39** illustrate a reverse circulation actuated bypass tool in accordance with another embodiment of the present invention;

**[0120]** FIGS. **40** to **44** illustrate a reverse pressure actuated bypass tool in accordance with a further embodiment of the present invention;

**[0121]** FIGS. **45** and **46** illustrate an alternative actuation arrangement for the tool of FIG. **40**; and

**[0122]** FIG. **47** is a schematic illustration of a reverse circulation actuated tool in accordance with a still further embodiment of the present invention.

## DETAILED DESCRIPTION OF THE DRAWINGS

**[0123]** Reference is first made to FIG. **1** of the drawings, which illustrates a bypass tool **30** in accordance with an embodiment of the present invention. The tool **30** features a generally tubular body **32** formed of two sections, an upper main section **34** having box connections at both ends and a lower saver sub section **36** which features pin connections at both ends. This particular configuration facilitates machining of the internal diameter of the main body section **34** from either end.

**[0124]** The tool body **32** defines an upper inlet **38** which communicates with a first outlet **40** at the lower end of the body **32**. Furthermore, the body wall **42** defines a number of circumferentially spaced radial second outlets ports **44**. In this embodiment, the ports **44** are provided with interchangeable tungsten carbide nozzles **46**, sealed in the ports with an O-ring **48** and held in place by a small circlip **50**.

**[0125]** The body **32** accommodates a valve sleeve **52** formed of two parts, which will hereinafter be referred to as the lower sleeve **54** and the upper sleeve **56**. The sleeves **54**, **56** are initially retained relative to the tool body **32** by respective shear pins **58**, **59**. These pins **58**, **59** extend through the body **32** and engage respective circumferential grooves **60**, **61**. The upper sleeve **56** further co-operates with a motion-controlling pin **62** which extends through the body **32** to engage an axially extending circumferential recess **64** on the sleeve **56**.

**[0126]** The adjacent sleeve ends are provided with oppositely directed shallow taper faces **66**, **67** which are initially separated by a small extent. Furthermore, in the initial configuration, the lower sleeve **54** extends across the ports **44**, with sets of seals **68**, **69** on the sleeve **54** located above and below the ports **44** ensuring that there is no flow of fluid from the body through the ports **44**. A single set of seals **70** is provided on the upper sleeve **56**.

**[0127]** Both sleeves **54**, **56** define a small internal seat towards their upper ends, the lower seat **72** being of slightly smaller diameter than the upper seat **73**.

**[0128]** The operation of the tool **30** will now be described with reference also being made to FIGS. **2** through **7**. The operation of the tool **30** will first be described in brief, followed by a more detailed description.

**[0129]** As noted above, FIG. **1** shows the tool **30** in an initial configuration; the tool **30** would be incorporated in a drill string in this configuration. If, at any point during the drilling operation, it is desired to open the ports **44**, a first actuating device, in the form of a sleeve **74**, is pumped into the string to land on the lower sleeve **54**. Pressure may then be applied across the sleeves **74**, **54**, to move the sleeve **54** downwardly and open and ports **44**, as illustrated in FIG. **3**. In this configuration the tool **30** provides 100% bypass, that is all of the fluid flowing down the string is directed through the ports **44**. Provision of an over pressure in the fluid in the string above the tool **30** results in the sleeve **74** being reconfigured to restore the axial flow path through the sleeve **54** as illustrated in FIG. **4**. In this configuration, fluid being pumped from surface may pass through the ports **44** and may also pass down through the string below the tool **30**. If it is desired to close the ports **44**, a second actuating sleeve **76** is pumped down the string from surface to land in the upper sleeve **56**, as illustrated in FIG. **5**. This allows a differential pressure to be applied across the sleeves **76**, **56**, causing the sleeve **56** to move downwardly and close the ports **44**, as illustrated in FIG. **6**. Application of further pressure reconfigures the sleeve **76** to reinstate the axial flow path through the sleeve **56**, as illustrated in FIG. **7**.

**[0130]** The operation of the tool **30** will now be described in greater detail.

**[0131]** Reference is first made in particular to FIG. **2**, which shows the actuating sleeve **74** after it has landed on the lower sleeve **54**. The sleeve **74** comprises a cylindrical body **77** of a lightweight material, such as aluminium alloy. The body **77** is dimensioned to fit snugly within the sleeve **54**, the trailing end of the body defining a landing profile **78** dimensioned to land on the seat **72**. The body **77** is filled with a low density fluid, the upper end of the body being closed by a thin wall **80** and the lower end being closed by a plastic nose piece **82**.

**[0132]** The actuating sleeve **74** has a relativity low density, and as such is easily pumped through any angle of hole. On landing on the sleeve **54**, the sleeve **74** blocks the flow of drilling fluid through the drill string, causing a pressure build-up across the sleeve **54**, which ultimately results in the pin **58** shearing. When this occurs, the sleeve **54** may move downwards within the body **32** to rest on the upper end of the saver sub **36**, as illustrated in FIG. **3**. As the sleeve **54** moves downwardly the set of seals **68** which were originally above the ports **44** will move across the ports **44**. There is a strong likelihood that the movement of the seals **68** across the ports **44** will result in damage to the seals **68**, which damage may render the seals ineffective. However, the configuration of this particular embodiment is such that this does not impact on the effectiveness of the tool, as will be described.

**[0133]** In this second configuration the tool **30** will now operate as a 100% bypass tool, that is all of the flow of fluid from surface through the drill string will be diverted through the ports **44**. The tool **30** will remain in this configuration while the flow of fluid into the string remains at a relatively low level. However, if the flow rate is increased this will create a pressure drop across the nozzles **46**, and a differential pressure will also be created across the actuating sleeve **74**. Above a predetermined flow rate, this pressure will be sufficient to rupture the thin wall **80** at the upper end of the sleeve **74**.

**[0134]** Immediately the wall **80** ruptures, the plastic nosepiece **82** and the light fluid within the sleeve **74** will also be washed away. The nosepiece **82** will travel down through the string until caught in a filter sub, or may even be circulated out of the hole. The configuration of the tool **30** at this point is as illustrated in FIG. **4**, and if fluid is pumped down through the string some of the flow will pass through the ports **44** to the surrounding annulus, and the remainder of the flow will carry on down through the drill string towards the drill bit. This particular configuration can be useful in a number of circumstances, for example if drilling a tapered hole where more flow is required in the annulus towards the upper end of the hole than the lower end of the hole.

**[0135]** If it is then wished to close the ports **44**, the second actuating sleeve **76** is pumped down through the string. The sleeve **76** is similar in form to the first actuating sleeve **74** but has a slightly larger outer diameter, such that the sleeve **76** will land on the seat **73** in the upper sleeve **56**, as shown in FIG. **5**. As with the first actuating sleeve **74**, an increase in pressure above the actuating sleeve **76** will place an increasing load on the shear pin **59**, and when the pin **59** fails the upper sleeve **56** will be moved axially downwards to assume the position as illustrated in FIG. **6** of the drawings. It will be noted that the lower end of the sleeve **56** has crossed the ports **44**, and the shallow taper faces **66**, **67** of the sleeves **54**, **56** having engaged. The angle of the faces **66**, **67** is selected to be less than 20°, such that the faces will be wedged together, and may now only be separated by application of very significant force. Thus, the faces **66**, **67** serve two functions, that of a metal-to-metal seal between the sleeves **54**, **56** and also as a lock to prevent the sleeves **54**, **56** being separated.

**[0136]** It should be noted that the difference is seal area defined by the seals **70** and the metal-to-metal seal between the faces **66**, **67** is such that a differential piston effect is created across the closed sleeve **56**. Thus, in normal flow situations, that is with fluid being pumped from surface through the string and returning to surface via the annulus, the higher fluid pressure within the string, and thus also within the tool **30**, will tend to urge the sleeve **56** to remain in the closed position. Accordingly, even if the seal faces **66**, **67** do not lock together, or the sleeves are provided with less acute seal faces, the tool **30** will remain in the closed configuration, and as such may be considered to be permanently closed by the operator. However, as has been noted, if the flow direction was reversed, the differential piston could be utilised to open the tool if considered necessary or desirable.

**[0137]** A still further increase in pressure will cause the second actuating sleeve **76** to be blown through, to reinstate the axial flow path through the tool, as illustrated in FIG. **7** of the drawings. It will be noted that the ports **44** are isolated from the body throughbore by the seals **68**, **70**, and by the metal-to-metal seal formed by the tapered faces **66**, **67**. No reliance is placed upon the potentially damaged seals **69**. Furthermore, the lock between the faces, **66**, **67** ensures that the sleeves **54**, **56** are permanently fixed together, and may only be separated by us of appropriate tools on surface, once the tool **30** has been removed from the drill string and is being re-set in a workshop.

**[0138]** In this embodiment there is no specific provision of an arrangement to lock the sleeves **54**, **56** relative to the tool body **32**. However, seal friction and fluid flow are normally such that there is no movement of the sleeves **54**, **56** from the configuration as illustrated in FIG. **7**. If considered necessary or desirable, however, it would be possible to incorporate a lock such as a snap-ring or the like in the lower sleeve **54**, to ensure that there was no possibility of upward axial movement of the sleeve **54**.

**[0139]** Downward axial movement of the locked sleeve **54**, **56** is restricted by engagement of the end of the lower sleeve **54** with the upper end of the saver sub **36** ensuring that the seals **70** do not traverse the ports **44**. Upward movement of the locked sleeves **54**, **56** is restricted by the pin **62**, which ensures that the lower seals **68** do not traverse the ports **44**, and the ports **44** remain isolated from the body throughbore.

**[0140]** Those of skill in the art will appreciate that the tools **30**, configured as illustrated in FIG. **7**, provides a substantially clear axial through bore, minimising the erosive action of drilling fluid on the tool **30** and allowing wireline access through the tool. Furthermore, the tool **30** will allow the passage of balls, sleeves, darts and the like which may be utilised to actuate other tools **30** located in the string below the tool **30**.

**[0141]** Reference is now made to FIGS. **8** through **11** of the drawings, which illustrate the operation of the bypass tool **30** but in which actuating devices in the form of balls are utilised, rather than the actuating sleeves **74**, **76**.

**[0142]** FIG. **8** shows the tool configuration after a smaller actuating ball **90** has landed on the seat **72** in the lower sleeve **54**, and fluid pressure has been applied to shear the pin **58** and expose the ports **44**. Operationally, the tool configuration illustrated in FIG. **8** is thus equivalent to the configuration illustrated in FIG. **3**, that is as a 100% bypass tool. However, to reinstate the axial flow path through the tool body **32**, the necessary increase in drilling fluid flow rate, and thus pressure across the ball **90**, will deform and push the ball **90** down through the sleeve **54**. The displaced ball **90** may then travel down through the string to be caught in a ball catcher, filter sub, or may even be circulated out of the hole. Fluid may now pass through the tool **30** towards the distal end of the string, and also through the ports **44** into the annulus, as illustrated in FIG. **9**.

**[0143]** To close the ports **44** once more a larger ball **92** is pumped through the string to land on the seat **73**, allowing fluid pressure to act on the sleeve **56** to close the ports **44**, as illustrated in FIG. **10**. A further build-up of pressure above the ball **92** will extrude the ball **92** from the seat **73** and then through the sleeves **56**, **54**, to reinstate the open axial through bore. Of course, as the ball **92** is extruded through the sleeve **56** the axial force experienced by the sleeve **56** will ensure that a locking and sealing force is applied to the tapered faces **66**, **67**.

**[0144]** As with the tool **30** when actuated by means of the sleeves **74**, **76**, the tool **30** actuated by means of the balls **90**, **92** allows the tool **30** to be configured to provide 100% bypass as illustrated in FIG. **8**, partial bypass as illustrated in FIG. **9**, and then the ports **44** to be permanently closed while providing substantially unobstructed access through the tool **30**, as illustrated in FIG. **11**.

**[0145]** The balls **90**, **92** may be formed of any suitable material which allows the balls to maintain a pressure force thereacross, but which will also allow the balls **90**, **92** to be extruded through the sleeves **54**, **56** when subject to a greater force. As with the sleeves **74**, **76**, it is also desirable that the balls **90**, **92** are of a relatively low density, to facilitate movement of the balls through strings located in deviated holes. The balls **90**, **92** may be of a solid construction of a material such as nylon, or may, for example, be formed as hollow spheres filled with a low-density fluid. Such spheres may be constructed such that they will burst on the balls being forced through the sleeves **54**, **56**, with the result that the extruded balls will be free to pass through other smaller restrictions located in the string below the tool **30**.

**[0146]** Reference is now made to FIGS. **12** through **14** of the drawings, which illustrate a bypass tool **100** in accordance with a further embodiment of the present invention. This tool **100** features a tool body **102** which is substantially the same as the tool body **32** of the first described embodiment. However, the tool **100** is initially only provided with a single sleeve **104** for closing the side ports **106**. As illustrated in FIG. **12**, the sleeve **104** is initially restrained to close the ports **106** by a shear pin **108**, while axial movement of the sleeve **104** is controlled by a further pin **110** which engages an axially extending slot **112** in the outer surface of the sleeve **104**.

**[0147]** The outer surface of the sleeve **104** also features three sets of seals **114**, **115**, **116**, and the lowermost sets of seals **114**, **115** initially straddle the ports **106**. The sleeve **104** also defines a pair of holes **118** located between the seals **115**, **116**.

**[0148]** The internal surface of the sleeve **104** features two tapered seats **120**, **121**, one seat **120** located below the holes

118, and a slightly larger seat 121 being provided above the holes 118. The internal diameter of the sleeve 104 adjacent the seats 120, 121 is turned to a very tight tolerance.

[0149] If it is desired to open the tool 100, to allow flow through the ports 106, an extrudable ball 122 is pumped through the string to land on the lower seat 120. Further pressure will cause the pin 108 to shear allowing the sleeve 104 to move axially downwards and to align the holes 118 with the ports 106, as illustrated in FIG. 13. In this configuration the tool 100 provides 100% bypass, that is all of the fluid being pumped into the string passes through the ports 106.

[0150] When it is desired to close the ports 106, an actuating sleeve 124 is pumped down the string from surface, at relatively high speed, to land on the seats 120, 121, with the sleeve 124 straddling the holes 118 and ports 106. A metal-to-metal seal is provided between the outer diameter of the sleeve 124 and the inner diameter of the sleeve 104 at the seats 120, 121 and at surfaces 126, 127 directly below the seats. The surfaces 126, 127 are dimensioned such that the actuating sleeve 124 forms an interference fit with the valve sleeve 104, effecting a seal and ensuring that the sleeve 124 remains fixed within the sleeve 104.

[0151] The actuating sleeve 124 includes an internal nozzle 128 to facilitate pumping of the sleeve 124 through the string and into engagement with the sleeve 104. However, the nozzle 128 is formed of a soft metal, and so is washed away in due course to minimise the restriction presented by the tool and to enlarge the area of the axial flow path through the sleeve 104.

[0152] Reference is now made to FIGS. 15 through 19 of the drawings which illustrate a bypass tool 200 which is similar to the bypass tool 100 described above, but for the provision of an internal groove 201 at the upper end of the sleeve 204. The tool 200 is initially opened in a similar manner to the tool 100, that is by pumping an extrudable ball 222 into the sleeve 204 to land on the lower seat 220 beneath the holes 218, such that pressure may be utilised to shear the pin 208, and push the sleeve 204 downwardly to align the holes 218 with the ports 206, as illustrated in FIG. 16.

[0153] However, the actuating sleeve 224 (FIG. 17), as utilised in this embodiment, differs in a number of respects from the sleeve 124. In particular, the sleeve 224 is significantly longer than the sleeve 124, the sleeve 224 featuring flexible fins 230 and an internal rupture disc 232 to allow the sleeve 224 to be pumped through the string at any hole angle. The sleeve 224 also features two pa irs of external seals 234, 235 and a lock ring 236.

[0154] FIG. 17 shows the sleeve 224 at the point where the lower end of the sleeve 224 engages the actuating ball 222. At this point the first of the larger set of seals 235*a* has mated with a corresponding sealing surface 238 on the inner surface of the sleeve 204, such that all of the pressure applied above the sleeve 224, and thus all of the resulting pressure force acting on the sleeve 224, is pushing on the ball 222. At a given pressure, the ball 222 will be forced through the seat 220.

[0155] Once the ball 222 has been dislodged from the seat 220, the sleeve 224 may move further down into the sleeve 204, as illustrated in FIG. 18. In this configuration both sets of seals 234, 235 are seated, preventing flow to the ports 206, and the lock ring 236 has engaged with the groove 201 in the sleeve 204.

[0156] At this stage flow through the tool 200 and sleeve 204 is still blocked by the burst disc 232, however any further increase in pressure will burst the disc 232.

[0157] The tool configuration after the burst disc 232 has been removed is as illustrated in FIG. 19, where it will be seen that the axial flow path through the sleeve 204 has been re-established.

[0158] Reference is now made to FIGS. 20 through 26, which illustrate a bypass tool 300 in accordance with a yet further embodiment of the present invention. The tool 300 comprises a tubular body 302 defining radial flow ports 304 which are initially closed by a lower sleeve 306 which operates in conjunction with an upper sleeve 308. The lower sleeve 306 differs from the sleeve 54 described above in that the sleeve seat 310 is provided on an inner sleeve part 312 which is spring-mounted to the lower sleeve 306.

[0159] Furthermore, rather than providing taper faces 66, 67, the sleeves 306, 308 feature parallel interference fit faces 314, 315.

[0160] It will also be noted that the flow ports 304 are not nozzled and are of relatively large cross-sectional area, to minimise the pressure drop in fluid passing through the ports 304.

[0161] To first open the ports 304, a neutral weight actuating sleeve 316, somewhat similar to the sleeves 74, 76, is dropped into the string and pumped through the string to land on the sprung seat sleeve part 312. Initially, the seat sleeve part 312 will be moved downwardly, under the influence of fluid pressure acting across the activating sleeve 316, to compress the spring 318 until opposing shoulders 320, 321 on the sleeve parts 306, 312 engage, as illustrated in FIG. 21.

[0162] A further increase in pressure will shear a lower sleeve retaining pin 322 and allow the upper end of the lower sleeve 306 to move clear of the ports 304. This relieves the pressure and 100% of the fluid flow into the string is now being bypassed through the ports 304. Given the release of pressure, the spring 318 will return the seat sleeve 312 to its initial position, as illustrated in FIG. 22.

[0163] To close the ports 304 a further activating sleeve 324 is pumped down the string towards the tool 300, the sleeve 324 being illustrated as it engages a seat 326 on the upper sleeve 308 in FIG. 23. The sleeve 324 features wiper fins 328 and a rupture disc 330 to facilitate pumping of the sleeve 324 through the string in holes of any angle. It will be noted from FIG. 23 that the sleeve 324 has a tapered nose profile 332 which engages with the sleeve seat profile 326 and thus effectively seals the body through bore when the sleeve 324 lands on the sleeve 308.

[0164] The sleeve 324 also features a hard ceramic plate 334 at the sleeve upper end. The plate 334 defines six holes which are spaced at 60° intervals around the centre of the plate.

[0165] Applying pressure above the sleeve 324 creates a pressure force on the sleeve 308 which is sufficient to shear the sleeve-retaining pin 336, allowing the upper sleeve to move downwardly into engagement with the lower sleeve 306, as illustrated in FIG. 24.

[0166] The pressure force applied to the valve sleeve 308 by virtue of the presence of the actuating sleeve 324 being in sealing engagement with the sleeve 308 results in the upper and lower sleeves 308, 306 mating together with an interference fit, which both seals and locks the two sleeves 306, 308 together. However, in the absence of the spring-loaded lower seat 310, there would be a possibility that pressure could be locked between the two actuating sleeves **316**, **324** once the ports **304** were closed-off. With this in mind, it will be noted that the travel of the spring **318** is longer than the axial extent of the metal faces **314**, **315**. This allows all, or substantially all, of the pressure acting on the actuating sleeve **324** to exert force and energise the seal between the faces **314**, **315**. This arrangement also allows all of the pressure to be exerted on the upper rupture disc **330**.

**[0167]** Accordingly, a sufficient increase in pressure will cause the upper rupture disc **330** to burst, as illustrated in FIG. **25**. The fluid pressure above the tool **300** is now acting across the first actuating sleeve **316** and will push the seat sleeve **312** downwardly onto the shoulders **320**, **321** once more. On the shoulders **320**, **321** engaging the pressure is exerted on the burst disc **338** at the upper end of the activating sleeve **316**.

**[0168]** A further increase in pressure will blowout the burst disc **338** and the plastic bung **340** provided at the lower end of the sleeve **316**, following which the spring **318** will extend once more, such that the tool **300** assumes the configuration as illustrated in FIG. **26**.

**[0169]** Although the apertured plate **334** provided in the activating sleeve **324** remains in place, the restriction provided by the plate **334** is useful in that it creates a pressure force to maintain the sleeves **306**, **308** in the closed position, and ensures that the metal-to-metal seal provided by the faces **314**, **315** is retained. Of course, like the other embodiments described above, the flow of fluid through the closed tool **300** is confined to the throughbore defined by the sleeves **306**, **308**.

**[0170]** Reference is now made to FIGS. **27** to **30** of the drawings, which are sectional views illustrating a reverse circulation actuated bypass tool **400** in accordance with an alternative embodiment of the present invention. The tool is intended to be incorporated in a drill string, but other embodiments of this aspect of the invention may be provided in clean-out strings and other strings, such as strings of casing, or indeed coiled tubing or other tubing forms.

**[0171]** The tool **400** comprises a tubular body **402** defining side ports **404** which are normally closed by a spring-biased valve sleeve **406**. A cam slot **408** formed in the outer surface of the sleeve **406** and body-mounted follower pins **410** cooperate to control axial movement of the sleeve **406** relative to the body **402**. The sleeve **406** includes a spring-mounted flapper **412** biased towards the closed position. However, the flapper-closing spring is a light spring, such that the flapper **412** will open in response to normal flow through the tool **400**, as illustrated in FIG. **27**.

**[0172]** In this initial configuration, it will be apparent that variations in flow through the tool **400** will have no effect on the tool configuration, other than to open the flapper **412**.

**[0173]** To open the ports **404**, the direction of fluid circulation in the bore is reversed. That is, fluid is pumped into the annulus surrounding the string in which the tool **400** is incorporated and allowed to flow upwardly though the string. Such flow will maintain the flapper **412** closed and create a significant fluid pressure force, as the piston area created by the flapper **412** equals the internal area defined by the bore internal diameter. This force will cause the sleeve **406** to be translated upwards, to open the ports **404**, as illustrated in FIG. **28**.

**[0174]** If the pumps are then shut off, and pressure bled off from the annulus, the spring **414** will move the sleeve **406** downward, however the cam slot **408** configuration is such that downward movement of the sleeve **406** is arrested before the sleeve **406** can close the ports **404**, as illustrated in FIG. **29**. With the sleeve **406** in this position, normal flow may be re-established, with a proportion of the flow being directed directly into the annulus, via the open ports **404**. As was the case with the initial tool configuration, variations in flow in the normal direction will have no impact on the tool configuration.

**[0175]** To close the ports **404**, reverse flow is once more utilised to move the sleeve **406** upwards, and advance the pins **410** along the slot **408**, to the position as illustrated in FIG. **30**. When the pumps are shut off, and pressure bled off from the annulus, the spring **414** will return the sleeve **406** to the closed position.

**[0176]** It will be apparent that the tool configuration does not change in response to variations in fluid flow through the string when fluid is being circulated normally, such that an operator may, for example, shut off and restart the pumps without concern that the tool may move to the open configuration. Also, the tool is thus not subject to unnecessary activation, and the tool components, such as seals, will not experience undue wear. Furthermore, as tool actuation does not require provision of a restriction which will provide an actuating force in response to normal fluid flow, there is no restriction present in the tool that would otherwise limit flow and induce pressure losses.

**[0177]** Referring now to FIG. **31**, there is shown an enlarged view of an alternative sealing arrangement **420** according to another embodiment of the present invention. The sealing arrangement **420** is suitable for, for example, sealing the ports **404** of the bypass tool **400** shown in FIG. **27**.

**[0178]** The sealing arrangement **420** comprises a tough insert **422** in two parts; a first insert part **424** and a second insert part **426**. The tough insert **422** incorporates an o-ring seal **428**, which provides a seal between the insert **422** and the tool body **402**, and a dove-tail seal **430**, which is held in position by the first and second insert parts **424**, **426**.

**[0179]** The differential piston effect will, in normal use with higher pressure inside the tool **400** than outside it, press an end surface **432** of the valve sleeve **406** against the surface **434** of the insert **422** forming the primary seal. The dove-tail seal **430** also seals against the end surface **432**, but this is a back up seal. A dove-tail seal is used in this embodiment rather than, for example, an o-ring because the dove-tail seal **430** will be retained securely in place when not in contact with the valve sleeve **406**. If the pressure on the outside of the tool **400** is greater than the pressure inside it, neither the differential piston effect nor the dove-tail seal **430** will prevent fluid passing through the ports **404** from the annulus and into the tool **400**.

**[0180]** Referring now to FIG. **32**, there is shown an enlarged view of a further alternative sealing arrangement **440** according to another embodiment of the present invention. This arrangement is substantially the same as the seal arrangement **420** of FIG. **31**, however in this case an additional o-ring seal **442** is provided. The o-ring seal **442** seals the interface between the valve sleeve **406** and the tool body **402** in both directions, that is when the pressure is higher inside the tool **400** than outside or vice versa. Should this seal **442** fail, the differential piston effect would create a seal between the valve sleeve **406** and the insert **422** when the fluid pressure inside the tool **400** is greater than the fluid pressure outside, as previously described.

**[0181]** Referring now to FIG. **33**, there is shown an enlarged view of a further alternative sealing arrangement **460** according to another embodiment of the present invention. In this arrangement, the insert dove-tail seal **462** is considerably larger the equivalent seal **430** of FIG. **31** and extends proud of the insert surface **434**. In this arrangement, an opposing second dove-tail seal **464** is provided in the valve sleeve end face **432** and extends proud of the face **432**. The dove tail seals **462**, **464** are made from an elastomeric material which is hard enough to resist compression and prevent the opposing surfaces **432**, **434** touching under the differential piston effect.

**[0182]** Turning now to FIGS. **34** and **35**, which are sectional views illustrating a reverse circulation actuated bypass tool **500** in accordance with an alternative embodiment of the present invention. The tool **500** is intended to be incorporated in a drill string, but other embodiments of this aspect of the invention may be provided in clean-out strings and other strings.

**[0183]** The tool **500** comprises a tubular body **502** defining side ports **504** which are normally closed by a spring-biased valve sleeve **506**. A cam slot **508** formed in the outer surface of the sleeve **506** and body-mounted follower pins **510** cooperate to control axial movement of the sleeve **506** relative to the body **502**. The sleeve **506** includes a spring-mounted flapper **512** normally-biased towards the closed position. However, the flapper-closing spring is a light spring, such that the flapper **512** will open in response to normal flow through the tool **500**.

**[0184]** The operation of the tool **500** is largely the same as for tool **400**, as discussed in connection with FIGS. **27** to **30**. It will be noted, however, that the valve sleeve **506** includes an end portion **520** defining a flow aperture **522**. When the ports **504** are open, as shown in FIG. **34**, the aperture **522** is pressed against, and sealed closed by, the saver sub **524**, therefore providing 100% bypass through the ports **504**.

**[0185]** When the ports **504** are closed, as shown in FIG. **35**, the sleeve end portion **520** has disengaged from the saver sub **524** and flow through the tool **500** can pass through the flow aperture **522**.

**[0186]** An alternative arrangement which permits 100% bypass through the flow ports is shown in FIGS. **36** and **37**, which are sectional views illustrating a reverse circulation actuated bypass tool **600** in accordance with an alternative embodiment of the present invention. The tool **600** is similar to the tool **500** of FIGS. **34** and **35** and similar components have been given the same reference numeral with the addition of 100.

**[0187]** In this case the valve sleeve **606** is provided with an internal collar **640** which defines a flow aperture **642** (most clearly seen on FIG. **37**). The tool further includes an aperture plug **644**. When the flow ports **604** are open (as shown in FIG. **36**), 100% bypass through the ports **604** is established by the flow aperture **642** being sealed by the aperture plug **644**. This embodiment also offers the advantage that aperture plug **644** eliminates the sump below the ports which is present in the tool **500**. This is particularly advantageous when the tool **600** is used in an application in which lost circulation material (LCM) is passed through the ports **604**. When the ports **604** are subsequently closed and normal fluid circulation reinstated, there is no sump of LCM which would otherwise be circulated through the string below the tool **600**, and potentially plug or damage devices below the tool **600**.

**[0188]** When the flow ports are closed (FIG. **37**) the internal collar **640** has disengaged from the plug **644** permitting flow through the aperture **642** and around the sides of the plug **644**.

**[0189]** A further alternative arrangement which permits 100% bypass through the flow ports is shown in FIGS. **38** and **39**, which are sectional views illustrating a reverse circulation actuated bypass tool **700** in accordance with an alternative embodiment of the present invention. The tool **700** is similar to the tool **500** of FIGS. **34** and **35** and similar components have been given the same reference numeral with the addition of 200.

**[0190]** In this arrangement, the valve sleeve **706** includes a further flapper valve **760**, which is spring biased to the tool throughbore **762** open position shown in FIG. **39**. In the configuration shown in FIG. **39**, the flow ports **704** are closed and fluid flowing through the tool **700** passes through the flapper valve **760**, as well as the normally closed flapper valve **780**. To open the ports **704**, a reverse pressure is applied to the tool **700** and acts on the piston area formed by the valve sleeve **706** and the closed valve **780**. Thus, the valve sleeve **706** is moved upwards and the pin **710** advances along the cam profile **708**. When pressure is bled off from the annulus, and as pressure equalises across the valve **780**, the cam profile **708** and pin **710** interaction permits the sleeve **706** to move fully downwards towards the saver sub **724**. The flapper valve **760** includes a chamfered edge **766** which engages the saver sub **724**. The engagement deflects the flapper valve **760** towards the valve closed position.

**[0191]** Continued movement of the valve sleeve **706** towards the saver sub **724** opens the ports **704** (FIG. **38**). In this configuration, the flapper valve edge **766** has formed a circumferential seal with a seat **768** defined by the saver sub **724** and 100% bypass is established through the flow ports **704**.

**[0192]** This arrangement does create a sump below the ports **704**, however the arrangement offers the advantage of an unobstructed through bore when the flapper valves are open.

**[0193]** Those of skill in the art will recognise that the particular embodiments of the invention described herein are merely exemplary of the various aspects of the present invention, and that various modifications and improvements may be made thereto without departing from the present invention. For example, reference has been primarily made herein to bypass tools. However, many features of the invention have application in other tools, for example spotting tools or bore cleaning tools.

**[0194]** Furthermore, in the embodiments of the reverse flow or pressure actuated tool, for example as shown in FIGS. **27** to **30**, it may be desirable to permit the tubular to which the reverse actuated bypass tool is fitted to self-fill as the tool and the tubular are run-in to the hole. To facilitate this, an additional sleeve could be provided to hold the flapper valve in the open position as the tubular and the tool are run in. This additional sleeve could be deactivated from restricting the flapper valve by the initial flow of fluid in the tool.

**[0195]** Embodiments of the invention also relate to tools which do not provide for fluid bypass. For example, a tool similar to the tool **700** may be provided without bypass ports **704**, and may be operated solely to open and close the string through bore, or control flow through other devices or tools, such as motors or MWD apparatus. Such tools may be useful to permit pressure to be built up above the tool to, for example, test the integrity of a string of jointed pipe, or to activate another tool or device. Indeed, tools in accordance with other embodiments of the present invention need not necessarily be utilised in flow control applications, and may utilise reverse pressure to provide actuation, control or activation of any downhole tool or device. Reference is now made to FIGS. **40** to **44** of the drawings, which illustrate a reverse pressure actuated bypass tool **800** in accordance with a further embodiment of the present invention. Reference is initially made to FIG. **40**, which illustrates the tool **800** in a dormant state, with the spring-biased valve sleeve **806** extending across and sealing two sets of ports **804***a*, **804***b* in the tool body wall **802**. The upper ports **804***a* are nozzled, while the lower ports **804***b* define a relatively large area unobstructed flow path. This arrangement allows the nozzles in the ports **804***a* to be replaced without dismantling the tool **800**, but in other embodiments two sets of ports could be provided in the sleeve **806** and a single set of ports provided in the body. The axial movement of the valve sleeve **806** is controlled by the interaction between a cam or j-slot **808** interacting with body-mounted cam pins **810**. The cam arrangement provides for three different downward positions for the sleeve **806**, as will be described. FIG. **40** illustrates the sleeve **806** in the first downward position, in which the ports **804***a*, **804***b* are closed.

**[0196]** The lower end of the tool **800** includes a catcher ring **880** with additional flow paths **882** around the large central through bore **884**.

**[0197]** The tool **800** is intended to be incorporated in a tubular string and is run into a bore with the string in the dormant configuration as illustrated in FIG. **40**. In this configuration, changes in fluid flow through the string and annulus, and changes in pressure in the string and annulus, will have no impact on the tool **800**. Thus, during run in and in subsequent operations the operators may effectively ignore the presence of the tool **800** in the string.

**[0198]** When it is desired to configure the tool **800** ready for actuation, a flow diverter **844** and a non return valve (NRV) **812** are dropped or pumped down the string to land in the tool **800**, as illustrated in FIG. **41**. The leading end of the diverter **844** lands in the catcher ring **880**, and initially allows fluid to continue to flow through the tool **800** to the portion of the string below the tool **800**, via the flow paths **882** in the catcher ring and via side slots **886** in a tubular portion of the diverter **844** which allow fluid to flow into and through the central through bore **884**.

**[0199]** The NRV **812** features a tapered body **812***a* having radially extending keys **812***b* adapted to engage with a sleeve profile **806***a*. A circumferential seal member **812***c* on the body **812***a* is adapted to engage the sleeve internal diameter below the profile **806***a*. The NRV body **812***a* defines a flow passage **812***d* which is normally closed by a spring-biased ball **812***e*. However, in the presence of a pressure differential across the NRV **812** as induced by normal flow, that is flow from surface down through the string, the ball **812***e* is pushed downwards to open the passage **812***d*. In the absence of flow the ball **812***e* will close that passage **812***d*, and such an NRV will typically withstand a reverse pressure of up to 5000 psi.

**[0200]** Both the NRV **812** and the flow diverter **844** are retrievable, for example utilising wireline mounted fishing tools, if considered necessary or desirable.

**[0201]** On the bore containing the string being subject to a reverse pressure, that is the pressure in the annulus surrounding the string being higher than the pressure within the string, the tool **800** is reconfigured to the position as illustrated in FIG. **42**. In a drill string, the reverse pressure may be communicated via, for example, the jetting nozzles on the drill bit. Thus, at this stage, the pressure integrity of the string is retained. Also, there is no danger of drill cuttings and the like flowing into the tool **800** and thus into the string above tools and devices which may be sensitive to blockage and damage by cuttings and larger particulates, such as MWD tools. Also, only a very small volume of fluid need pass from the annulus into the drill string to effect actuation of the tool **800**. If considered appropriate or desirable, it is of course possible for the operator to circulate fluid through the string for a period without drilling, to ensure that the annulus adjacent the drill bit is substantially free of cuttings and other debris.

**[0202]** The reverse pressure maintains the ball in position to close the NRV **812**, and the reverse pressure, acting over the whole area of the tool internal diameter D, moves the valve sleeve **806** upwardly, against the action of the spring **806***b*. Due to the large area of the piston created by the NRV **812** and the sleeve **806**, only a relatively small reverse pressure will provide a very significant pressure force on the sleeve **806**, and such that jamming or sticking of the sleeve is unlikely. The upward movement of the sleeve **806** also rotates the sleeve **806**, due to the interaction between the cam slot **808** and the follower pins **810**.

**[0203]** When the pressure between the annulus and the string interior is equalised, the sleeve spring **806***b* pushes the sleeve **806** downwards. The cam slot **808** and follower pins **810** are now configured such that the sleeve **806** may move fully downwards to the second downward position, to open the ports **804***b*, as illustrated in FIG. **43**. As the opening of the ports **804** occurs when the pressure is equalised across the tool body, there is no rush of fluid through the ports **804**, as tends to be the case with conventional fluid pressure actuated tools. Thus, there is no corresponding erosion of the areas around the ports or tendency for seals to be washed out.

**[0204]** The sleeve defines flow ports **806***c* positioned to be aligned with the body flow ports **804***b* when the sleeve **806** is in the second downward position. In this position the lower end of the sleeve **806** also extends over the flow diverter **844**, which closes the end of the sleeve **806**, thus preventing fluid passage from the tool **800** into the string below the tool **800**.

**[0205]** If the drilling fluid pumps are restarted, fluid will flow into the tool **800**, through the NRV **812**, and then into the annulus via the aligned ports **806***c*, **804***b*. Changes in flow rate or pump pressure will not affect the tool configuration, other than that the NRV **812** will close when there is no flow.

**[0206]** As the ports **806***c*, **804***b* provide a relatively unobstructed flow path, high fluid flow rates are possible, which are useful in bore clean-out operations. Also, the prevention of flow beyond the tool **800**, and the absence of a sump below the ports, makes this configuration ideal for delivering LCM to the bore.

**[0207]** To change the configuration of the tool **800** once more, a reverse pressure is created, and the pressure then equalised. This moves the sleeve **806** upwards and then downwards, under the control of the cam slot **808** and pins **810**, to the third downward position, as illustrated in FIG. **44**. It will be noted that in the third downward position the sleeve **806** is not positioned as far downwards as in the second downward position, and an annulus is retained between the larger internal diameter lower end of the sleeve **806** and the upper end of the flow diverter **844**. Thus, a flow path is maintained through the tool **800**. It will also be noted that in this configuration the sleeve ports **806***c* are aligned with the nozzled body flow ports **804***a*.

**[0208]** When the pumps are restarted on surface, fluid will flow downwardly through the string, and on reaching the tool

**800** a proportion of the flow will be diverted through the flow ports **804***a*, the remainder of the flow passing into the string below the tool **800**. This tool configuration may be detected from surface by monitoring the back pressure of the drilling fluid; this will be greater than the back pressure produced by the sleeve in the second downward position. In drilling applications this configuration is thus useful situations in which it is desired that a proportion of the fluid being pumped into the string bypasses the BHA, and passes directly into the annulus. The division of flow will vary depending on a number of factors, including the degree of flow restriction provided by the nozzles in the ports **804***a*, and the flow area of the nozzles may be selected as desired.

**[0209]** To close the ports **804***a*, flow through the string and tool is stopped, a reverse pressure is applied, and pressure is then balanced between the annulus and the string bore, such that the sleeve may move upwards and then downwards and return to the first downward position.

**[0210]** The tool **800** is thus capable of adopting a selected one of three working configurations. In some applications the operator may only wish to utilise two configurations, and in this case the pressure may be cycled twice such that there is no conventional flow while the tool **800** is in an intermediate configuration.

**[0211]** Reference is now made to FIGS. **45** and **46** of the drawings, which illustrate an alternative actuation arrangement for the tool **800** of FIG. **40**. In particular, these figures illustrate an alternative non-return valve (NRV) **912**, comprising a valve body in the form of a sleeve **912***a*, which sleeve **912***a* is pinned to the sleeve **806**, and also supported by a sleeve shoulder **806***f*. Thus, the sleeve **912***a* is present in the tool **800** as the tool is run into the bore. However, the sleeve **912***a* features a fishing profile, to allow the sleeve **912***a* to be utilised to move the sleeve **806** to actuate the tool **800**, and to allow the sleeve **912***a* to be removed from the sleeve **806** if necessary.

**[0212]** To activate the tool **800**, a ball **912***b* is pumped down the string to land in the sleeve **912***a*, as illustrated in FIG. **45**. The sleeve **912***a* comprises two ball seats **912***c*, **912***d*, the upper seat **912***c* being flexible such that an elevated pressure will push the ball **912***b* past the seat **912***c* to land on the lower seat **912***d*. Flow slots **912***e* are provided between the seats **912***c,d*, such that fluid may flow through the **800** tool in the conventional manner with the ball **912***b* in place within the sleeve **912***a*. However, in the event of reverse circulation, the ball **912***b* is lifted into contact with the lower face of the upper ball seat **912***c*. A relatively small reverse pressure will cause the sleeve **806** to move upwards, allowing cycling of the tool **800**, and selective opening of the flow ports **804***a,b*.

**[0213]** A larger reverse pressure will extrude the ball **912***b* past the flexible upper seat **912***c*, allowing unhindered reverse circulation if required. Alternatively, as noted above, the sleeve **912***a* and ball **912***b* may be fished from the tool **800**, this also providing unhindered access to the string below the tool **800** to permit, for example, fishing operations below the tool **800**.

**[0214]** Reference is now made to FIG. **47** of the drawings, which illustrates a reverse circulation actuated tool **1000**. The tool **1000** comprises a fluid transmitting body **1002** incorporated in a drill string **1004**. Mounted within the body **1002** are an actuation arrangement **1006** and a flow restriction in the form of a non-return valve **1008**, located just above a drill bit **1010**. The actuation arrangement **1006** includes a differential piston.

**[0215]** In normal drilling operations drilling fluid is pumped from surface through the string bore **1012**, exiting the string via jetting nozzles in the bit **1010**. The fluid then passes to the surface via the annulus **1014** between the string **1004** and the surrounding bore wall **1016**.

**[0216]** With this conventional fluid circulation, the fluid pressure within the string **1004** is higher than the fluid pressure in the annulus **1014**.

**[0217]** The differential piston is configured such that normal fluid circulation tends to maintain the tool **1000** in a first configuration. To reconfigure the tool the operator reverses the pressure differential between the string **1004** and the annulus **1014**. This may be achieved by stopping the pumps on surface such that the pressure equalises, then draining drilling fluid from the upper end of the string as described above. When the air filled upper portion of the string is lowered into the bore, the taller column of drilling fluid in the annulus **1014** results in a higher hydrostatic pressure in the annulus **1014** adjacent the tool **1000**. The pressure imbalance induces fluid flow from the annulus **1014** into the string **1004** and thus closes the valve **1008**, which maintains the reverse pressure differential.

**[0218]** This reverse pressure differential acts on the differential piston in the actuating arrangement **1006** to reconfigure the tool **1000**.

**[0219]** If the string **1004** is then top-filled the pressure is equalised between the string bore **1012**, and the annulus **1014**.

**[0220]** It will be noted that in this embodiment there is no mechanical linkage between the valve **1008** and the actuating arrangement **1006**, the valve **1008** serving only to block reverse flow and thus allow maintenance of the reverse pressure differential.

**[0221]** In another embodiment, the blow-out preventer (BOP) at surface could be closed to seal the annulus which could then be pressurised. This method would be particularly well suited for use in a fully-cased well, where pressure may be applied without the risk of damaging the formation.

**1-160**. (canceled)

**161**. A method of actuating a tool in a downhole string, the method comprising utilising a flow restriction in a downhole tubing string, which restriction provides less restriction to fluid flow from the string and into a surrounding annulus than to fluid flow from the annulus into the string, to selectively induce a positive fluid pressure differential between the annulus and the string to permit actuation of the tool.

**162**. The method of claim **161**, further comprising:
- providing a fluid column in the string;
- providing a fluid column in an annulus surrounding the string;
- creating a hydrostatic pressure differential between the fluid columns; and
- utilising the hydrostatic pressure differential to actuate the tool.

**163**. The method of claim **162**, comprising filling a portion of the string with lower density fluid.

**164**. The method of claim **163**, comprising filling an upper portion of the string with gas.

**165**. The method of claim **163**, comprising raising an upper portion of the string from the bore, draining liquid from the upper portion of the string, and then lowering the lower density fluid-filled upper portion of the string into the bore.

**166**. The method of claim **161**, comprising pumping fluid into an annulus surrounding the string.

**167**. The method of claim **161**, comprising applying a reverse pressure to a differential piston adapted to apply an actuating force in response to a positive pressure differential between the annulus and the string.

**168**. The method of claim **161**, comprising one of dropping and pumping at least a part of the flow restriction into the string.

**169**. The method of claim **161**, comprising removing at least a part of the flow restriction from the string.

**170**. The method of claim **161**, comprising providing a non-return valve in the tool.

**171**. The method of claim **170**, comprising top-filling the string to equalise the fluid pressure differential.

**172**. The method of claim **161**, comprising cycling the tool between different configurations.

**173**. The method of claim **161**, comprising utilising a cam arrangement to control movement of elements of the tool.

**174**. The method of claim **161**, comprising releasably retaining the tool in an initial configuration.

**175**. The method of claim **161**, comprising biasing elements of the tool to resiliently resist forces created by a positive fluid pressure differential between the annulus and the string.

**176**. The method of claim **161**, comprising initially configuring the tool in a dormant configuration.

**177**. The method of claim **176**, comprising utilising at least one cycle of a positive fluid pressure differential between the annulus and string followed by an equalised fluid pressure differential to actuate the tool.

**178**. The method of claim **161**, comprising configuring a valve member to open a side port in the string.

**179**. The method of claim **178**, comprising opening the side port following equalisation of the fluid pressure differential.

**180**. The method of claim **161**, comprising configuring a valve member to close a side port in the string.

**181**. The method of claim **161**, comprising actuating a valve member controlling opening and closing of a side port in the string by application of a positive fluid pressure differential between the annulus and the string.

**182**. The method of claim **161**, comprising controlling flow of fluid into the string below a valved side port.

**183**. The method of claim **161**, comprising selectively configuring a valve member in a first open configuration to open a first side flow passage and in a second open configuration to open a second flow passage.

**184**. The method of claim **161**, comprising operatively associating a valve member controlling opening and closing of a side port in the string with a flow control arrangement to control flow of fluid into the string below the tool.

**185**. The method of claim **184**, comprising flowing fluid through a first side port and simultaneously preventing flow of fluid into the string beyond the tool.

**186**. The method of claim **185**, comprising flowing fluid through a second side port and simultaneously flowing fluid into the string beyond the tool.

**187**. The method of claim **161**, comprising preventing flow of fluid into a string below the tool.

**188**. The method of claim **161**, comprising opening a side flow passage in the tool to provide fluid bypass.

**189**. The method of claim **161**, comprising opening a side flow passage in the tool and delivering fluid to a selected portion of a bore.

**190**. The method of claim **161**, wherein the string is a drill string.

**191**. A downhole tool for mounting on a tubular support string and for location in a bore whereby the interior of the string and a surrounding annulus are in fluid communication and whereby fluid may flow in a first direction from the interior of the string into the annulus, the tool comprising:

a fluid-transmitting body; and

a tool function assembly including an actuation arrangement adapted for actuation in response to selective application of a positive differential pressure between the annulus and the string,

the tool being adapted to follow an actuation cycle, the tool having one configuration when fluid is initially flowing in the first direction and a different configuration after flow in the first direction has been re-established following application of said positive differential pressure.

**192**. The tool of claim **191**, wherein the tool function assembly includes a flow restriction which provides less restriction to fluid flow from the string into a surrounding annulus than to fluid flow from the annulus into the string.

**193**. The tool of claim **191**, wherein flow restriction substantially prevents flow from the annulus into the string.

**194**. The tool of claim **191**, wherein the tool is configurable such that variations in flow in the first direction do not affect the tool configuration.

**195**. The tool of claim **192**, wherein the flow restriction is provided below and spaced from the actuation arrangement.

**196**. The tool of claim **192**, wherein the flow restriction is operatively associated with the actuation arrangement.

**197**. The tool of claim **191**, wherein the actuation arrangement includes a differential piston adapted to apply an actuating force in response to a pressure differential between the annulus and the string.

**198**. The tool of claim **191**, wherein the actuation arrangement is configured such that a reverse pressure directly actuates the tool.

**199**. The tool of claim **191**, wherein the actuation arrangement is configured such that a positive differential pressure between the annulus and the string reconfigures the tool.

**200**. The tool of claim **199**, wherein the actuation arrangement is adapted such that, following reconfiguring of the tool, a reduction of the pressure differential allows the tool be at least one of actuated and assume a desired operating configuration.

**201**. The tool of claim **192**, wherein the flow restriction is normally closed.

**202**. The tool of claim **192**, wherein the flow restriction closes in response to flow from the annulus into the string.

**203**. The tool of claim **192**, wherein the flow restriction tends towards an open configuration in response to normal flow.

**204**. The tool of claim **192**, wherein, in an open configuration, the flow restriction provides an open through bore.

**205**. The tool of claim **192**, wherein the flow restriction comprises a flapper valve.

**206**. The tool of claim **192**, wherein the flow restriction comprises a non-return valve.

**207**. The tool of claim **191**, wherein the actuation arrangement is adapted to define a piston area responsive to a positive differential pressure between the annulus and the string.

**208**. The tool of claim **207**, wherein the piston area corresponds to an internal diameter of the tool body.

**209**. The tool of claim **192**, wherein the flow restriction is adapted to be configurable to a non-operative configuration.

**210**. The tool of claim **192**, wherein at least an element of the flow restriction is removable.

**211**. The tool of claim **192**, wherein at least an element of the flow restriction is adapted to be dropped or pumped into the tool.

**212**. The tool of claim **191**, wherein the tool is adapted to be cycled at least twice.

**213**. The tool of claim **191**, comprising a cam mechanism adapted to control the movement of elements of the tool.

**214**. The tool of claim **213**, wherein the tool function assembly comprises a pin which follows a cam slot.

**215**. The tool of claim **191**, wherein an element of the tool function assembly is releasably retained in an initial configuration.

**216**. The tool of claim **191**, wherein the tool function assembly comprises a return arrangement adapted to act in opposition to a positive differential pressure between the annulus and the string.

**217**. The tool of claim **216**, wherein the tool function assembly comprises a return spring.

**218**. The tool of claim **191**, wherein the tool is adapted to be initially configured in a dormant configuration and subsequently activated.

**219**. The tool of claim **191**, wherein the body has a side port and a valve member configurable to close the side port.

**220**. The tool of claim **219**, wherein the side port is initially closed.

**221**. The tool of claim **219**, wherein the valve member is adapted to be actuated by a positive differential pressure between the annulus and the string.

**222**. The tool of claim **219**, wherein the tool function assembly includes a flow restriction which provides less restriction to fluid flow from the string into a surrounding annulus than to fluid flow from the annulus into the string and the flow restriction is provided above the side port.

**223**. The tool of claim **219**, wherein a flow control arrangement is provided below the side port.

**224**. The tool of claim **223**, wherein the flow control arrangement is adapted to prevent flow of fluid into a string below the tool.

**225**. The tool of claim **223**, wherein the flow control arrangement is retrievable.

**226**. The tool of claim **223**, wherein the flow control arrangement is adapted to be one of dropped and pumped into the tool.

**227**. The tool of claim **223**, wherein the flow control arrangement is adapted to initially permit flow into the string below the tool.

**228**. The tool of claim **219**, wherein the valve member comprises a sleeve.

**229**. The tool of claim **219**, wherein at least first and second side ports are provided in at least one of the body and the valve member and the valve member is configurable in a first open configuration to open the first side port and a second open configuration to open the second flow port.

**230**. The tool of claim **229**, wherein the first and second side ports define different flow areas.

**231**. The tool of claims **229**, wherein the valve member is operatively associated with a flow control arrangement.

**232**. The tool of claim **231**, wherein the valve member is adapted to cooperate with the flow control arrangement to control flow of fluid into the string below the tool.

**233**. The tool of claim **232**, wherein with the valve member in the first open configuration the flow control arrangement prevents flow beyond the tool.

**234**. The tool of claim **232**, wherein with the valve member in the second open configuration the flow control arrangement permits flow beyond the tool.

**235**. A method of actuating a downhole tool, the method comprising:

providing a fluid column in a string;

providing a fluid column in an annulus surrounding the string;

creating a hydrostatic pressure differential between the fluid columns; and

utilising the hydrostatic pressure differential to actuate a downhole tool.

**236**. The method of claim **235**, wherein the hydrostatic pressure is higher in the annulus, to create a reverse pressure differential.

**237**. The method of claim **235**, comprising filling a portion of the string with lower density fluid.

**238**. The method of claim **237**, comprising filling an upper portion of the string with gas.

**239**. The method of claim **238**, comprising raising an upper portion of the string, draining liquid from the upper portion of the string such that the upper portion fills with air, and then lowering the air-filled upper portion of the string into the bore.

**240**. The method of claim **235**, comprising directing compressed gas into the string.

**241**. A downhole tool for mounting on a tubular support string and for location in a bore whereby the interior of the string and a surrounding annulus are in fluid communication and whereby fluid may flow from the interior of the string into the annulus, the tool comprising:

a fluid-transmitting body having a side port and a valve member configurable to close the side port; and

a valve member actuation arrangement having a flow restriction above the side port, which restriction provides less restriction to fluid flow down the string than to fluid flow up the string, the arrangement being adapted for actuation in response to selective application of a positive differential pressure between the annulus and the string,

**242**. A downhole tool comprising:

a fluid-transmitting body and a valve member, one of the body and the valve member defining first and second side ports,

the valve member being configurable in a first open configuration to open the first side port and a second open configuration to open the second flow port.

**243**. A device adapted for location in a downhole tubular to engage a downhole apparatus and permit the creation of an actuating fluid pressure differential, the device defining an erode-able flow restriction.

**244**. A downhole tool comprising:

a fluid transmitting tubular body having an inlet and first and second outlets;

a sleeve defining a throughbore located in the body and initially closing the second outlet, the sleeve being axially moveable in one direction to open the second outlet and then permanently close the second outlet; and

an actuating device adapted to land on the sleeve and cause the sleeve to permanently close the second outlet and wherein, following closure of the second outlet, the actuating device is configurable to permit flow between the inlet and the first outlet through the sleeve, said flow through the sleeve being substantially confined to said sleeve throughbore.

**245**. A method of controlling flow in a downhole tubular comprising a tubular body having an inlet and first and second outlets, the second outlet being initially closed by a sleeve defining a throughbore, the method comprising:

translating the sleeve in a first direction to open the second outlet;

directing fluid from the body inlet through the second outlet;

locating an actuating device in the body and operatively associating the actuating device with the sleeve;

translating the sleeve in said first direction to permanently close the second outlet; and

directing the fluid from the body inlet through the first outlet, the fluid passing through the sleeve and being substantially confined to said sleeve throughbore.

**246**. A downhole tool comprising:

a fluid transmitting tubular body having a first inlet and first and second outlets;

a valve member configurable to close the second outlet; and

a seal arrangement operatively associated with the valve member and comprising first and second sealing surfaces relatively movable from a spaced apart non-sealing configuration to a contacting sealing configuration in which a seal is formed between contacting hard portions of the surfaces.

**247**. A method of controlling fluid flow downhole through a tubular body having an inlet and first and second outlets, the method comprising:

directing fluid from the body inlet through the second outlet; and

translating a valve member to close the second outlet and form a seal between first and second sealing surfaces of a tough material.

**248**. A downhole tool comprising:

a fluid transmitting tubular body having a side port;

a valve member configurable to close the side port; and

a seal arrangement operatively associated with the valve member and comprising first and second sealing surfaces relatively movable from a spaced apart non-sealing configuration to a contacting sealing configuration in which a seal is formed between contacting hard portions of the surfaces.

**249**. A method of controlling fluid flow downhole through a tubular body having a side port, the method comprising:

directing fluid through the side port; and

translating a valve member to close the side port and form a seal between first and second sealing surfaces of a rigid material.

* * * * *