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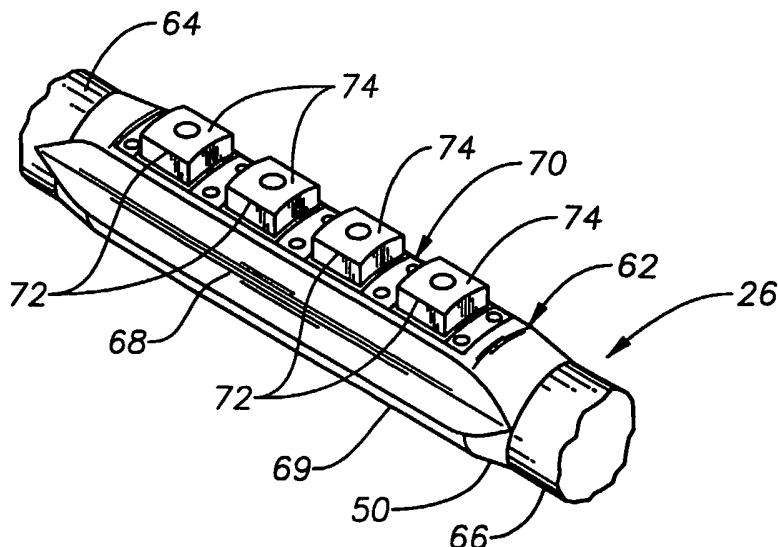
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(54) Title: METHOD AND APPARATUS FOR IN-SITU MEASURING STATIC ROCK MODULI AND STRENGTH



(57) Abstract: An in-situ rock strength measurement tool features a sub that is integrated into a drill string, or other downhole tool string, and lowered into an uncased borehole. The sub includes a plurality of lateral pistons that are selectively extendable in a radial orientation to engage the wall of the borehole. The pistons exert a force against a defined area of the borehole wall and penetrate the borehole across the defined area. The force needed to penetrate the borehole may then be measured and used to calculate rock strength and to determine other formation properties.

METHOD AND APPARATUS FOR IN-SITU MEASURING STATIC ROCK MODULI AND STRENGTH

BACKGROUND OF THE INVENTION**1. Field of the Invention**

[0001] The invention relates generally to devices and methods for determining the
5 strength and moduli of rock formations within a wellbore. More particularly, the
invention relates to devices and methods for making such determinations in-situ.

2. Description of the Related Art

[0002] Subsurface formations encountered in oil and gas drilling are compacted
10 under in situ stresses due to overburden weight, tectonic effects, confinement and pore
pressure. Measurements of static rock moduli and strength during drilling are
necessary to calculate the stability of soil and rock construction and to optimize the
drilling process. As Figure 1 depicts in schematic fashion, rock strength can be
measured by exerting a defined force (F) against a contact area (A) over a measured
15 distance, or way, (I). Rock moduli include Young's modulus and other static rock
moduli (i.e., tangent modulus, average modulus, and secant modulus).

[0003] State of the art uniaxial compressive rock strength is measured using a
confined or, in the majority of cases, unconfined cylindrical rock sample in the
laboratory. These techniques require removal of sample from the earth, by coring or
20 the like, and then transporting the sample to a laboratory or other suitable facility for
testing. This is time consuming. Additionally, the rock sample is subject to being
damaged or deteriorating during the removal process or while enroute to the
laboratory, thereby skewing the results of the testing.

[0004] There are some devices known that endeavor to measure rock strength and
25 formation properties in-situ. These devices employ radially extendable pistons that
engage and penetrate the borehole wall in order to determine rock strength, formation
stress states, and the like. These devices are useful, but have certain problems that

may make them unsuitable in certain situations.

[0005] U.S. Patent No. 4,149,409, issued to Serata discloses a downhole penetrometer device that uses diametrically opposed pistons that extend radially outwardly to engage and penetrate a borehole wall. U.S. Patent No. 5,165,274 issued to Thiercelin describes a downhole penetrometer device that uses a pair of diametrically opposed indenters that also are radially extended to penetrate a borehole wall.

[0006] The use of diametrically opposed pistons creates problems and, therefore, is undesirable. First, smaller penetrations of the borehole wall in two opposing directions in softer formations may result in skewed measurement results. It is also difficult, as a practical matter to construct a device that will effectively operate diametrically opposed pistons as intended by Serata. The space constraints of a borehole make it difficult to house the fluid volume required to urge the two pistons outwardly into and penetrate the formation to a desired depth.

[0007] The Serata device is actuated by hydraulic fluid that is pumped down into the wellbore by a separate, surface-based fluid pump. This arrangement requires additional equipment that is costly to deploy as the hydraulic fluid used for actuation flows into the wellbore via a flexible hose that is disposed between the wellbore casing and the drill string. Large amounts of hydraulic fluid are required for actuation.

[0008] The device described in the Thiercelin patent is typically run in on a wireline. Thus, a downhole pump is used to energize the penetrometer device. A downhole motor in turn, actuates the pump. This arrangement is not optimal for use within a drill string.

[0009] The present invention addresses the problems of the prior art.

SUMMARY OF THE INVENTION

- [0010] The invention provides improved devices and methods for measuring rock strength and formation isotropic properties in situ. An in-situ rock strength measurement tool features a sub that is integrated into a drill string, or other downhole tool string, and lowered into an uncased borehole. The sub includes a plurality of lateral pistons that are selectively extendable in a radial orientation to engage the wall of the borehole. The pistons exert a force against a defined area of the borehole wall and penetrate the borehole across the defined area. The force needed to penetrate the borehole may then be measured and used to calculate rock strength and to determine other formation properties.
- 10 In one currently preferred embodiment, the tool features a set of pistons that are spaced axially apart from one another along an axial line upon the sub body. Thus, when actuated, the force of the pistons is exerted upon a single side of the borehole wall, thereby permitting more accurate measurement of rock strength and other borehole and formation parameters.
- 15 [0011] The pistons of the sub are actuated for radial outward and inward movement hydraulically or electrically and energized by a mud turbine that is contained within the drill string. The mud turbine is powered by flowing drilling mud downward through the drill string. Control of the pistons is preferably surface-based.
- [0012] In other preferred aspects, the tool features radially expanded stabilizer portions with enlarged engagement surfaces for generally centering the tool within the borehole during operation and mud channels defined on the outer surface of the tool to permit drilling mud to move upwardly within the borehole past the tool. This feature permits the tool to be sized so that its outer diameter will be in close proximity to the borehole wall, thereby lessening the distance over which the piston must be moved to engage the
- 20 borehole wall. In one described embodiment, the pistons are provided with a curved
- 25

engagement plate having a roughened engagement surface. A further embodiment of the invention is described wherein the tool body provides three sets of axially aligned pistons that are angularly spaced from one another about the circumference of the tool. The tools of the present invention also perform the desirable function of locking the drill string into
5 place against the borehole wall to secure the drill string against axial and rotational movement.

[0013] In other aspects, embodiments of the invention are described for deploying the pistons radially outwardly into contact with the borehole wall. In one exemplary embodiment, the pistons are actuated into a deployed position using a spindle drive with a
10 sliding shoe. In another exemplary embodiment, pistons are deployed outwardly by a radially expandable inflatable element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The advantages and further aspects of the invention will be readily appreciated by those of ordinary skill in the art as the same becomes better understood
15 by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference characters designate like or similar elements throughout the several figures of the drawing and wherein:

[0015] Figure 1 is a schematic drawing depicting the measurement of rock strength using applied force over a defined area.

20 [0016] Figure 2 is a schematic side view of an exemplary land-based well illustrating use within a borehole of an in-situ rock strength measurement tool constructed in accordance with the present invention.

[0017] Figure 3 is a schematic side view of an exemplary offshore well illustrating use within a borehole of an in-situ rock strength measurement tool constructed in accordance
25 with the present invention.

[0018] Figure 4 is an external, isometric view of an exemplary rock strength measurement tool constructed in accordance with the present invention.

[0019] Figure 4A is an external, isometric view of an alternative rock strength measurement tool depicting arrangement of piston members helically about the axis of the tool.

[0020] Figure 5 is a side, cross-sectional cutaway view of the rock strength measurement tool shown in Figure 4.

[0021] Figure 6 is an axial cross-section taken along lines 6-6 in Figure 4.

[0022] Figure 7A is a cross-sectional view of an alternative embodiment for a rock strength measurement tool constructed in accordance with the present invention.

[0023] Figure 7B is an external, isometric view of a lower side of the tool shown in Figure 7A.

[0024] Figure 8 is a side, cross-sectional cutaway of a further alternative embodiment for a rock strength measurement tool constructed in accordance with the present invention.

[0025] Figure 9 is an enlarged view of a portion of the exterior of the rock strength measurement tool shown in Figure 8, illustrating features of the engagement plate.

[0026] Figure 10 is an exterior view of a further exemplary alternative rock strength measurement tool in accordance with the present invention.

[0027] Figure 11 is a cross-sectional view of a piston assembly for use with the rock strength measurement tools previously depicted.

[0028] Figure 12 is a side view, partially in cross-section, illustrating an exemplary deployment arrangement for a piston assembly utilizing a spindle drive and sliding shoe.

[0029] Figure 13 is a side view of the deployment arrangement depicted in Figure 12 with the piston assembly in the deployed position.

[0030] Figure 14 is a side view, partially in cross-section, depicting an alternative exemplary deployment arrangement incorporating an inflatable element.

[0031] Figure 15 is a side, cross-sectional view of the arrangement shown in Figure 14 with the piston assembly in the deployed position.

5 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

[0032] Figures 2 and 3 depict in schematic fashion two general scenarios for the use of the rock strength measurement tool assemblies described herein. In the first, a land-based hydrocarbon well 10 is depicted wherein a borehole 12 has been drilled through the earth 14 and into a subterranean hydrocarbon formation 16 from a surface based wellhead 18. A drill string 20 is shown disposed within the borehole 12, which is not lined by casing. In the scenario depicted, the drilling operation is ongoing. However, it is desired to test the strength of rock within the formation 16 and to determine other formation parameters. The drill string 20 includes a plurality of standard drill pipe sections, of a type known in the art, that define an axial bore therein for transmission of drilling mud downwardly from the wellhead 18. The lower, or furthest downstream, end of the drill string 20 includes a bottom hole assembly (BHA) 22 having a drill bit thereupon. There may be a measurement-while-drilling (MWD) assembly 24, also of a type known in the art, incorporated into the drill string 20 just above the BHA 22. The drill string 20 may also incorporate centralizers or other known devices, which are well known and, therefore, will not be described in any detail here. A rock strength measurement tool assembly, generally shown at 26, is shown integrated into the drill string 20 above the MWD tool 24. The tool assembly 26 is used to perform in-situ rock strength tests of the formation 16 in a manner that will be described shortly.

[0033] Figure 3 illustrates a drilling scenario wherein an offshore well 30 provides a wellbore 32 that is drilled into the seabed 34 into subterranean formation 36. The drill

string 20 extends downwardly from a floating vessel 38 having a support rig 40 thereupon. The drill string 20 is constructed in essentially the same manner as the drill string 20 described earlier, having a BHA, MWD tool 24 and the rock strength measurement tool assembly 26. It is noted that the drill string 20 of the offshore well 30
5 is subject to movement with respect to the wellbore 32 as a result of wave action. Thus, it is important to be able to lock the drill string securely in position with respect to the wellbore 32 during an in-situ test of the formation 36.

[0034] Referring to Figures 4, 5, and 6, an exemplary embodiment for the rock strength measurement tool assembly 26 is shown. The tool assembly 26 includes a piston tool sub
10 50 and a mud motor sub 52. The piston tool sub 50 has a generally cylindrical tool body 54 that defines an axial bore 56 within and has a pair of axial ends 58, 60. The ends 58, 60 are configured, by threading or the like for attachment to adjacent threaded members. The tool body 54 has a central portion 62 of enlarged diameter and end portions 64, 66 that have a reduced diameter.

[0035] Exterior mud channels 68 are formed into the enlarged portion 62 of the tool
15 body 54. As best shown by Figures 4 and 6, the mud channels 68 are areas of reduced diameter that extend from reduced diameter portion 64 to reduced diameter portion 66 and are sized and shaped to permit drilling mud to pass around the enlarged central portion 62. Additionally, the enlarged portion 62 of the tool body 54 presents an enlarged
20 stabilizer portion 69 with a curved outer surface that will rest against the borehole wall during actuation of the tool assembly 26.

[0036] The central portion 62 of the tool body 54 also presents a piston section 70 that houses four piston members 72. As best seen in Figure 4, the piston members 72 are axially aligned with one another and serve as testing arms for determining rock strength
25 of the formation 16 or 36. It is noted that the piston members 72 are positioned

diametrically across the tool from the stabilizer portion 69 (see Figure 6). Figure 4A illustrates an alternative tool 26' wherein the piston members 72 are arranged helically, rather than axially, upon the body 54.

[0037] Referring once more to Figures 4, 5, and 6, the piston members 72 each present an engagement surface 74 of defined and known area. The piston members 72 are reciprocally mounted within the tool body 54 so that they may be moved between a radially inward position and a radially outward position. Details of the construction and operation of the piston members 72 are best shown in Figure 6, which shows the piston 72 in a radially extended position and Figure 11, which shows a piston 72 in a radially withdrawn position. As seen there, the piston member 72 has an enlarged piston head 76 and a radially reduced insert portion 78 that is secured to the piston head 76 by a threaded connector 80. The piston head 76 is shaped in Figure 6 to present an engagement surface 74 that is convexly curved. Figure 11 illustrates a slightly modified piston head 76a wherein the engagement surface 74a is substantially flat. The insert portion 78 resides within a surrounding piston sleeve 82. A first hydraulic chamber 84 (visible in Figure 6) is formed between the insert portion 78 and the piston sleeve 82 so that, when the chamber 84 is filled with hydraulic fluid (as in Figure 6), the piston member 72 is urged radially outwardly from the tool body 54. A second hydraulic chamber 86 is also formed between the insert portion 78 and the piston sleeve 82 so that, when the second hydraulic chamber 86 is filled with hydraulic fluid, the piston member 72 is moved radially inwardly with respect to the tool body 54.

[0038] As the axial cutaway view provided by Figure 6 illustrates, a pair of hydraulic fluid passages 88, 90 extend axially through the central portion 62 of the tool body 54. A lateral fluid pathway (not shown) extends from the first fluid passage 88 to the first hydraulic chamber 84. A lateral fluid pathway (not shown) also extends from the second

fluid passage 90 to the second hydraulic chamber 86. Additionally, a pair of drilling mud tubes 92 extends through the central portion 62 of the tool body 54 from the end portion 64 to the end portion 66 and joins, at each end, the axial bore 56. As a result, drilling mud pumped down the drill string 20 may pass completely through the tool assembly 26 via the axial bore 56 and mud tubes 92.

[0039] The tool body 54 also houses a set of four pressure transducers 94 that are each positioned within the first hydraulic chamber 84 in order to detect the amount of fluid pressure within the first hydraulic chamber 84 during actuation of the tool assembly 26 to move the piston member 72 radially outwardly into penetrating contact with the wall of the borehole 12. Additionally, a linear variable differential transducer (LVDT) 95 (shown in Figure 11) is incorporated into the wall of the piston housing 82 for sensing the position of the insert portion 78 and, thus, detecting movement of the piston 72 with respect to the housing 82. The pressure transducers 94 and LVDTs 95 are electrically interconnected with a means for recording the pressure sensed and the location and movement of the piston 72. However, as the details of such interconnection and recording means are well known to those of skill in the art, they are not described herein.

[0040] The mud motor sub 52 includes an outer housing 96 that defines an axial bore 98 therethrough. A mud motor 100 resides within the outer housing 96. The mud motor 100 converts kinetic energy from the axial flow of drilling mud through the drill string 20 into hydraulic power. The mud motor 100 includes a rotary mud turbine 102 and a power generator 104 that is operably interconnected with the mud turbine 102 to be driven thereby. In a currently preferred embodiment, the mud motor 100 may comprise a BCPM device, which is commercially available from Baker Hughes, INTEQ in Houston, Texas. The power generator 104 selectively provides pressurized hydraulic fluid through the first

and second fluid passages 88, 90 of the tool body 54 in order to provide hydraulic fluid to either the first or second hydraulic chambers 84 or 86, thereby moving the piston members 72 radially inward or outward as necessary.

[0041] Alternatively, the power generator 104 of the mud motor 100 can comprise a device that generates electrical power rather than hydraulic power from the kinetic energy of drilling mud flow. If an electrical power generator is used, the pistons 72 will need to be actuated using electrical energy.

[0042] In operation, the drill string 20 is positioned within the wellbore 12 so that the tool assembly 26 is proximate the location in the formation 16 or 36, wherein it is desired to perform testing of the formation 16 or 36. Drilling mud is flowed down the drill string 20 to actuate the mud motor 100 and cause it to operate the piston tool sub 50 and drive the piston members 72 radially outwardly against a side of wellbore 12. The drilling mud continues past the mud motor 100 through the piston tool sub 50 and downward to the BHA 22. Drilling mud exiting the BHA 22 is returned up the annulus formed between the wellbore 12 and the drill string 20. The mud channels 68 permit the drilling mud to bypass the piston tool sub 50.

[0043] When the piston tool sub 50 is energized by hydraulic fluid, the pistons 72 are urged outwardly into penetrating contact with the wall of the wellbore 12. This contact also locks the drill string 20 into place within the borehole against relative movement, thereby substantially precluding axial or angular movement of the drill string 20 with respect to the borehole 12. Such movement is a particular problem when the well is an offshore well, such as that shown in Figure 3 and, thus, the locking function of the tool assembly 26 is quite valuable. It is noted that, when the pistons 72 are placed into penetrating engagement with the wall of the borehole 12, the stabilizer portion 69 is also set against the wall of the borehole 12. The pressure required to set the pistons 72 is

measured, as is the amount of movement of the pistons 72 during setting. These data are then used to determine rock strength and moduli.

[0044] Retraction of the piston members 72 from engagement is accomplished by energizing the mud motor 100 so that the second hydraulic chamber 86 is filled with pressurized hydraulic fluid. Thus, an active, positive release mechanism is provided for the piston members 72. The drill string 20 may then be relocated within or removed from the wellbore 12.

[0045] Figures 7A and 7B depict an exemplary alternative embodiment for a rock strength measurement tool 110. The tool 110 is similar in most respects of construction and operation to the piston tool 50 described earlier. In this embodiment, however, the four piston members 112 (visible in Figure 7A) support a unitary engagement plate 114. The engagement plate 114 is generally rectangular and has a longitudinal axis that lies parallel with the axis of the tool body 116. The short axis of the engagement plate 114 is curved so as to substantially match the curvature of the tool body 116.

[0046] Figures 8 and 9 illustrate a further exemplary rock strength measurement tool assembly 120 which also features a unitary engagement plate 122 that is longitudinal and substantially rectangular in shape and is secured to four axially aligned pistons 124. The engagement surface 126 of the engagement plate 122 is roughened by the use of horizontally disposed ridges 128. The roughened engagement surface 126 is provided to increase the gripping power of the assembly 120. A large engagement surface area, such as is provided by the large unitary plate 122 provides a gripping advantage over the use of a number of separate pistons, such as pistons 112. In preferred embodiments, the engagement plate 122 also features a defined measurement area portion 129 (visible in Figure 9) that projects radially outwardly beyond the roughened surface 126. The measurement area portion 129 engages a borehole wall prior to the roughened surface 126

and provides an area of known size so that strength and moduli calculations may be made.

[0047] Figure 10 depicts a further alternative embodiment for an exemplary rock strength measurement tool 130 being configured for testing and measurement of in-situ rock strength and stress anisotropy. The tool 130 features a generally tubular mandrel 132 with axial ends 134, 136 configured for integration of the tool 130 into a drill string. The mandrel 132 houses a plurality of piston members, or testing arms, 138. In this case, the piston members 138 are in three, axially aligned groups (only two of which are visible) in Figure 10. The three groups of pistons are separated angularly about the tool body by approximately 120 degrees. While the tool 130 presents piston members 138 that are expanded radially outwardly in more than one radial direction, none of the piston members 138 are diametrically opposed to one another. As a result, the tool 130 is more easily actuated than a tool that might utilize diametrically opposed piston members. The tool 130 allows for variations in the roughness of the borehole wall.

[0048] Referring now to Figures 12 and 13, there is depicted an exemplary rock strength measurement tool 140 having an outer tool housing 142 with lateral windows 144 cut therein. Although two such windows 144 are shown in Figures 12 and 13, it should be understood that there may be more or fewer than two such windows. Piston members 146 have enlarged portions 147 that reside within the housing 142 to dispose contact portions 148 through the windows 144. The piston members 146 are capable of moving radially inwardly and outwardly so that the contact portions 148 are retracted or extended through the windows 144, as may be seen by a comparison between Figure 12 (retracted) and Figure 13 (extended). The tool 140 incorporates therein a deployment arrangement, generally indicated at 150, that includes a motor 152 and spindle drive 154 that is rotationally driven by the motor 152. The motor 150 is indicated schematically

and may be a mud motor of the type described earlier or other power sources known in the art. The spindle drive 154 includes a shaft 156 with a threaded spindle portion 158. The threads of the spindle portion 158 engage complimentary threads 160 on an axial wedge member 162 that is reciprocally retained with the tool housing 142. The wedge member 162 is a cylindrical body 164 that presents an annular frustoconical surface 166 at its lower end. The frustoconical surface 166 lies adjacent upwardly and inwardly directed surfaces 168 on the piston members 146. Rotation of the spindle drive 154 by the motor 152 causes the wedge member 162 to be moved axially within the tool housing 142. This axial movement causes the frustoconical surface 166 to slide along the surfaces 168 of the piston members 146, thereby urging them radially outwardly to the deployed position shown in Figure 13 in the manner of sliding shoes. When it is desired to unset the tool 140, the spindle drive 154 is rotated in the opposite direction to move the wedge member axially upwardly within the housing 142. Pressure transducers and LVDTs may be incorporated into the frustoconical surface 166 of the wedge member 164, as schematically indicated at 170, so that the movement and pressure applied by the piston members 146 may be measured.

[0049] Figure 14 and 15 illustrate a further exemplary rock strength measurement tool 180 which incorporates an radially expandable deployment mechanism. The tool 180 features an outer housing 182 with a plurality of lateral windows 184 disposed therethrough. An inner housing 186 is retained radially within the outer housing 182 and defines a mud flow bore 188 therewithin through which drilling mud is pumped downwardly for lubrication of a drilling bit. An annular space 190 is defined between the inner and outer housings 182, 186. In addition, a radially expandable bladder element, commonly referred to as an inflatable packer, 192 is secured within the annular space 190 and is aligned within the windows 184. A solid plug 194 is disposed within the annular

space 190 at the lower end of the bladder element 192 to help secure the bladder element 192 in place and to form a fluid seal within the space 190. A second plug 196 is disposed within the space 190 at the upper end of the bladder element 192 to help secure the upper end of the bladder element 192 in place. The second plug 196 has a fluid passage 198
 5 disposed therethrough. Piston members 200 are secured to the outer radial surface of the bladder element 192. Pressure transducers and LVDTs 202 may be sandwiched between the bladder element 192 and the piston members 200.

[0050] Figure 14 depicts the tool 180 in a retracted position, the position used for running the tool 180 into a wellbore. When it is desired to deploy the piston members 200
 10 into contact with a surrounding wellbore wall (not shown), the bladder element 192 is inflated to the position illustrated by Figure 15. This may be done by transmitting fluid, under pressure, through the fluid passage 198 of the upper plug 196 and into the fluid chamber 204 that is defined between the upper and lower plugs 196, 194 and between the inner and outer housings 186, 182. The increased fluid pressure, causes the bladder
 15 element 192 to inflate. There are, of course, numerous other well-known techniques for inflating and deflating such packer assemblies and elements, and those will not be described in detail here.

[0051] Means for accurately measuring static rock moduli and strength in-situ utilizing the devices of the present invention would materially improve data logging. One
 20 preferred method for strength measurement of rock employs the concept that shear stress (τ) tends to cause failure across a plane (A) that is resisted by the cohesion (c) of the material being tested and by the coefficient of internal friction (μ) times the normal stress (σ_n) across the plane A. Expressed mathematically:

$$\tau = \mu \cdot \sigma + c$$

where:

τ = shear stress;

σ_n = normal stress;

μ = coefficient of internal friction (related to the angle of internal friction $\mu = \tan \varphi$); and

5 c = cohesion

Using principal stress components (σ_3 axial principal stress, $\sigma_1 = \sigma_2$ = radial principal stress) the criterion is:

$$\sigma_1 = \sigma_3 \cdot \tan^2 \left(45 - \frac{\varphi}{2} \right) - 2c \cdot \left(\tan 45 - \frac{\varphi}{2} \right)$$

- 10 For practical problems, uniaxial compressive rock strength is used. This strength parameter is defined as the axial strength (σ_3) of an unconfined ($\sigma_1 = \sigma_2 = 0$) cylindrical sample:

$$\sigma_3 = \frac{2c}{\tan \left(45 - \frac{\varphi}{2} \right)}$$

- The strength properties of igneous, metamorphic and consolidated sedimentary rocks are
15 influenced strongly by fracturing and porosity.

Static rock moduli may also be determined. There is a quasistatic loading and measurement of the deformation as a function of pressure following Hooke's definition:

$$\sigma = E \cdot \varepsilon$$

$$E_{(p)} = \frac{dp}{d\varepsilon}$$

- 20 Natural rocks show the phenomenon of deformation hysteresis: loading and unloading curves differ as a result of non-elastic deformation. With a rock strength measurement as it is depicted in Figure 1, the Young's modulus E can be calculated as:

$$E = \frac{F}{A \cdot \frac{\Delta l}{l^*}}$$

with I^* to be defined for the borehole conditions, it is possible to calculate the Young's modulus.

For engineering use, the deformation properties are described by a number of moduli, including the Tangent modulus, Average modulus, and Secant modulus. These moduli
5 can be measured and calculated as well. In combination with the orientation of the tool (i.e., azimuth, inclination), in-situ stress anisotropy can be estimated from the comparison of the force/way diagrams when multiple arms are instrumented and measured.

[0052] Those of skill in the art will recognize that numerous modifications and changes may be made to the exemplary designs and embodiments described herein and that the
10 invention is limited only by the claims that follow and any equivalents thereof.

CLAIMS

What is claimed is:

- 1 1. A rock strength measurement tool assembly for incorporation within a tool string and use
2 within a borehole, the tool assembly comprising:
3 a generally cylindrical tool body having a pair of axial ends, the ends being configured for
4 integrating the tool body within a tool string;
5 a piston member disposed within the tool body for reciprocal motion with respect thereto
6 to selectively bring the piston member into contact with a borehole wall and penetrate the
7 borehole wall; and
8 a mud motor disposed proximate the tool body and operably associated with the tool body
9 for actuation of the piston member, the mud motor being actuated by flow of drilling mud within
10 a tool string.
- 1 2. The tool assembly of claim 1 wherein there are multiple piston members that are axially
2 aligned with one another upon the tool body.
- 1 3. The tool assembly of claim 1 wherein there are multiple piston members that are helically
2 aligned with one another upon the tool body.
- 1 4. The tool assembly of claim 1 further comprising a sensing element for determining the
2 amount of pressure force exerted by the piston upon a portion of borehole wall.
- 1 5. The tool assembly of claim 1 further comprising a sensing element for determining the
2 amount of radial movement of the piston with respect to the tool body.

- 1 6. The tool assembly of claim 5 wherein the sensing element comprises a linear variable
2 differential transducer.
- 1 7. The tool assembly of claim 2 further comprising a unitary engagement plate that is
2 secured to each of the piston members.
- 1 8. The tool assembly of claim 7 wherein the engagement plate presents a roughened
2 engagement surface for contacting a borehole wall.
- 1 9. The tool assembly of claim 1 wherein the tool body further comprises at least one mud
2 channel extending between the axial ends of the tool body, the mud channel being sized to permit
3 drilling mud to pass by the tool body within a wellbore.
- 1 10. The tool assembly of claim 1 wherein the tool body further includes at least one radially
2 enlarged stabilizer portion opposite the piston upon the tool body and having a stabilizer surface
3 for resting against the borehole wall during actuation of the piston body.
- 1 11. The tool assembly of claim 2 wherein there are three groups of axially aligned pistons,
2 each of the three groups being angularly separated about the circumference of the tool body.
- 1 12. The tool assembly of claim 11 wherein the angle of separation is approximately 120
2 degrees.

1 13. The tool assembly of claim 1 wherein the mud motor comprises a mud turbine and a
2 power generator operably interconnected with the mud turbine to be actuated thereby.

1 14. The tool assembly of claim 13 wherein the power generator generates hydraulic fluid
2 power.

1 15. The tool assembly of claim 13 wherein the power generator generates electrical power.

1 16. A rock strength measurement tool assembly for incorporation within a tool string and use
2 within a borehole, the tool assembly comprising:

3 a tool body having a pair of axial ends, the ends being configured for integrating the tool
4 body within a tool string;

5 a piston member disposed within the tool body for reciprocal motion with respect thereto
6 to selectively bring the piston member into contact with a borehole wall and penetrate the
7 borehole wall;

8 a radially enlarged stabilizer portion presenting a stabilizer surface to rest against a wall
9 of the borehole, the stabilizer portion lying opposite the piston member upon the tool body;

10 a mud motor disposed proximate the tool body and operably associated with the tool body
11 for actuation of the piston member, the mud motor being actuated by flow of drilling mud within
12 a tool string.

1 17. The tool assembly of claim 16 further comprising a radially enlarged central portion
2 located between the axial ends and a radially reduced mud channel on the central portion to
3 permit the passage of drilling mud past the central portion.

1 18. The tool assembly of claim 16 wherein the piston member is operably associated with a
2 sensor for measurement of piston movement.

1 19. The tool assembly of claim 16 wherein the piston member is operably associated with a
2 sensor for measurement of fluid pressure required to move the piston into penetrating contact.

1 20. A method of determining rock strength comprising the steps of:

2 integrating a rock strength measurement tool into a drill string, the rock strength
3 measurement tool comprising:

4 a tool body;

5 a piston member mounted within the tool body for reciprocating radial movement
6 therein; and

7 a stabilizer portion lying opposite the piston member upon the tool body;

8 disposing the drill string within a wellbore to locate the rock strength measurement tool
9 proximate a desired location within the wellbore;

10 radially moving the piston member outward from the tool body and into penetrating
11 contact with the wellbore; and

12 determining the force required to move the piston into penetrating contact with the
13 wellbore.

1 21. The method of claim 20 wherein the step of radially moving the piston into penetrating
2 engagement with the borehole further comprises flowing drilling mud into a drill string to
3 operate a mud motor, the mud motor, in turn providing power to move the piston.

- 1 22. The method of claim 20 wherein the step of radially moving the piston into penetrating
2 engagement with the borehole comprises using an electrically driven mechanical system having a
3 spindle drive.
- 1 23. The method of claim 20 wherein the step of radially moving the piston into penetrating
2 engagement with the borehole comprises inflating an inflatable element.
- 1 24. The method of claim 20 wherein the step of radially moving the piston into penetrating
2 engagement with the borehole comprises moving a single piston into penetrating engagement for
3 in-situ rock strength measurement.

1/9

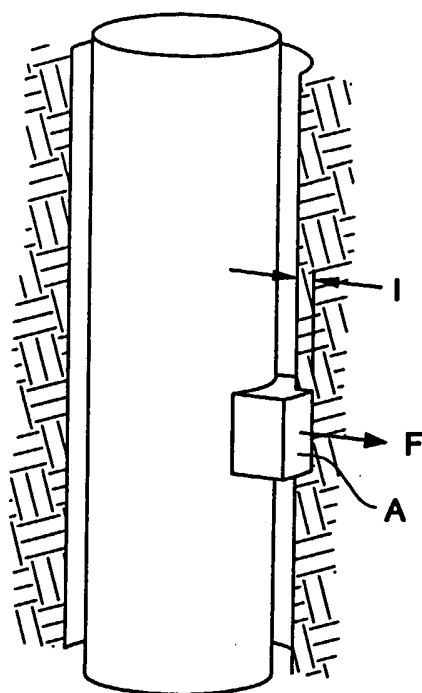


Fig. 1

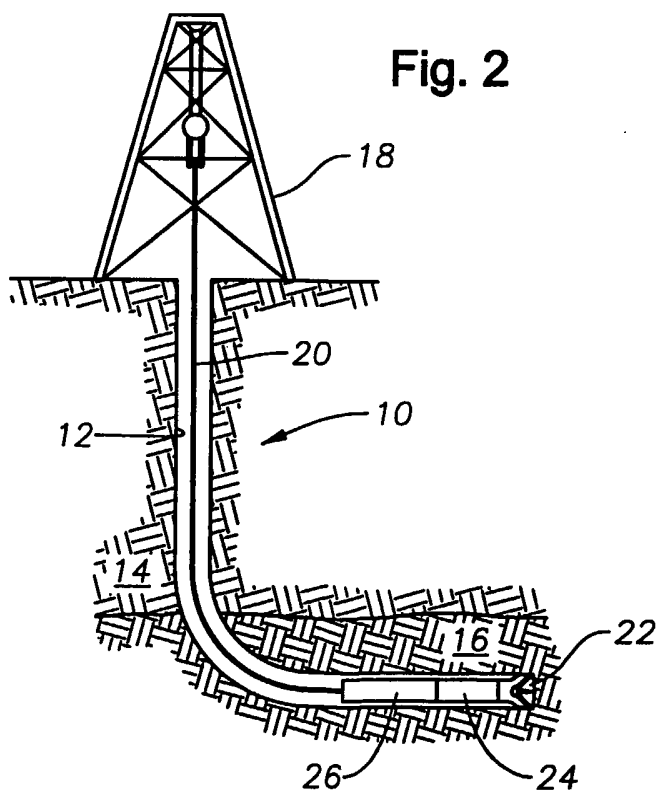
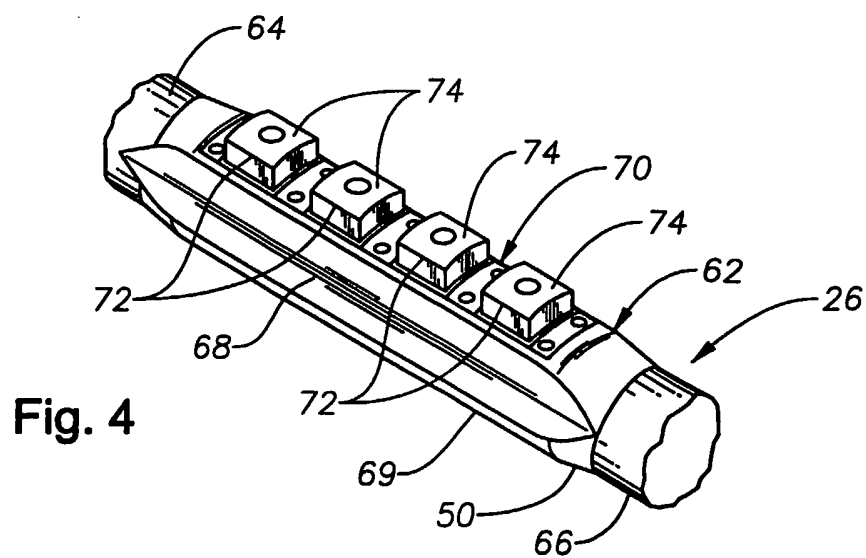
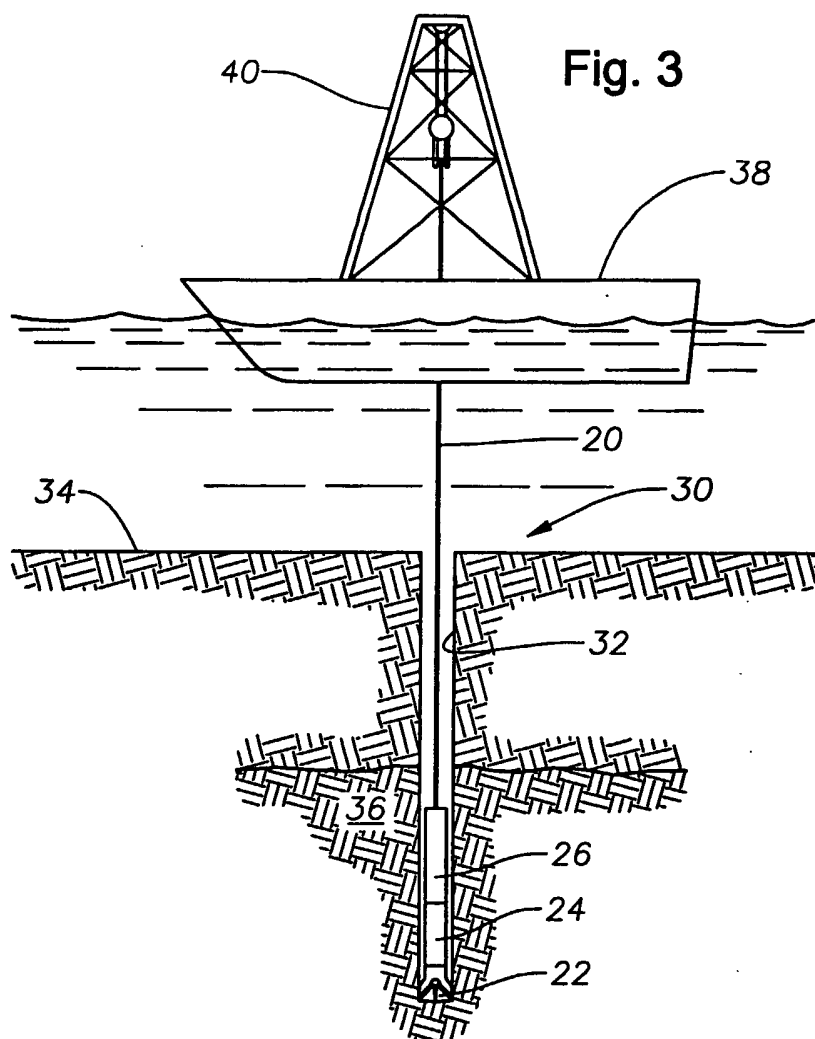


Fig. 2

2/9



3/9

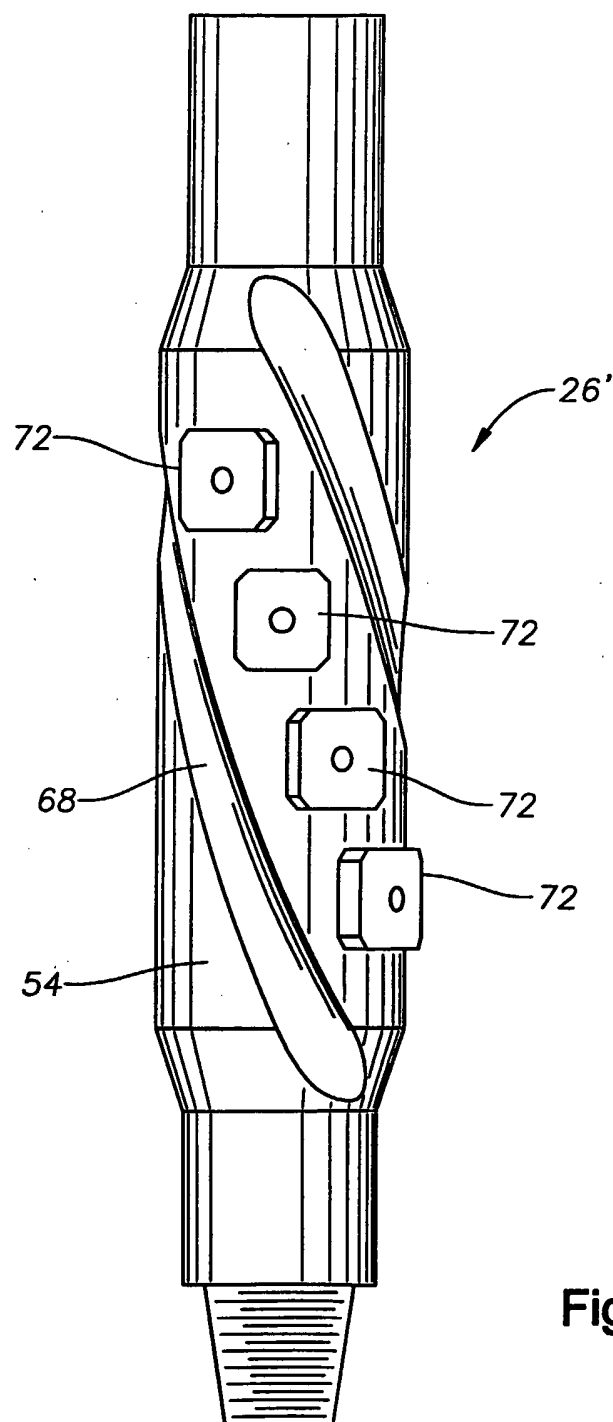
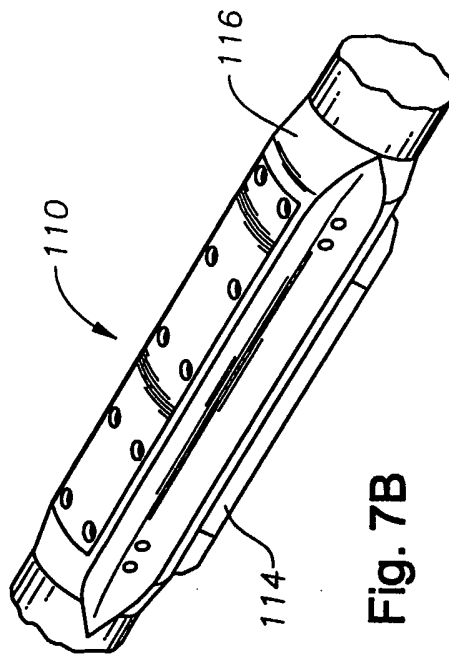
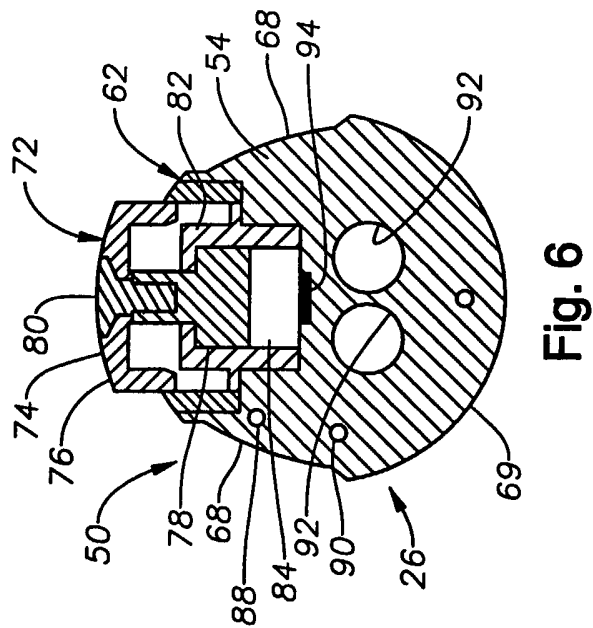
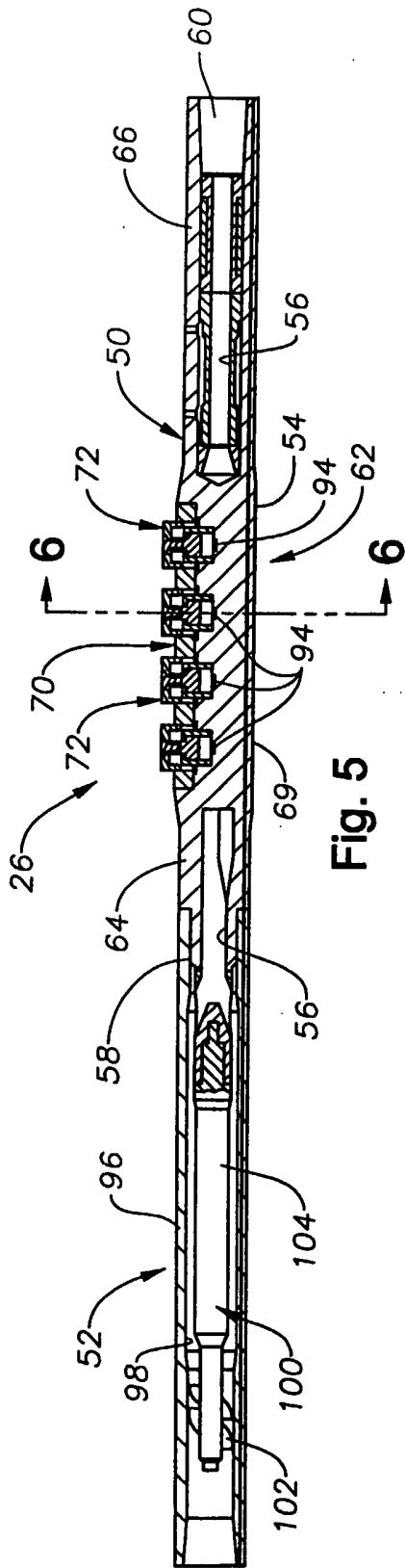


Fig. 4A



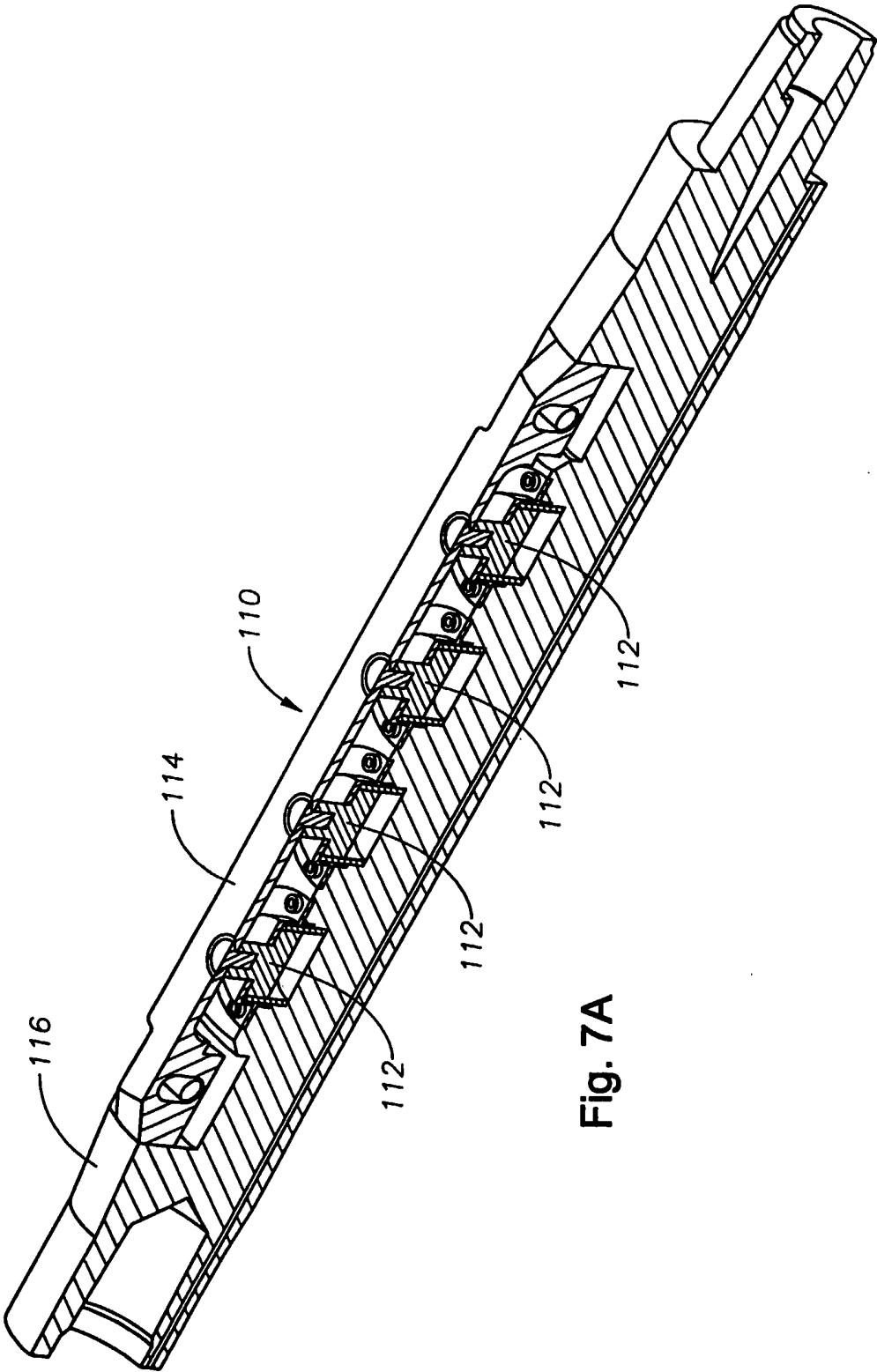
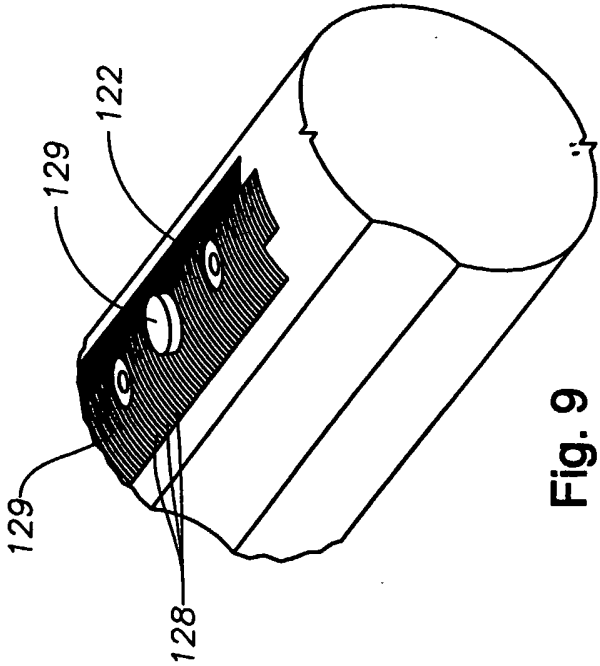
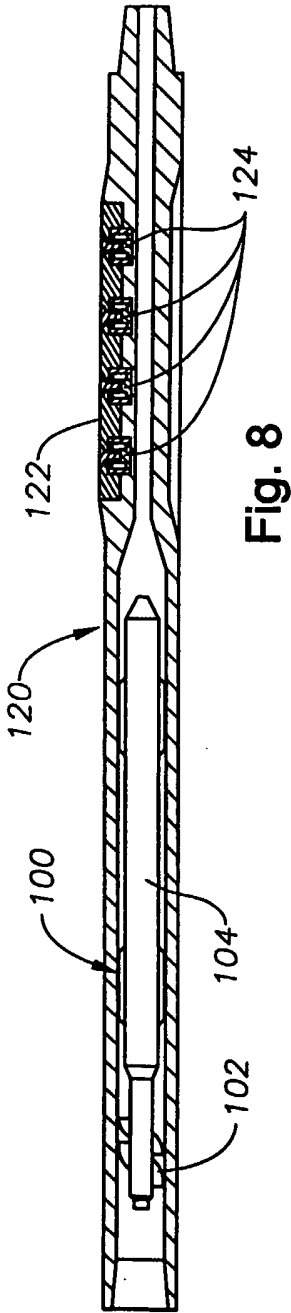
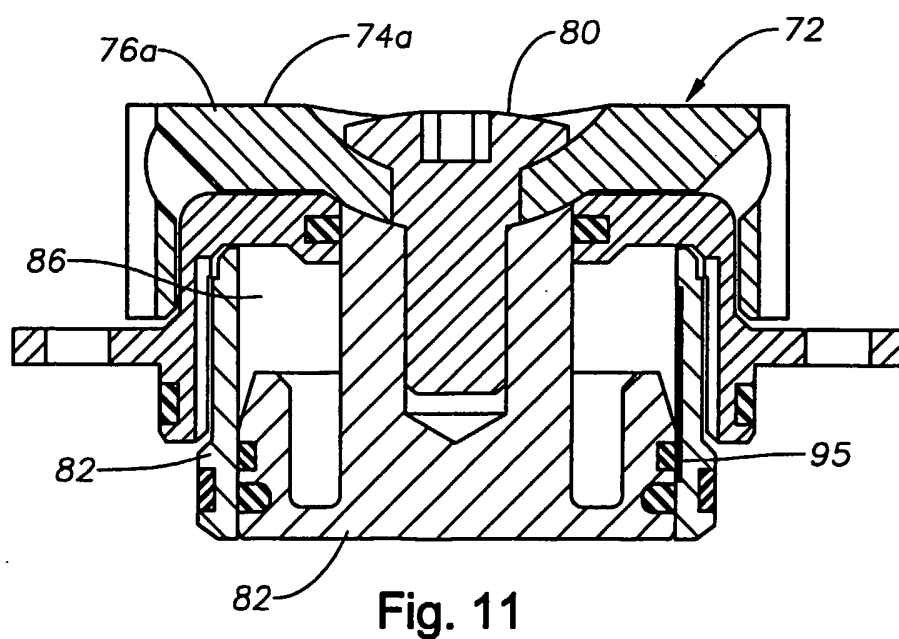
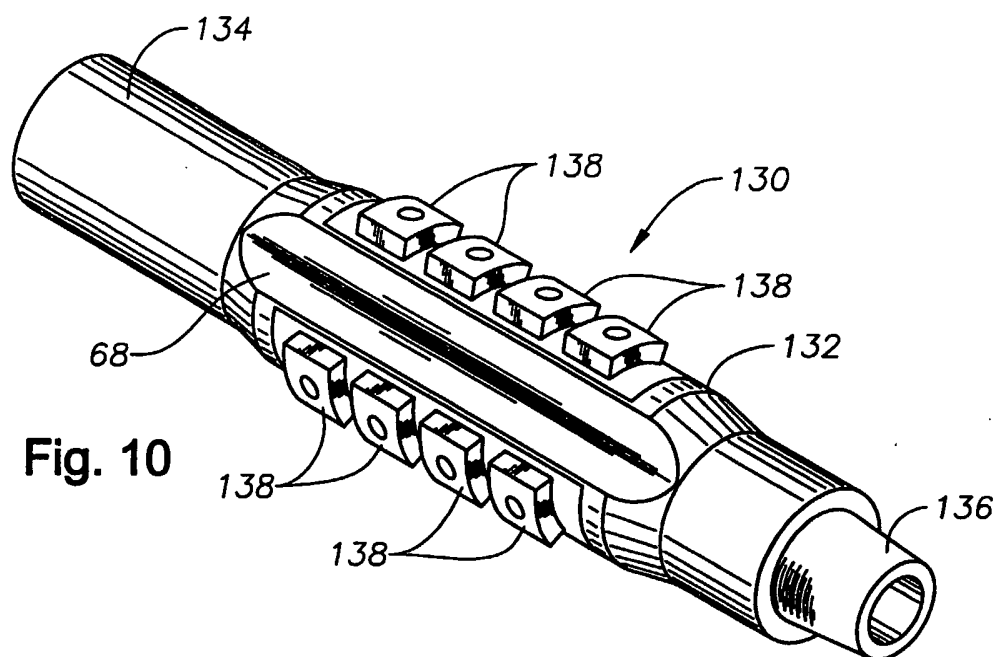


Fig. 7A



7/9



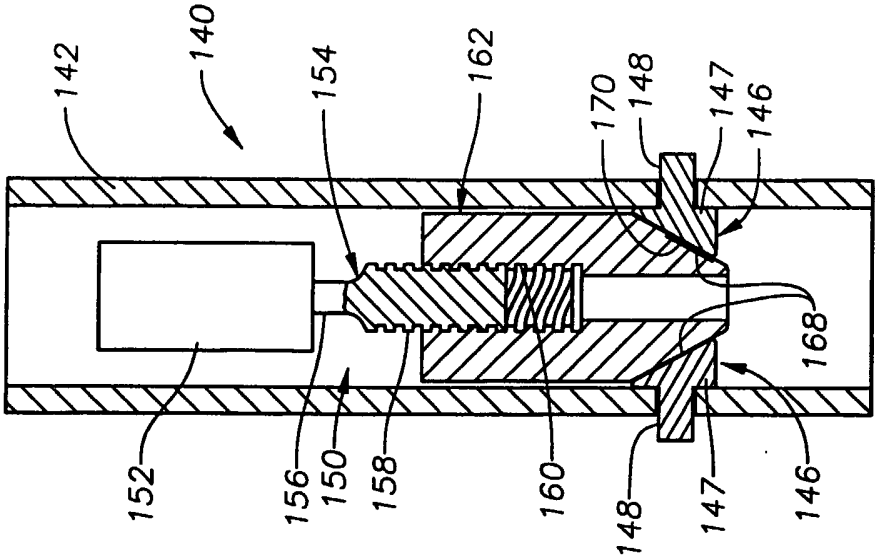


Fig. 13

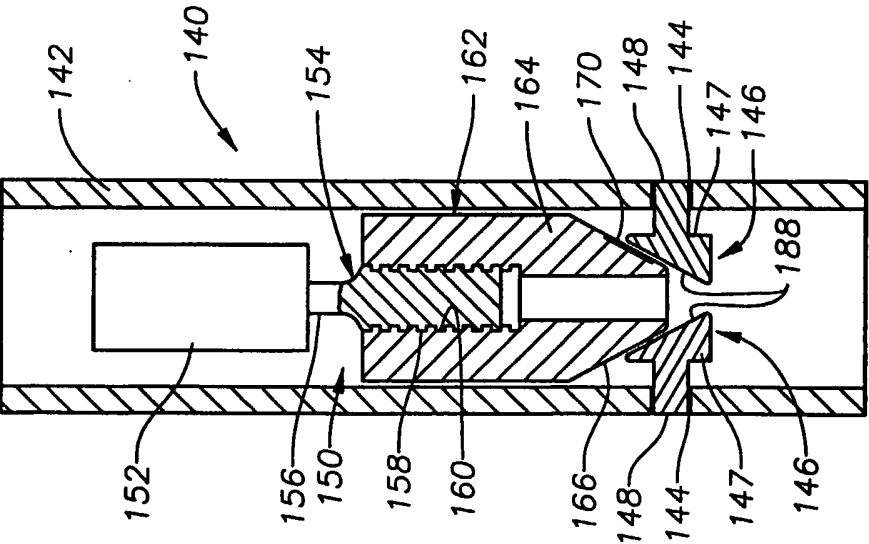


Fig. 12

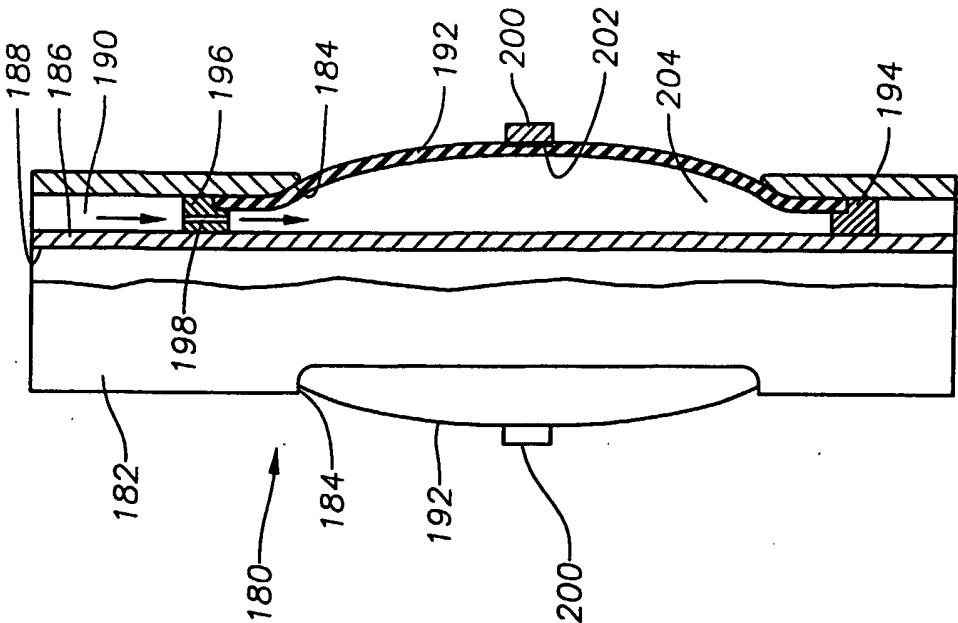


Fig. 15

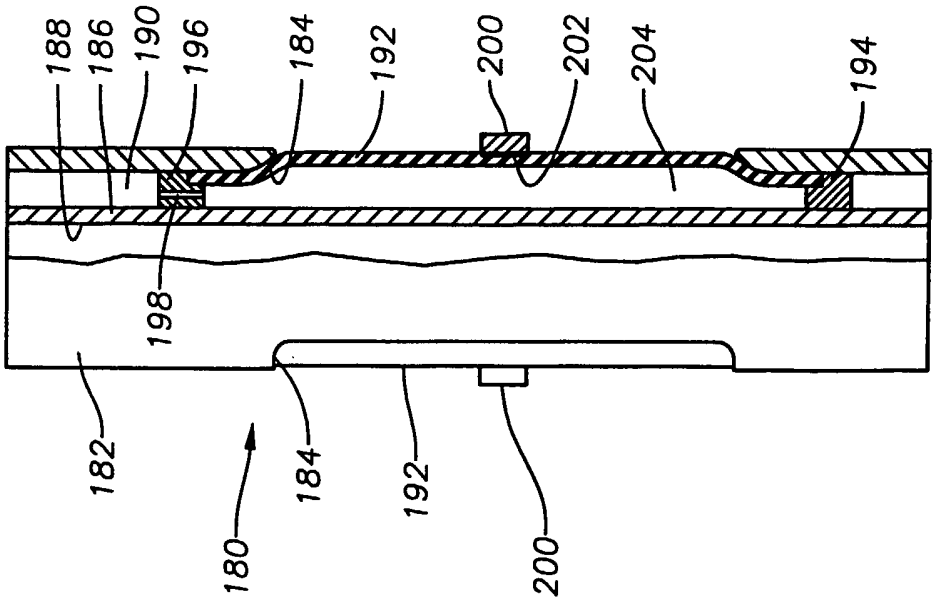


Fig. 14

INTERNATIONAL SEARCH REPORT

International Application No
PC ... S2004/016695

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 E21B49/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, TULSA, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	-----	10, 16-19,23
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

1 October 2004

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INTERNATIONAL SEARCH REPORT

Int. Patent Application No.
P: 2004/016695

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Information on patent family members

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