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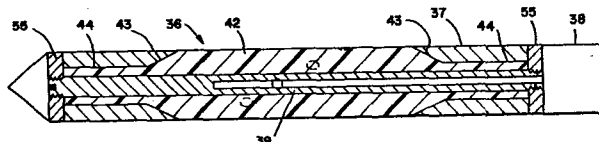
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Method and apparatus for measuring in situ earthen stresses and properties using a borehole probe.

A borehole probe (36) includes a soft outer plastic cylinder (42) secured to a central mandrel (39) and inflatable by hydraulic pressure conducted therethrough to impinge upon the sidewall of a borehole (22) with controlled pressure. A plurality of LVDT diameter sensors (67) are secured to the probe (36) in planes perpendicular to the axis thereof and spaced angularly thereabout. A plurality of acoustic transducers (73) is also secured to the exterior of the probe to monitor acoustic emissions as well as to survey the earthen media with ultrasonic emissions.

The cylinder inflation pressure is increased gradually to exceed both the tensile strength of the media and also the principal stress therein to initiate fracture of the media surrounding the borehole. The cylinder (42) is then deflated to unload the fractured media, and gradually reinflated to first elastically deform the fractured media and then re-expand the fractures previously created. The diameter data together with the hydraulic pressure and the acoustic emissions data and ultrasonic data are analysed to determine the major and minor stress fields in the media, and also the tensile strength, yield strength, and deformation characteristics of the borehole media.

The construction of the probe and the diameter measuring means may be varied when higher pressures are to be used and greater changes in diameter are expected.



METHOD AND APPARATUS FOR MEASURING IN SITU EARTHEN
STRESSES AND PROPERTIES USING A BOREHOLE PROBE

This invention relates to a method and apparatus for measuring in situ earthen stresses and properties using a borehole probe.

Accurate measurement of in situ stress states
5 and mechanical properties of ground media is the
most fundamental requirement for proper analysis and
sound design of earthen structures, underground
openings, dams, foundations, and the like. Such
information is also vital in determining the likeli-
10 hood of failure of critical installations located
near fault systems, such as nuclear power generating
stations in the Pacific Rim countries.

Methods and devices have been developed in
the prior art to analyse the stress states and
15 material properties of ground media, including,

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principally, pressure meters, hydraulic fracturing devices, and overcoring methods. A complete discussion of the pertinent prior art is provided in United States Patents Nos. 3,796,901, of March 12, 5 1974, and 4,149,409, of April 17, 1979, both issued to Shosei Serata. In general, the prior art is deficient in that it has not been possible to analyse ground media which is non-homogeneous and does not obey idealized elastic conditions, such as 10 fractured, permeable, non-elastic, or ductile media. Furthermore, the limited data that may be obtained is derived only after extensive laboratory work and data analysis, quite contrary to the ideal goal of virtual real-time measurement of earthen properties 15 and stress states.

The present invention generally comprises a method and apparatus for determining the principal stress states as well as material properties such as tensile strength, shear strength, and deformation 20 characteristics in earthen media surrounding a borehole. A salient feature of the invention is that it can provide complete stress and property data in a very short time, approximately one to two orders of

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magnitude faster than prior art methods and devices. The invention is also unique in that it can be used effectively to analyse complex ground formations, such as hard-brittle, soft-ductile, fractured, and stratified ground.

The apparatus of the present invention includes a unique borehole probe. One embodiment of the borehole probe includes a soft outer plastic cylinder secured to a central mandrel and inflatable by hydraulic pressure conducted therethrough to impinge upon the sidewall of a borehole with controlled, time-varying pressure. A plurality of LVDT diameter sensors are secured to the probe in planes perpendicular to the axis thereof and spaced angularly thereabout. A plurality of acoustic transducers is also secured to the exterior of the probe to monitor acoustic emissions as well as to survey the earthen media with active ultrasonic scanning. The cylinder inflation pressure is increased gradually to exceed both the tensile strength of the media and also the maximum and minimum tangential stresses therein to initiate fracture of the media surrounding the borehole. The cylinder is then deflated to unload the

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fractured media, and gradually reinflated to first elastically deform the fractured media and then re-expand the fractures previously created. The test may be repeated at incremental angles about the bore-
5 hole axis to resolve the angular orientation of the principal stress vectors. The diameter data together with the hydraulic pressure and the acoustic emissions data and ultrasonic data are correlated and analysed to determine the major and minor stress fields in
10 the media, and also the tensile strength and yield strength of the borehole media.

The embodiment described above may be adapted for differing borehole diameters and pressure and elasticity requirements by providing interchangeable plastic
15 cylinders of differing thicknesses and materials. Another embodiment of the borehole probe adapted for extremely high pressure work includes a plastic cylinder which is reinforced with a plurality of high strength cables extending longitudinally and
20 disposed about the peripheral surface of the cylinder in sleeve-like fashion. An outer layer of coil springs extends annularly about the cable sleeve to cause contraction of the assembly during hydraulic

deflation and assure removability of the device from the borehole. A plurality of strain gauges are secured within the probe and coupled through cantilever assemblies to sensing needles extending outwardly to the surface of the probe to measure the diametrical expansion of the probe under hydraulic inflation.

Although the borehole probe is designed for the measurement of stresses and material properties, it can also be utilised as a powerful rock breaker. The probe is found to be especially effective for breaking extremely hard rocks. Rock breaking by the probe is an alternative to conventional blasting methods in ground where such blasting is not acceptable due to possible damage from the blasting.

The invention will be described further, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a cross-sectional elevation of one embodiment of the borehole probe of the present invention;

Fig. 2 is an enlarged cross-sectional view of the LVDT assembly of the embodiment depicted in Fig. 1;

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Fig. 3 is a partially cutaway elevation of the probe depicted in Figure 1, showing the acoustic transducer network on the surface of the probe;

5 Fig. 4 is a transaxial cross-sectional schematic view of the acoustic transducer network of Fig. 3;

Fig. 5 is a schematic perspective view of the acoustic transducer network of Figs. 3 and 4;

10 Fig. 6 is a block diagram of the stress and property measuring system of the present invention;

Fig. 7 is an enlarged cross-sectional detailed view of the end cap assembly of the embodiment of Figs. 1-5, shown in the deflated condition;

15 Fig. 8 is a cross-sectional detailed view as in Fig. 7, showing the cylinder and end assembly in the inflated disposition;

Fig. 9 is a transaxial cross-sectional end view of the end cap assembly of Figs. 7 and 8;

20 Fig. 10 is a cross-sectional detailed view of a high expansion adaption of the probe structure of the previous Figures, shown in the deflated disposition;

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Fig. 11 is a cross-sectional detailed view as in Fig. 10, shown in the hydraulically inflated disposition;

5 Fig. 12 is a graphical representation of the pressure of radial hydraulic loading vs. diametrical expansion measured by the probe of the present invention;

10 Fig. 13 is a graphical representation of the pressure of radial hydraulic loading vs. diametrical expansion measured by the probe, showing the derivation of the principal stress vectors;

Fig. 14 is a schematic view of the borehole probe orientation with respect to the axis thereof, depicting the angular relationships of Figure 13;

15 Fig. 15 is a cross-sectional elevation of a further high pressure borehole probe construction of the present invention, shown in the deflated disposition;

20 Fig. 16 is a cross-sectional view as in Fig. 15, showing the probe in the inflated disposition;

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Fig. 17 is a transaxial cross-sectional view of the embodiment of Fig. 16, showing the strain gauge cantilever measuring assembly;

Fig. 18 is a cross-sectional detailed view
5 of the strain gauge assembly of Fig. 17; and

Fig. 19 is a transaxial detailed cross-sectional view of the measuring needle and cantilever assembly depicted in Figs. 17 and 18.

The present invention generally comprises a
10 method and apparatus for determining the principal stress vectors in ground media, and also for determining mechanical properties such as tensile strength, yield strength, and deformation characteristics of the ground media. With reference to Fig. 6, the
15 apparatus generally includes a probe unit 21 which is adapted to be received within a borehole 22 and to interact with the sidewall thereof at selected depths and angular orientations about the axis of the borehole. The probe unit 21 is connected
20 through an hydraulic cable 23 to a pump 24 disposed outside the borehole and adapted to provide hydraulic pressure to expand portions of the probe 21 against the sidewall of the borehole.

The probe 21 is also connected through an electrical cable 26 to a digital data recorder 27 which receives all the data from the diameter sensors and acoustic sensors mounted on the probe 21. This data is formatted and recorded on a magnetic media 28. The recorded data is retrieved through a playback unit 29, and processed and analysed by a computer and graphics system 31. The output data concerning stress states and properties of the ground media may be printed by a graphics plotter 32, or displayed on a video output of the system 31.

With reference to Figs. 1, 2, and 7, one embodiment 36 of the borehole probe 21 includes an expandable cylindrical section 37 which is connected in end adjacent relationship to a cylindrical electronics section 38. The electronics section 38 includes circuitry for amplifying signals from sensors, and may also include analog/digital signal converting circuitry. The expandable section 37, is comprised of a central mandrel 39 disposed coaxially and including a central bore 41 therein. A cylindrical member 42 is secured about the mandrel in sleeve-like fashion, the member 42 being formed of a soft, elastic plastic material of generally high

yield strength. The opposed ends of the cylindrical member 42 include tapered portions 43 which are joined to end portions 44 of narrow diameter. As shown in Figs. 8 and 7, the mandrel includes

5 hydraulic passages 46 extending from the bore 41 to the interstitial space between the peripheral surface of the mandrel and the interior surface of the member 42. One end of the bore 41 is connected to the hydraulic supply line 23 to deliver pressurized

10 fluid through the passages 46 and cause radial expansion of the member 42 against the sidewall of the borehole. The pressure delivered can be selectively varied to cause expansion and fracture of the earthen media.

15 A salient feature of the present invention is the construction of the end portions of the section 37 which permits substantial radial expansion of the medial portion thereof while retaining and confining the substantial hydraulic pressure necessary to

20 expand and fracture the borehole wall. This construction is accomplished by a detachable cylindrical unit end cap assembly 57 fitted onto narrow diameter portions 44 of the cylinder 42. A steel ring 53 is

bonded to the respective distal end 54 of the cylinder 42. An O-ring seal 56 blocks hydraulic leakage between the mandrel and the ring 53. The end cap assembly 57 is received about the end of the
5 cylinder 42 and threaded to the mandrel to retain the assembly. The end cap assembly 57 includes a steel cylinder 58, a set of a large number of bridging blocks 61, a coil spring 63, two cylindrical layers 51 of fine steel cables, and a cylindrical layer
10 52 of high strength fabric 52, all molded together into a single unit using soft urethane. Each bridging block 61 includes a rounded end 62 which is fitted into a groove 59 formed in the steel cylinder 58. As the probe 36 expands, each block
15 61 rotates in the groove 59 to provide an umbrella-like opening of the end cap assembly 57 to bridge the large gap between the probe 36 and the bore-hole wall, as illustrated in Fig. 8. It may be appreciated that the outward flare of the groove
20 59 permits the bridging blocks 61 to rotate outwardly about their rounded ends 62. The sleeve-like cable layers 51 and the fabric lining 52 are provided to form a barrier which prevents the hydraulic pressure

from driving the cylinder portion 44 into the space between the bridging blocks 61.

In the preferred embodiment there are approximately 40 of the retaining blocks 61, this number
5 being large enough to reduce the separation between the individual blocks 61 when the device is expanded, yet not too large to weaken the strength of the individual blocks 61. The rounded shape of the end
62 of each block 61 provides no sharp geometric change
10 at the junction when the device is expanded.

The ring in the form of the coil spring 63 is disposed adjacent to the tapered portion 43 of the cylinder. The ring 63 is positioned to limit the outward radial expansion of the ring-like
15 array of blocks 61 and of the proximal ends of the cable layers 51. The interstitial spaces between the individual components of the end cap assembly 57 are filled with a soft, easily deformed plastic substance which joins the components into a cohesive
20 assembly. The ring 63 is positioned to prevent the soft plastic from squeezing into the space between the individual blocks 61 under pressure.

As shown in Fig. 8, a charge of hydraulic fluid under a pressure P may be pumped into the bore 41 to expand the cylinder 42. In fact, the medial portion of the cylinder 42 expands, while
5 the distal end portions are retained by the end cap assemblies 57 and undergo little expansion. The sloping zone between the substantial radial expansion at the middle and the unexpanded ends are supported by the end cap assemblies 57. This
10 flexible mechanical seal accommodates substantial radial expansion and contraction while retaining the high pressure hydraulic fluid.

The section 37 also includes devices for measuring the diametrical changes of the cylinder 42 as it is
15 expanded against the borehole wall under varying hydraulic pressures. With reference to Figs. 1 and 2, a plurality of LVDT (Linear Variable Displacement Transducer) diameter sensors 67 is secured to the section 37, each sensor 67 being disposed in a transaxial,
20 diametrical bore 68 extending through the mandrel 39 and the cylinder 42. Each bore 68 is sealed at each end by a threaded plug 69. The LVDT core is secured to one plug 69, and its coil is secured to

the other. Relative movement between the core and the coil causes inductive changes therebetween which effect a signal passing through wires 71 to the electronics section 38. The LVDT sensors are arrayed
5 in increments of 45° about the axis of the device, to measure angular variations in borehole wall deformation under conditions of cyclic loading by the cylinder member 42.

It should be noted that the probe section 37
10 is designed to employ any one of a plurality of plastic cylinder members 42 of varying thickness, elasticity, and the like. The end cap assembly construction permits the selection and interchange of cylinder members 42 according to the expected
15 nature of the ground media and the level of hydraulic pressure to be used. The removability of the LVDT sensors from the cylinder members hastens their interchange, so that the instrument may be modified quickly in the field to accommodate in situ
20 conditions.

Another salient feature of the instrument is the provision of a plurality of acoustic transducers

73 secured to the medial portion of the outer loading surfaces of the cylinder member 42. The transducers 73, which comprise in the preferred embodiment piezoelectric crystals, are adhered to the surface in a pattern of plural circles about the cylinder 42, the transducers 73 being disposed at equal angle thereabout. The lead wires may be passed through small diameter radial ports in the cylinder 42 which are filled and sealed with a suitable plastic material.

The transducers 73 may act as both acoustic emitters and acoustic sensors. For example, with reference to Fig. 4, the transducers 73 may be used as an acoustic monitoring network to pickup acoustic emissions from the ground media which accompany events such as fracture failure. Such events, which often appear well-defined in idealized graphs but not necessarily in pressure vs. diameter expansion data, must be detected by correlating acoustic emissions of the ground media with diameter expansion of the borehole 22. When the cylinder 42 expands sufficiently to initiate a fracture in the borehole wall media, the fracture 74 radiates acoustic energy which traverses paths of differing

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length to reach the various transducer sensors 73. The time delay in the received signals, together with the phase relationships and the waveforms, can be used to determine information such as:

- 5 1. Nature of the failure: Distinction between brittle fracture and ductile shear in the borehole boundary failure;
2. Failure location: Location of the failing events, for both brittle and ductile failures;
- 10 3. Failure pressure: Loading pressure levels for initiation of the failures;
4. Failure growth: Speed and extent of the failures in both brittle and ductile grounds is related to the load pressure;
- 15 5. Orientation distribution: Orientation and distribution of the failing events around the borehole in relation to the loading pressure which causes those events.

 The acoustic transducers 73 may also be used
20 as an active sonar network to probe the ground media around the borehole 22, as depicted in Fig. 5. One of the transducers 73a is driven by an AC signal to radiate acoustically at high frequency.

This signal is conducted and reflected through the ground media to the remaining transducers 73, which are operated as passive receivers. The acoustic signals can be processed, using techniques well known in the prior art, to determine information such as the following:

1. Initial geomechanical conditions: The borehole media may be probed prior to stress testing to determine initial conditions such as homogeneity, isotropy, and anomalies;
2. Initial fractures: Presence, location, and extent of both macroscopic and microscopic fractures existing prior to the borehole loading;
3. Changing fracture conditions: Observing changes of the above fractures during and after cyclic loading;
4. Created fractures: Detection of initiation, growth, and contraction of fractures created by the loading, distinguishing from the natural fractures;
5. Yielding failure: Initiation, growth, and distribution of yielding failure distinguished from the fracturing failure in relation to the radial loading of the borehole wall.

It should be noted that the acoustic transducer network may be switched rapidly from passive acoustic monitoring to active sonar probing, so that both data streams may be correlated in virtually continuous fashion.

A salient feature of the present invention is the method for determining significant information on ground media, using an instrument such as the probe 36 described in the foregoing. With reference to Fig. 12, it is presumed that the stress field within the earthen media surrounding the borehole 22 can be resolved into principal stress vectors P_0 and Q_0 , the two vectors being orthogonal and disposed in a plane perpendicular to the borehole axis. It is also presumed that the media has a tensile strength T and that a tangential stress σ_{θ} exists at the borehole wall boundary. The media may be surveyed ultrasonically before hydraulic loading to find any fractures, anomalies, unexpected stress fields, and the like. The hydraulic pressure is then increased from zero to point A in Fig. 12, causing initial contact and consolidation between the probe surface and the

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borehole wall. The pressure is then increased from point A to point B, causing a generally proportional increase in borehole diameter and indicating the modulus of elasticity of the stressed media. At
5 point B both the tensile strength and the tangential stress of the media are overcome by the radially outward force of the expanding probe, causing initiation of fractures at the borehole boundary. This event may be verified by acoustic emission
10 signals.

The loading pressure is increased from points B to C, causing an increased rate of expansion with respect to the increasing pressure, due to the fact that induced fractures are expanding. The
15 hydraulic loading is then reduced to zero permitting the probe to deflate and the borehole wall to contract. However, due to the fact that the wall boundary has been substantially fractured, the tensile strength of the media has been reduced to virtually zero,
20 and the media has expanded, resulting in non-recoverable deformation O-D. Another loading cycle is then commenced, the pressure increasing from points D to E. This step causes elastic deformation before the

fracture planes open once more at pressure E. From point E to point F the increasing pressure causes increasing expansion as the fracture planes open. It is insignificant that the fracture planes begin to expand at the lower pressure (point E) in the second cycle of hydraulic loading, due to the fact that there is no more tensile strength in the fractured media. Thus the pressure at point E comprises the tangential stress σ_{θ} alone, and is thus determined.

With reference to Figs. 13 and 14, it is possible to reorient the probe about the axis of the borehole so that the maximum and minimum principle stresses P_0 and Q_0 lie along the axes of two of the LVDT sensors. The sensors are numbered 1-4 in their $\theta = 0^\circ$ disposition, and 1'-4' in the $(\theta)'$ position. The P-D curves of Figure 14 are labelled accordingly to show the reading of the various LVDT sensors in both orientations. It is clear that rotation of the probe alters the slopes of the P-D curves but does not change the pressure levels at which significant events occur, nor the ability to discern these events. It is known from classic

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mechanics that the minimum tangential stress on the P_0 direction is given by the relationship:

$$(\text{Sigma sub theta}) = 3Q_0 - P_0 ,$$

and the maximum tangential stress on the Q_0 direction
5 is:

$$(\text{Sigma sub theta})' = 3P_0 - Q_0 ,$$

where $(\text{theta})' = (\text{theta}) + 90^\circ$. When the expanding pressure is increased from zero to point 78, fracture initiation at Y_0 is detected by LVDT 3, yielding a
10 value for sigma sub theta. When expansion is increased to point 79, fracture initiation at X_0 is detected by LVDT 1, yielding a value for the tangential stress in the $(\text{theta})'$ direction. Knowing these two values, the two equations above may be solved simultaneously
15 to determine P_0 and Q_0 . It should be noted that any probe angular orientation would yield this data.

A further embodiment of the present invention, depicted in Figures 10 and 11, is designed to adapt the probe to boreholes which are over-sized. It
20 includes an exterior sleeve assembly 80 received about each end portion of the probe section 37 and disposed to occupy a substantial portion of the excess radial

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dimension of the borehole. The sleeve assembly 80 includes a plurality of small rectangular blocks 81 arrayed in equal angular increments about the axis of the probe, each block 81 disposed in registration with and impinging on one of the blocks 61 of the end assembly 57. The blocks 81 are embedded in a sleeve 82 formed of an elastic polymer material. As clearly shown in Figure 11, the blocks 81 act as spacers to limit the radial expansion of the cable layers 51, blocks 61, and the barrier ring 63. Without this spacer effect, the end assembly 57 would expand beyond safe limits, causing leakage of the hydraulic fluid or rupture of the cylinder 42.

The embodiments described in the preceding specification are designed to probe earthen media at pressures up to 10,000 psi. Beyond that limit and up to a maximum of 30,000 psi the probe embodiment depicted in Figs. 15-19 is provided to examine earthen media using high pressure deformation. In this embodiment the mandrel 39 is replaced by a plurality of high strength cables which are capable of withstanding more axial tensile loading than the mandrel, and are more yielding in the radial

direction than the cylinder member 42. The cables extend longitudinally and are arrayed in sleeve-like fashion in two adjacent layers 83, the cables in each layer being wound in opposite directions. Disposed
5 outwardly of the cable layers 83 is a layer 84 of coil springs wound helically thereabout. The springs, which are embedded in a yieldable plastic material, expand upon inflation of the probe. The spring restoring force assures that the probe will deflate
10 and disengage the borehole sidewall. The springs also protect the cable layer 83 from sharp edges and deep cracks in the borehole wall.

A layer 86 of fine fabric screens is disposed radially inwardly from the cable layer 83 and is
15 directly adjacent thereto. The layer 86 is composed of a coarse screen of steel braids, and a fine screen of high strength fabric. The layer 86 comprises a flow barrier for a soft plastic cylinder 87 disposed concentrically and inwardly of the
20 other layers. As before, the plastic cylinder 87 retains the pressurized hydraulic fluid. As the fluid pressure P increases, the probe expands as depicted in Fig. 16 and grows shorter in the axial

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dimension. The ends of the probe are held together by end caps 88 which join the various layers by compressive engagement thereof against the cylinder 87. This probe embodiment has a self-sealing capability when expanded into a borehole with a diameter much larger than the probe diameter. The sealing function is provided by the cable layers 83 which can support the full force and deformation under loading pressure, up to 30,000 psi.

10 The present embodiment also includes a novel diameter sensing assembly which is designed to accommodate the large diameter changes experienced under extremely high pressure, as well as the significant foreshortening effect along the axis of the probe, as illustrated by comparing Figs. 15 and 16. This assembly includes a central post 91 extending axially inwardly from each of the end caps 88. A collar 92 is secured about each post 91 in slidable fashion, and a plurality of cantilever arms 93 extend inwardly from the collar 92 parallel to the axis, as shown in Figs. 17 and 18. The cantilever arms 93 are disposed in a ring array about the collar 92 and secured at one end

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thereto so as to move with the collar 92 as it slides on the post 91. A pair of SR-4 strain gauges 90 is secured to the inner and outer surfaces of each arm 93 close to the collar 92.

5 The other end of each of the cantilever arms 93 is provided with a tapered, threaded socket 94 formed in the radially outwardly facing surface thereof. A plurality of sensing needles 96 are also provided, each having a sensing head 97
10 threaded into an appropriately formed socket in the plastic material of the outer spring layer 84. The inner end of each needle 96 is secured in the socket 94 of a respective cantilever arm 93, thus connecting the outer loading surface of the
15 probe with the movable ends of the cantilever arms 93. It should be noted that the arms 93 are sufficiently long so that the needles 96 may be positioned in a medial portion of the expandable probe, thereby measuring the maximum diameter
20 changes of the probe. The needles 96 are arrayed in a common plane which is transverse to the axis of the probe, the needles 96 being angularly spaced in correspondence with their respective cantilever arms 93.

When the probe is expanded, the sensing needles 96 pull the ends of the cantilever arms 93 radially outwardly and create a strain in the arms 93. This strain is detected by the strain gauges 90, and the signals from the strain gauges 90 may be correlated with radial movement of the respective sensing head 97. The array of cantilever arms 93 provides readings at relatively small angular increments about the axis of the probe, so that significant events induced by the expanding probe may be resolved with sufficient angular accuracy. It should be noted that as the inflating probe becomes shorter, the engagement of the needles 96 with the cantilever arms 93 will cause each collar 92 to slide along its post 91. This movement prevents the build up of tensile stress in the arms 93 which would otherwise affect the functioning thereof.

The probe designs and methods described in preceding specification delineate an invention with several unique and salient features. These novel features include:

1. **Comprehensiveness:** The ability to determine critical yet comprehensive information

on magnitude and orientation of the principal stresses as well as in situ material properties, essential for quantitative analysis and design of earth structures;

5 2. Combined observations: Both deformational and acoustic observations are combined to assure the accuracy of the information;

 3. Ground Complexity: Applicable to general ground materials with expected geomechanical compli-
10 cations including fractures, permeabilities, non-elasticity, and ductility in contrast to the ideally elastic ground model imposed by prior art techniques;

 4. Fracture initiation: Ability to measure fracture initiation, growth, and contraction in the
15 individual principal stress directions which are essential for accurate determination of the stress conditions and material properties of the naturally complex ground;

 5. Fractured ground: Ability to determine
20 stress conditions in fractured ground, which has not been possible using prior art techniques;

6. Ductile ground: Effective measurement of stresses in ductile ground, which has not been possible using prior art techniques;

5 7. Measurement speed: Speed of measuring the stress conditions and material properties, which is at least 10 to 1000 times faster than prior art techniques;

10 8. Applicability: Serious limitations imposed on prior art techniques, including borehole depth, ground permeability, initial stress field, and geomechanical complexity of the media are eliminated by the present invention;

15 9. The expandable probe can be used solely for its expansion effect to break hard rocks effectively and economically, without using the measuring function of the probe.

CLAIMS:

1. A method for determining the material properties and ambient stress field of a portion of ground media surrounding a borehole, comprising the steps of :

Inserting a stress-materials probe (21) into
5 the borehole (22),

expanding an outer portion (42, 83, 84, 87) of the probe under high pressure to impinge upon and deform the borehole wall until the ground media fractures in the minimum and maximum principal stress
10 directions, while simultaneously measuring the diameter expansion of the probe at angular increments thereabout to detect and locate the fractures,

measuring the pressure in the probe as a function of time to determine the pressure at which
15 the fractures occur, and comparing the pressure and diameter data to determine the maximum and minimum principal stresses in the ground media.

2. A method as claimed in claim 1, further including the step of simultaneously monitoring
20 the acoustic emissions of the ground media to verify the occurrence and location of the fractures.

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3. A method as defined in claim 1 or 2, further including the step of surveying the ground media with ultrasonic sound to determine ambient fractures, fracture growth under expanding pressure, ground
5 anomalies, and yielding failure of the ground media.

4. A method for determining the material properties and ambient stress fields of a portion of ground media surrounding a borehole, the ground media having a tensile strength and an existing tangential
10 stress about the borehole, comprising the steps of:

inserting a stress-materials probe (21) into the borehole (22),

expanding the probe (21) under high pressure to impinge upon and deform the borehole wall,

15 increasing the pressure until the tensile strength and tangential stress of the media are overcome and the media begins to fracture,

increasing the pressure further to expand the fracture and destroy the tensile strength of the
20 media

reducing the pressure to substantially zero to deflate the probe (21),

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increasing the pressure again to expand the probe (21) until said tangential stress is exceeded and the fracture begins to expand,

all the while simultaneously measuring the pressure
5 as a function of time,

and comparing the pressure levels for the initiation of fracture and the re-initiation of fracture to determine the ambient tangential stress and tensile strength.

10 5. Apparatus for carrying out the method of claim 1 or claim 4 comprising a probe in the form of a tubular cylindrical member (42; 83, 84, 87) adapted to contain high pressure fluid and expand elastic-
ally in response to the pressure of the fluid, a
15 pair of end cap assemblies (57, 88) joined to the cylindrical member to limit expansion of the ends thereof and to contain the high pressure fluid, and diameter measuring means (67; 90 - 97) for determining the expansion of the cylindrical member
20 as a function of pressure.

6. Apparatus as claimed in claim 5, further including a mandrel (39) extending axially within

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the cylindrical member (42), and means for joining the end cap assemblies (57) to opposed ends of the mandrel.

5 7. Apparatus as claimed in claim 6, wherein the mandrel (39) includes a bore (41) extending axially therein and the apparatus includes means (23) for delivering the high pressure fluid to the bore.

10 8. Apparatus as claimed in claim 7, wherein the cylindrical member (42) impinges concentrically on the mandrel (39) in the unexpanded disposition, and further including fluid passages (46) extending in the mandrel (39) from the bore (41) to the cylindrical member (42) to deliver high pressure fluid to the latter.

15 9. Apparatus as claimed in any of claims 5 to 8 wherein the opposed ends (44) of the cylindrical member (42) are tapered in diameter.

20 10. Apparatus as claimed in claim 9, wherein the end cap assemblies (57) are secured about the tapered ends (44) of the cylindrical member (42).

11. Apparatus as claimed in claim 10, wherein each

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end cap assembly (57) includes a steel cylinder (58) secured about the distal portion of each of the tapered ends (44).

12. Apparatus as claimed in claim 11, further including a plurality of bridging blocks (61) arrayed annularly about the tapered ends (44), each block (61) extending generally longitudinally of the cylindrical member (42).

13. Apparatus as claimed in claim 12, wherein each of the steel cylinders (58) includes an outwardly flared groove (59) in the proximal end thereof, the bridging blocks (61) each including a rounded end (62) adapted to be received in the groove (59) in rotatable fashion to permit the bridging blocks (61) to pivot outwardly in umbrella fashion as the cylindrical member (42) expands.

14. Apparatus as claimed in any of claims 9 to 13 further including a layer of high strength fabric (52) disposed about each of the tapered ends (44) of the cylindrical member (42), and a pair of concentric layers of steel cable (51) secured about the high strength fabric (52) at each tapered end (44).

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15. Apparatus as claimed in any of claims 5 to 14 wherein the diameter measuring means includes a plurality of LVDT sensors (67) secured in the cylindrical member (42) in diametrical fashion and spaced at angular increments about the axis of the cylindrical member (42).

16. Apparatus as claimed in claim 5, further including a plurality of high strength cables extending longitudinally and secured in layers (83) about the exterior surface of the cylindrical member in sleeve-like fashion.

17. Apparatus as claimed in claim 16, further including a layer of coil springs (84) secured about the outer surface of the layers (83) of high strength cables, the coils (84) extending annularly thereabout.

18. Apparatus as claimed in claim 16 or 17, further including a fine screen of fabric and a coarse screen of steel braid (86) secured concentrically about the cylindrical member within the cable layers (83).

19. Apparatus as claimed in claim 16, 17 or 18,

wherein the end cap assemblies each including a steel cylinder (88) secured about one end of the probe exteriorly of the cable layers (83) and adapted to secure the assembly of layers and prevent radial expansion thereof as the cylindrical member expands.

20. Apparatus as claimed in any of claims 16 to 19 wherein the diameter measuring means includes a pair of posts (91), each extending axially inwardly from one of the end cap assemblies (88).

21. Apparatus as claimed in claim 20, further including a pair of collars (92), each slidably secured on one of the posts (91).

22. Apparatus as claimed in claim 21, further including a plurality of cantilever arms (93) secured to each of the collars (92), the cantilever arms (93) being secured at like ends to their respective collar (92) and extending inwardly therefrom parallel to the axis of the probe.

23. Apparatus as claimed in claim 22, further including a pair of strain gauges (90) secured to

each of the cantilever arms (93).

24. Apparatus as claimed in claim 22 or 23, further including a plurality of sensing needles (96), each joined at one end to the cylindrical member and at
5 the other end to the proximal end of one of the cantilever arms 93 to deflect the cantilever arms outwardly as the cylindrical member expands, the sensing needles (96) extending generally diametrically and being spaced at angular increments
10 about the axis of the probe.

25. Apparatus as claimed in any of claims 5 to 24, further including a plurality of acoustic transducers (73) secured to the exterior of the probe and adapted both to pickup acoustic emissions
15 of the ground media under expansion and to survey the ground media in sonar fashion.

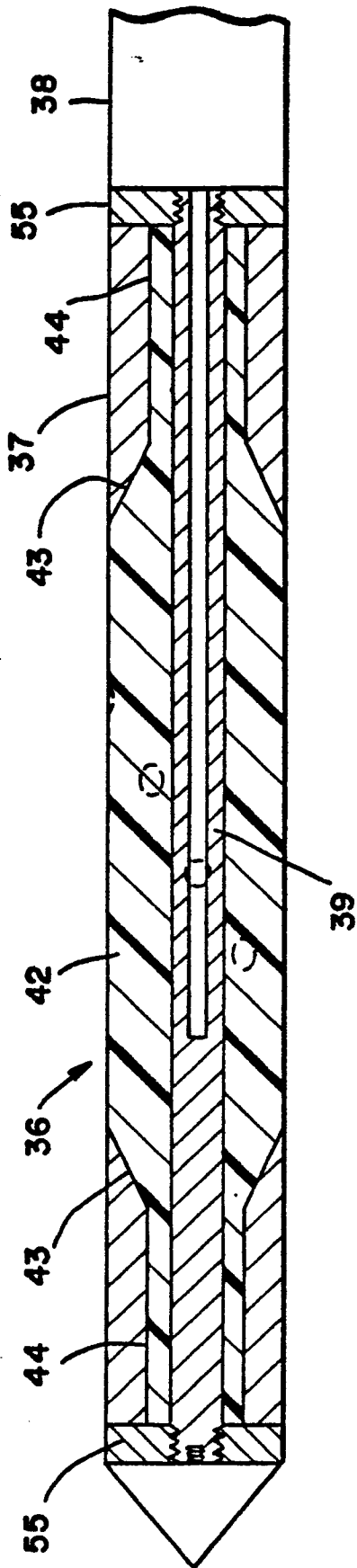


FIG - 1

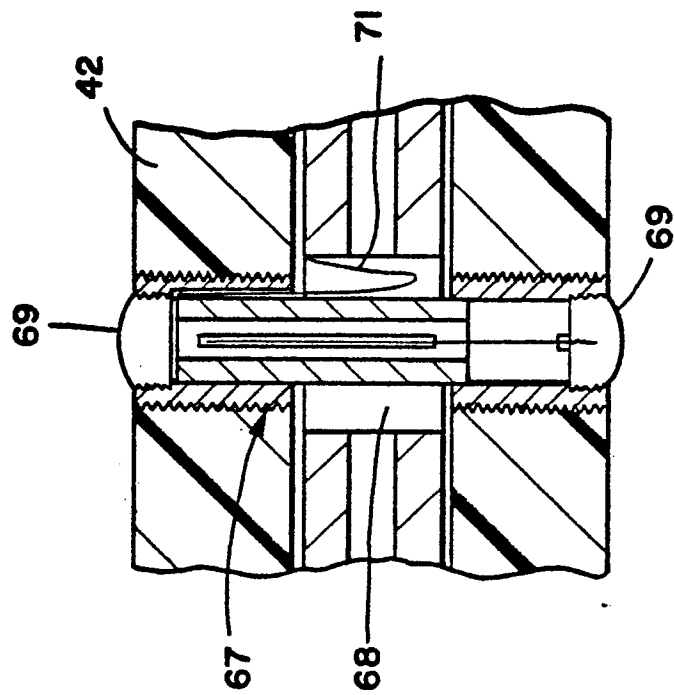
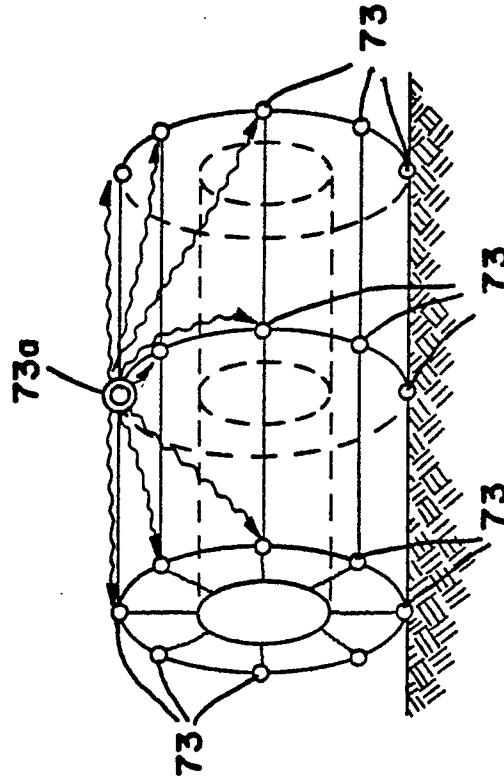
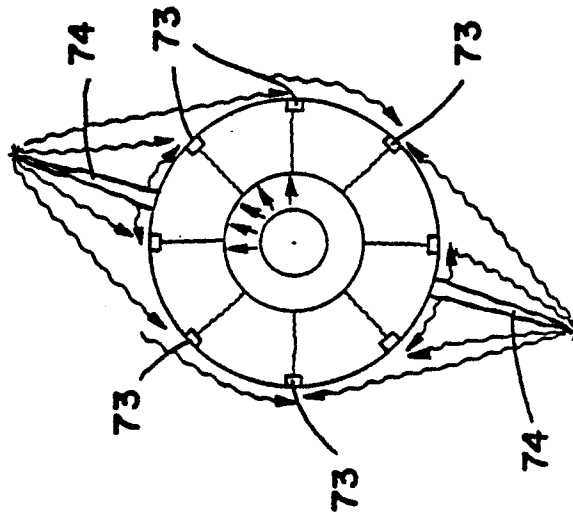
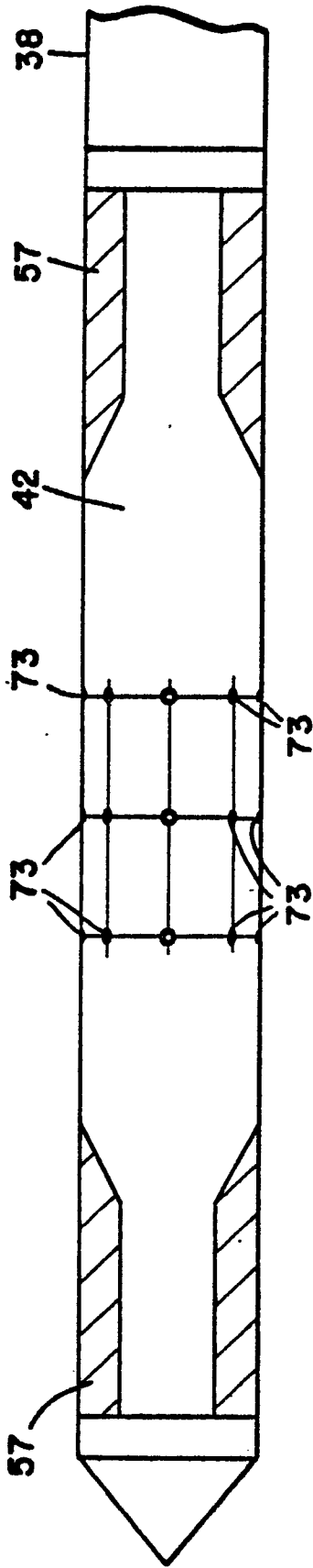


FIG - 2



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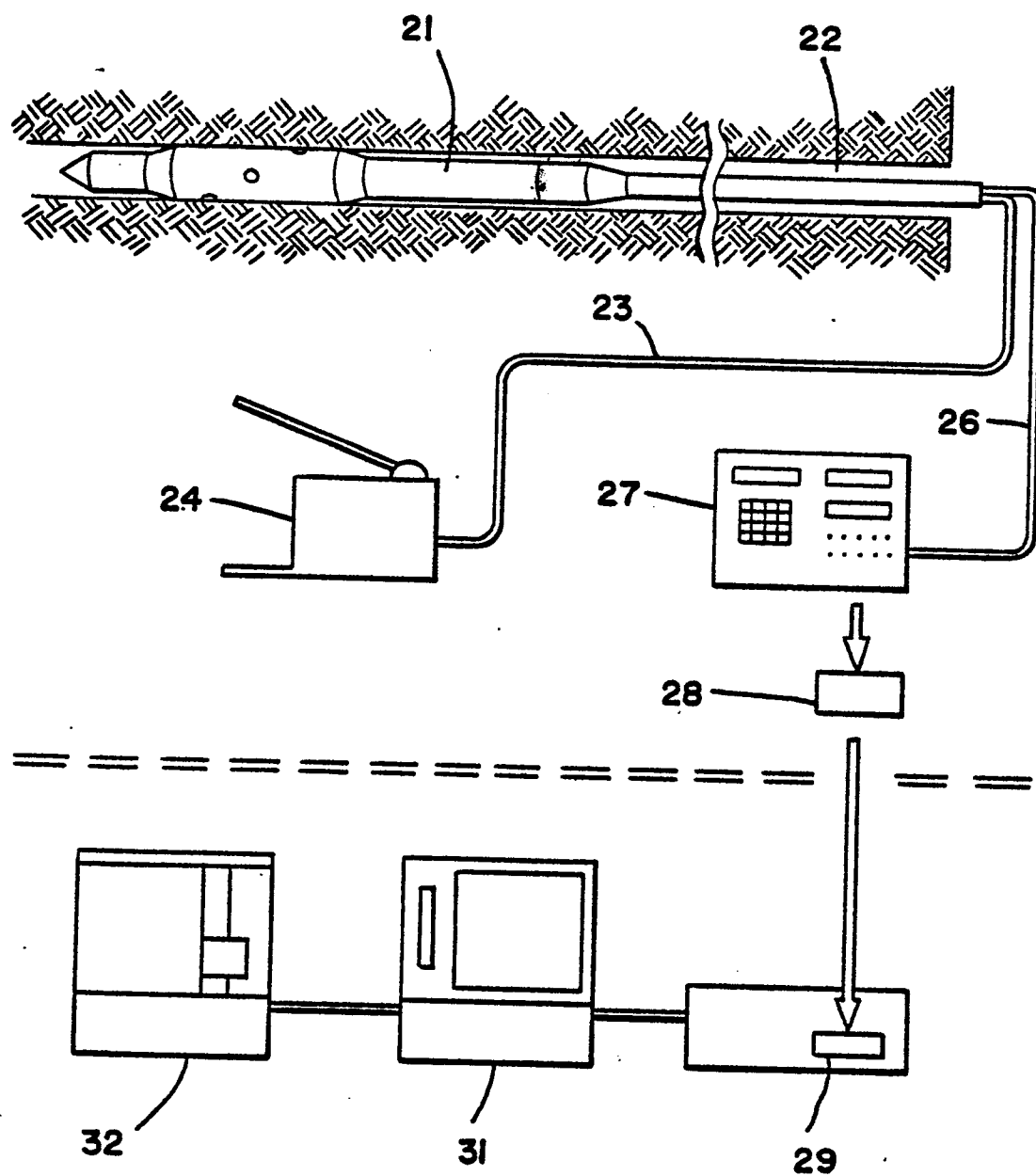
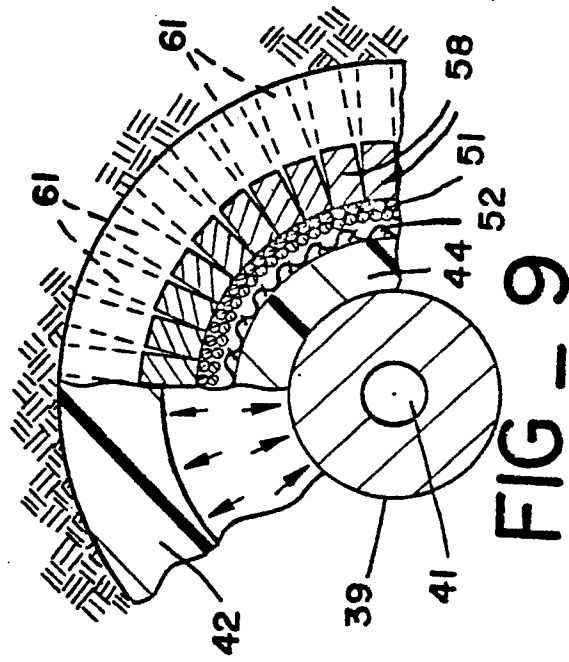
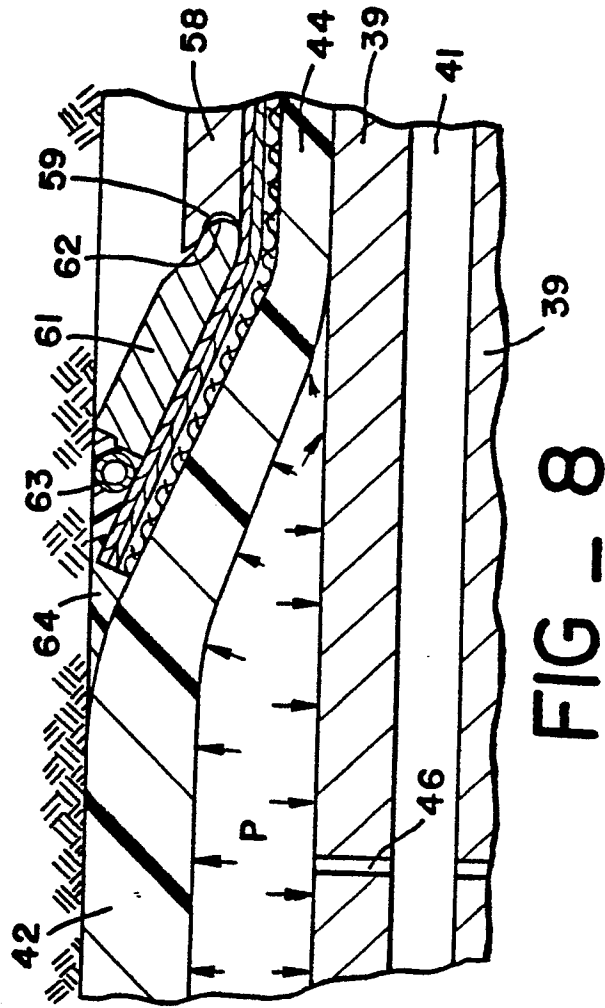
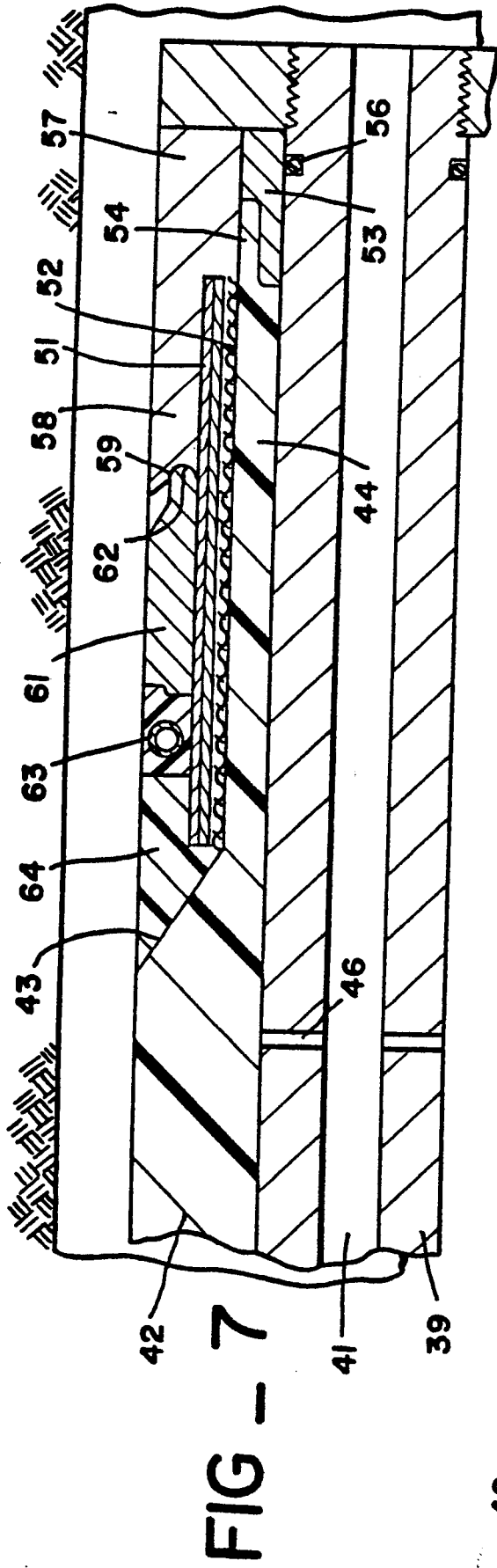
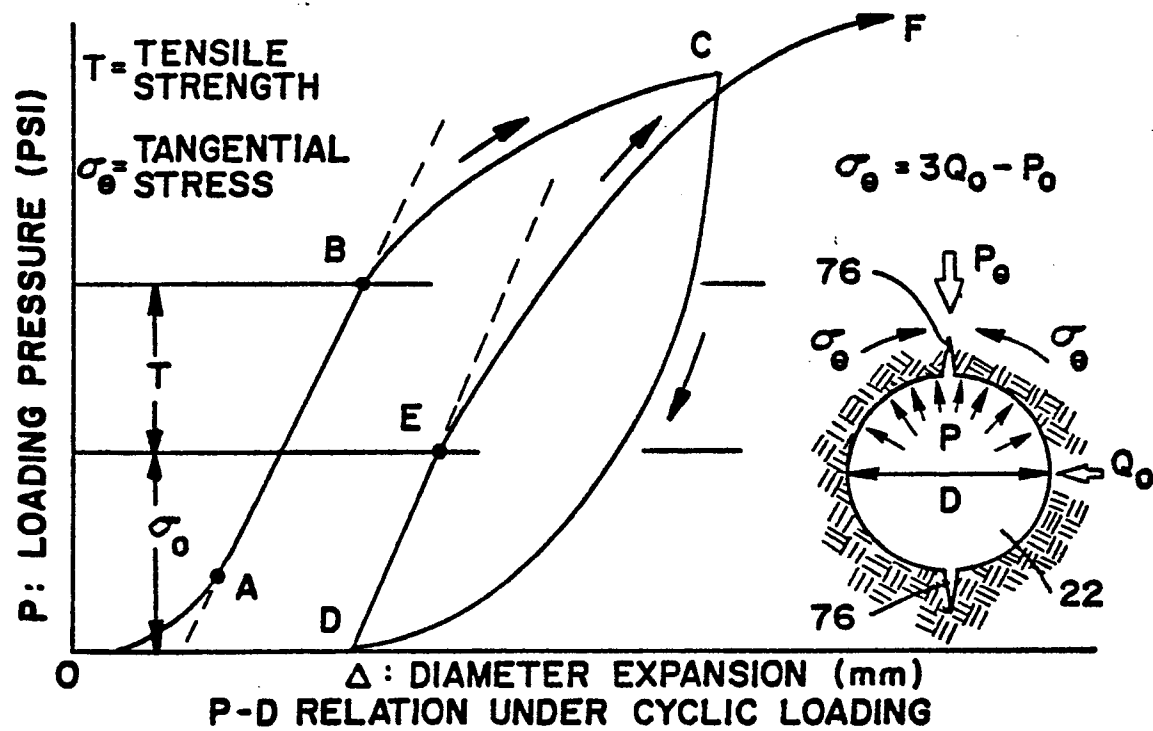
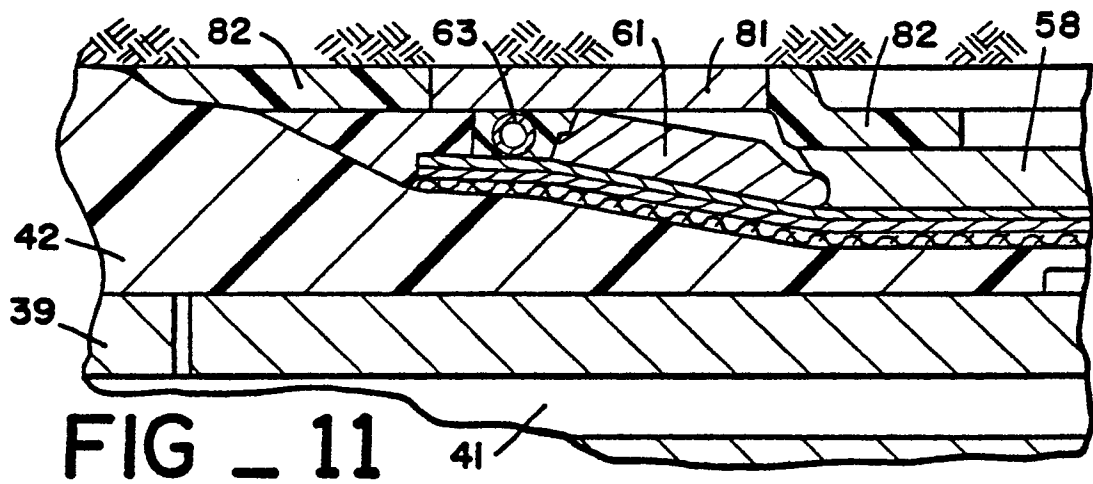
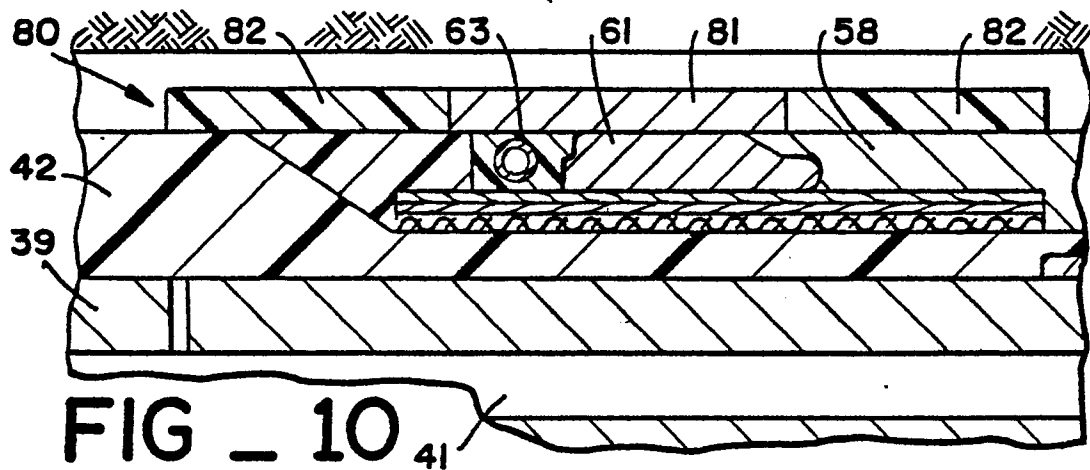


FIG _ 6



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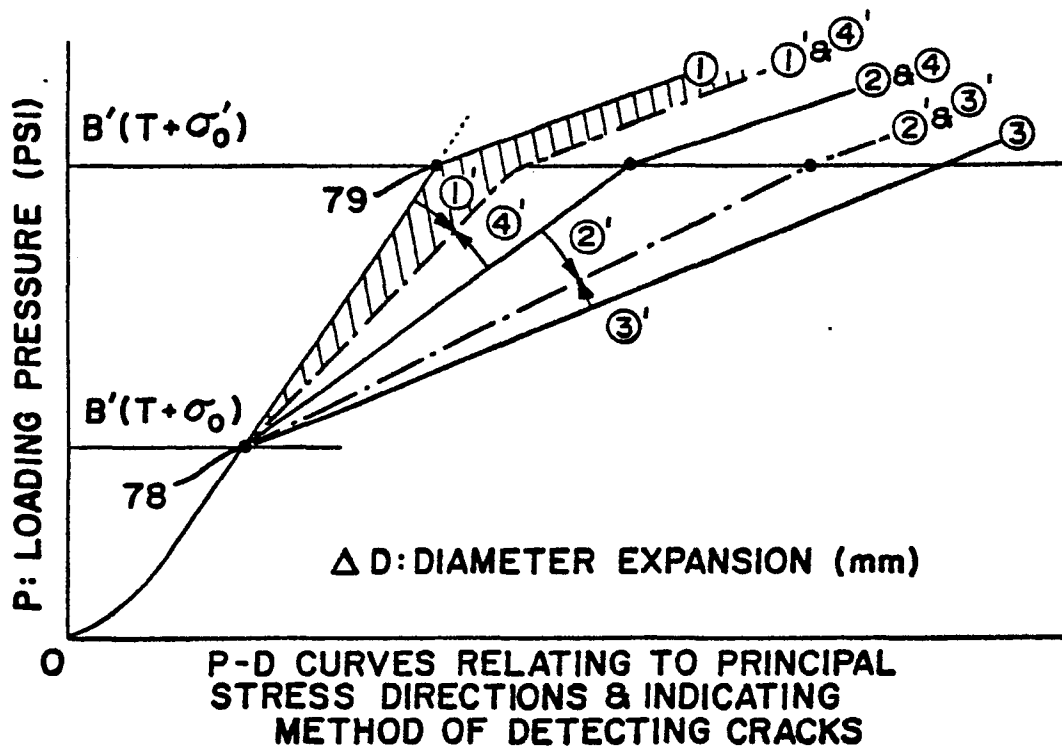


FIG _ 13

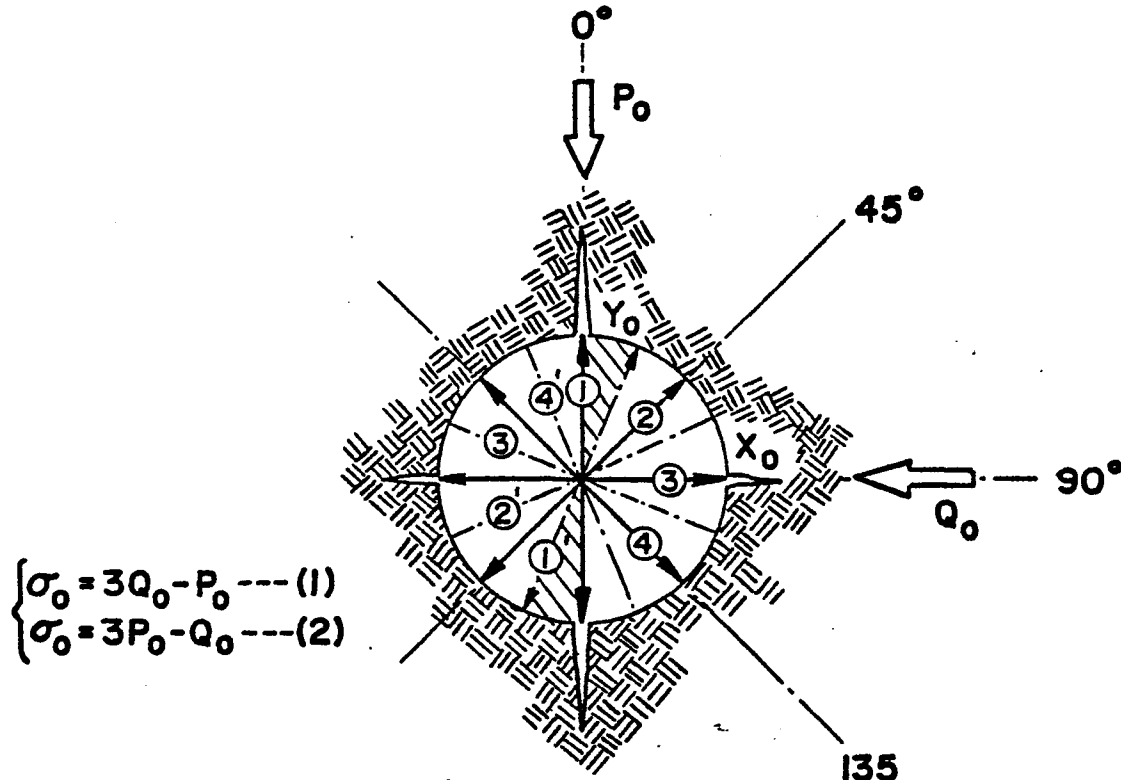


FIG _ 14

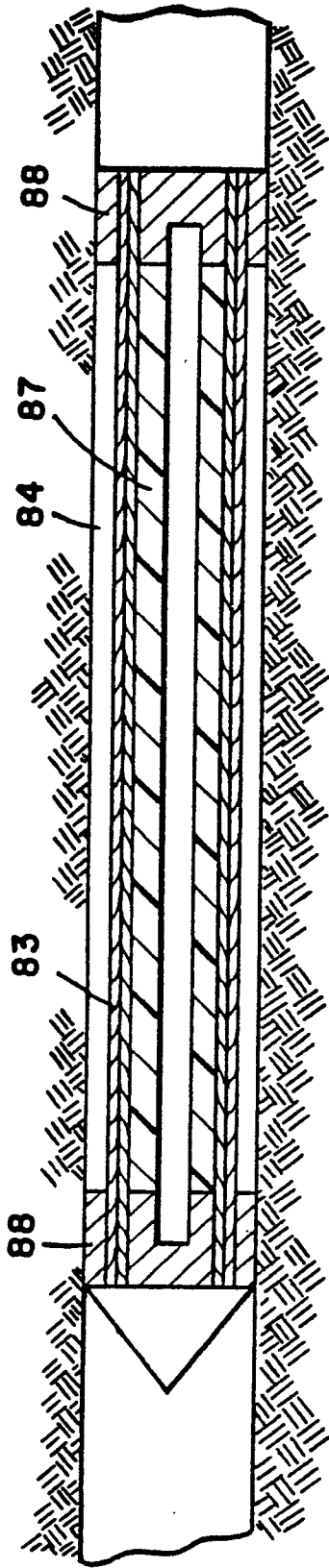


FIG - 15

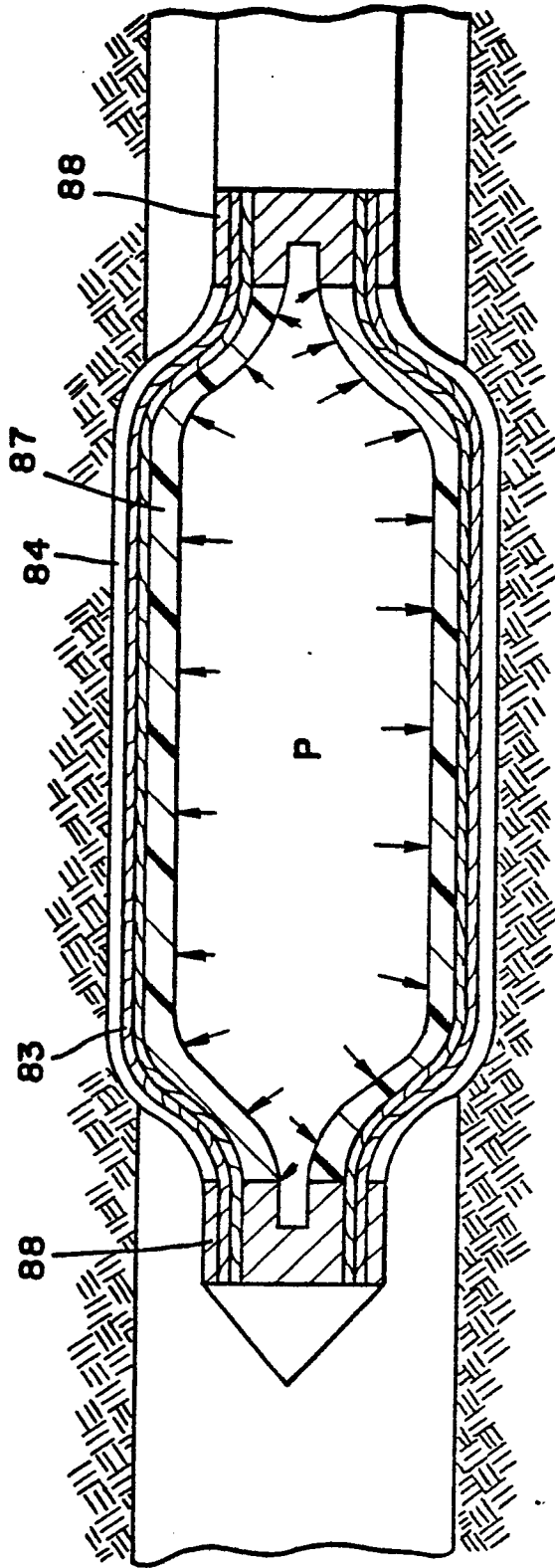


FIG - 16

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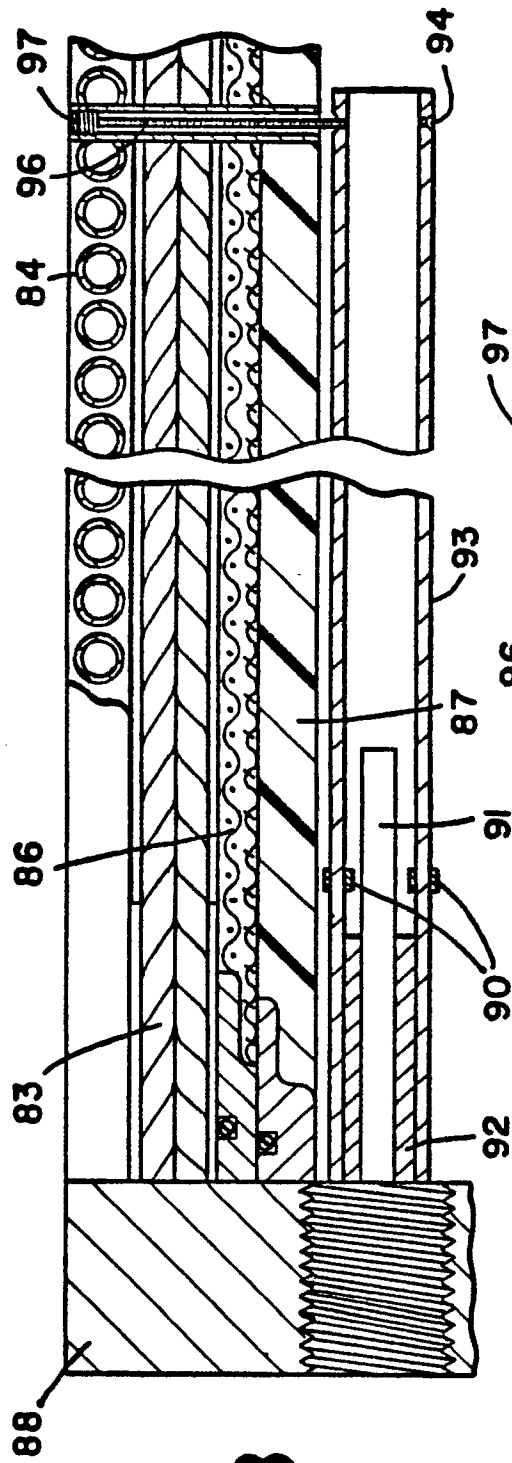


FIG - 18

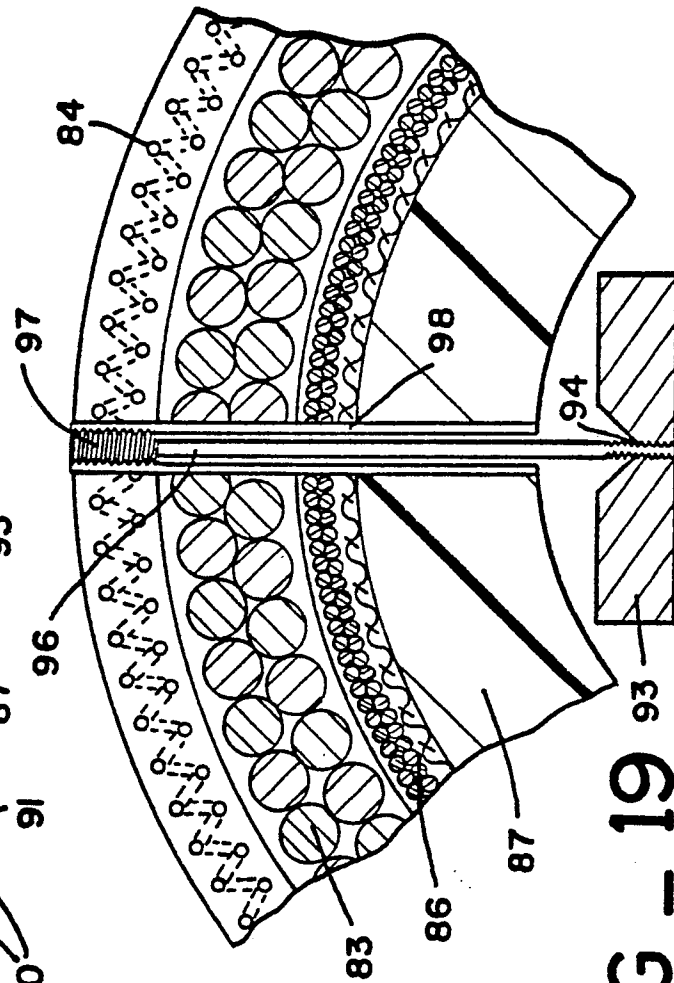


FIG - 19

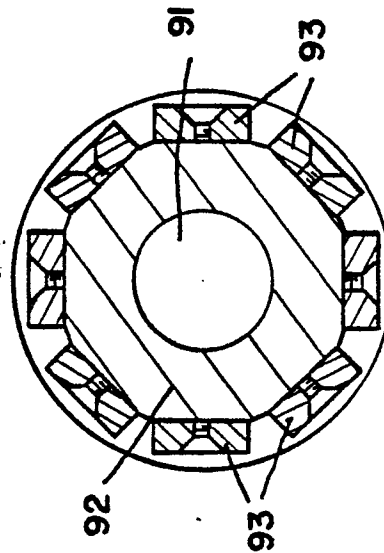


FIG - 17