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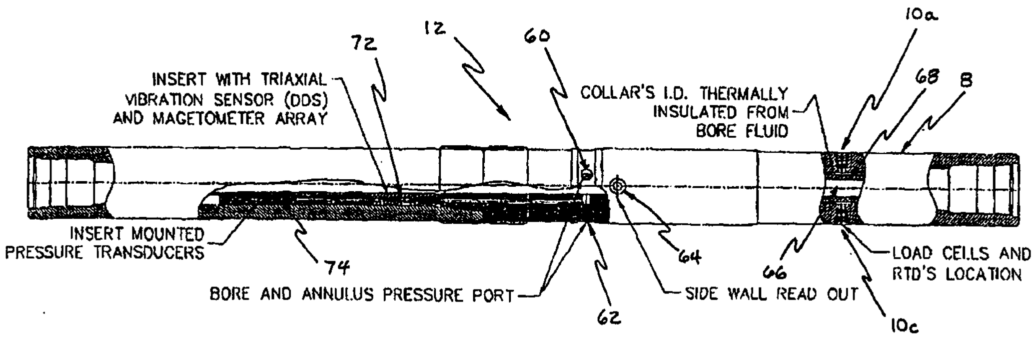
(54) Title: APPARATUS FOR MEASURING DOWNHOLE DRILLING EFFICIENCY PARAMETERS



TOP LEVEL SCHEMATIC FOR DES APPARATUS

(57) Abstract

A downhole drilling efficiency sensor (DES) apparatus for use with drilling operations in oil and gas exploration, that accurately measures important drilling parameters at or near the drill bit in order to increase the effectiveness and productivity of the drilling operation. The parameters measured include weight–on–bit (WOB), torque–on–bit (TOB), bending–on–bit (BOB), annulus pressure, internal bore pressure, triaxial vibration (DDS – drilling dynamics sensor), annulus temperature, load cells (10a, 10c) temperature, and drill collar wall (8) inside diameter temperature of a drill string (12). The direction of the bending–on–bit measurement is also determined with respect to the low side of the hole while rotating (or stationary) by using a triaxial vibration sensor and magnetometer array (72). The device combines sensors (74), temperature readings and other sensors capable of collectin all the indicated parameters, for presenting them to the drilling operator such that an accurate views of the downhole drilling parameters, as thermally isolated (66) from thermal effects of borehole fluid (66) are obtained via side wall readout (64).

TITLE: APPARATUS FOR MEASURING DOWNHOLE DRILLING EFFICIENCY PARAMETERS

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates generally to devices and tools for the measurement of downhole environmental parameters during oil and gas drilling operations. The present invention relates more specifically to a downhole drilling efficiency sensor for use with oil and gas drilling operations that accurately measures drilling parameters at or near the drill bit in order to increase the effectiveness and productivity of the drilling operation.

2. DESCRIPTION OF THE RELATED ART

U.S. Patent No. 4,662,458 issued to **Ho** entitled Method and Apparatus for Bottom Hole Measurement and commonly assigned with the present application describes a downhole tool with strain gauges and includes measurements for weight-on-bit (WOB), torque-on-bit (TOB), bending-on-bit (BOB), and side forces.

U.S. Patent Nos. 4,821,563 and 4,958,517, both issued to **Maron** and both entitled Apparatus for Measuring Weight, Torque, and Side Force on a Drill Bit, each describe an apparatus that includes strain gages located in radial holes in the wall of the drill collar sub. The strain gages are position in a non-symmetrical arrangement.

U.S. Patent No. 5,386,724 issued to **Das et al.** entitled Load Cells for Sensing Weight and Torque on a Drill Bit While Drilling a Well Bore also describes the use of an array of load cells made up of strain gages for measuring weight and torque parameters. The **Das et al.** disclosure includes a recent review of the relevant art and a description of selected methods for calculating strain using strain gages of the type employed herein and is therefore cited and incorporated by reference herein in its entirety.

SUMMARY OF THE PRESENT INVENTION

The present invention provides a downhole drilling efficiency sensor (DES) apparatus for use with drilling operations in oil and gas exploration, that accurately measures important drilling parameters at or near the drill bit in order to increase the effectiveness and productivity of the drilling operation. The parameters measured include weight-on-bit (WOB), torque-on-bit (TOB), bending-on-bit (BOB), annulus pressure, internal bore pressure, triaxial vibration (DDS - Drilling Dynamics Sensor), annulus temperature, load cell temperature, and drill collar inside diameter temperature. The direction of the bending-on-bit measurement is also determined with respect to the low side of the hole while rotating (or stationary) by using a triaxial vibration sensor and magnetometer array.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a partial cross-sectional view of the structural configuration of the apparatus of the present invention.

Fig. 2a is a circumfrentially expanded view of the strain gauges of the present invention positioned on an inside diameter of the load cell of the present invention.

Fig. 2b is a schematic side view of a representative load cell of the present invention showing the position of the associated strain gauges shown in Fig. 2a.

Fig. 3a is an electronic schematic diagram showing a representative weight-on-bit Wheatstone bridge circuit.

Fig. 3b is an electronic schematic diagram showing a representative torque-on-bit Wheatstone bridge circuit.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is made first to Figure 1 for a detailed description of the overall structure of the present invention. Four independent load cells (10a) - (10d) are mounted at either a single cross-sectional position or may be spaced apart at 90° intervals around drill collar wall (8). Each load cell (10a) - (10d) comprises a ring (14) (best seen in Figure 2a) consisting of two independent Wheatstone bridges (18) and (19) (best seen in Figures 3a and 3b) with each bridge being constructed of four foil strain gauges (20), (24), (28), (32) and (22), (26), (30), (34) (best seen in Figure 2b). The gauges (20) - (34) are located on the inside diameter wall (16) of the ring (14). The load cells (10a) - (10d) are press fit into the drill collar (8) and sealed in an atmospheric chamber. The gauges (20) - (34) are covered with a protective coating and the atmospheric chamber is dry inert gas purged before the assembly is sealed. The necessary electrical connections (40) - (58) are provided to each of the strain gauges (20) - (34) and the temperature sensors (36) (described in more detail below). Routing of these conductors (40) - (58) within the tool is accomplished in a manner well known in the art. Appropriate electronics, also well known in the art and not disclosed herein, are utilized to make the appropriate resistance measurements and the associated strain calculations.

The drill collar wall (8) in which the load cells (10a) - (10d) are located is thermally insulated (68) from the borehole fluid (66). Applied forces to the drill collar (8) cause the load cell rings (10a) - (10d) to deform from a circular geometry into an oval geometry (see for example Figures 10 and 11 in the **Das et al.** patent). The distortion of the load cells (10a) - (10d) causes either the weight-on-bit (WOB) or the torque-on-bit (TOB) resistances to change. This resistance change is calibrated in advance for a given load. Since each load cell (10a) - (10d) provides an independent measurement, the bending-on-bit (BOB) can be calculated with the drill string (12) either stationary or rotating. The independent load cells (10a) - (10d) also allow for redundant measurements of weight-on-bit, torque-on-bit, and bending-on-bit.

The direction of the bending-on-bit with respect to the low side of the hole can be determined using a triaxial vibration sensor and magnetometer array (72) for finding and tracking the low side of the hole even while rotating.

Three RTD temperature sensors (36a) - (36c) are radially spaced in the drill collar wall (8) in line with the load cells (10a) - (10d). The RTD sensors (36a) - (36c) measure the drill collar outside diameter temperature, the load cell temperature, and the drill collar inside diameter temperature. From the temperature sensor (36a) - (36c) locations the temperature gradient across the drill collar wall (8) can be determined.

The apparatus of the present invention additionally comprises two fluid communication ports (60) and (62) which communicate fluid pressure through the drill collar wall (8) to insert mounted pressure transducers. One port (60) is ported to the annulus and the other port (62) is ported to the internal bore to allow for measuring the respective pressures. In addition, a side wall readout (64) is provided as shown in Figure 1.

A triaxial vibration sensor (DDS) (72), as is known in the art, measures the g-levels (acceleration forces) that the tool is subjected to while in operation.

The apparatus of the present invention provides a drilling efficiency sensor (DES) with the ability to measure a number of drilling parameters. Prior efforts have only made questionable attempts to correct for the effects of temperature and pressure variations on the load cells used and generally do not provide means for measuring all of these important environmental parameters. The apparatus of the present invention measures these ancillary parameters and determines their effect on the load cell in a manner that permits accurate correction of the load cell output. The appropriate algorithms for incorporating the effects of these parameters into the corrected calculations of the various force measurements is known in the field.

By utilizing the ring structure of the present invention, load cell sensitivity is dramatically increased. This eliminates the need to couple a half bridge from one load cell to the half bridge of the other load cell as is described in **Das et al.** (referenced above). In addition, since the entire Wheatstone bridge is located on one removable ring, the load cells of the present invention are more reliable, easier to assemble, and easier to maintain.

The ring structure of the present invention allows the load cell sensitivity to be adjusted by increasing or decreasing the ring's wall thickness. By having four independent Wheatstone bridge measurements, located at 90° intervals from each other, the bending moment can be determined regardless of drill string rotation. The **Moran** disclosures referenced above describe the calculation of bending-on-bit while rotating by coupling a half bridge from one port to the half bridge of the other port. Coupling of bridges is not required with the apparatus of the present invention. The **Das et al.** disclosure does not include a bending-on-bit calculation. In addition, in the **Das et al.** disclosure, weight-on-bit measurements have an uncorrectable error from bending-on-bit due to the coupling of the half bridges. The sum of this coupling ends up being included in the measurement.

As indicated above, the Drilling Efficiency Sensor apparatus of the present invention incorporates three RTD temperature sensors, radially spaced in the drill collar wall, in line with each of the four load cells. The temperature sensors are radially located in order to measure temperature at the drill collar's outside diameter, the drill collar's inside diameter, and at the load cells. A temperature gradient can therefore be measured across the drill collar wall. This allows for a correction of each load cell's output to remove the effects of thermal stresses that are generally present in the drill collar wall. The temperature sensors also allow for a steady state temperature correction to be made (not just fluctuations in temperature or temperature gradients). The systems described in the prior art generally have no mechanisms for correcting for temperature gradients or for determining steady state temperature offset. Instead, many systems in the prior art incorrectly suggest that locating the strain gauge(s) at a mid wall position in the drill collar will nullify the effects of thermal stresses.

The drill collar wall in which the load cells of the present invention are positioned is thermally isolated from the bore fluid and its temperature. This structural geometry makes a temperature gradient correction possible since there is essentially only a single thermal effect on the load cells. This structure also allows the drill collar wall in which the load cells are located to reach a constant temperature, giving a more stable measurement that for the most part remains unaffected by the temperature differential between the internal bore fluid and the annulus fluid. Given that the internal bore fluid and annulus fluid temperatures are different (as is most often the case), the prior art systems will generally be subject to a temperature gradient across the drill collar wall in which the load cells are located. The prior art has generally not been able to correct for the effect that this temperature gradient has on load cell output.

In addition, the apparatus of the present invention has two insert mounted quartz pressure transducers (74) (seen best in Figure 1) that are ported (60) and (62) to the annulus and internal bore through the drill collar wall (8). Since the transducers (74) are insert mounted, they are easy to install and maintain. These transducers measure the annulus and internal bore fluid pressures and correct the load cell's output for the effects of any pressure differential across the drill collar wall. The effect of a pressure differential across the drill bit (axial and tangential stress) can also be corrected for. The systems described in the prior art have applied questionable methods to correct for pressure differentials across the drill collar wall and cannot correct for the pressure differential across the bit. In general, the prior art systems do not provide mechanisms for measuring downhole pressures.

Finally, the apparatus of the present invention provides a triaxial vibration sensor (DDS - Drilling Dynamics Sensor) that is capable of measuring the g-levels (acceleration forces) that the drill string is subjected to. The systems described in the prior art do not generally provide mechanisms for measuring these forces.

The direction of the bending-on-bit with respect to the low side of the bore hole can be determined by the present invention by using the triaxial vibration sensor and magnetometer array (72) to find and track the low side of the hole even while the drill string is rotating. The systems described in the prior art do not generally provide mechanisms for determining the direction of the bending-on-bit with respect to the low side of the bore hole.

CLAIMS

1. A downhole drilling parameter sensor device for use with drilling operations in oil and gas exploration, the sensor device comprising:

a plurality of load cells orthogonally positioned within a drill collar wall of a drill string, said load cells comprising:

a first Wheatstone bridge comprising four strain guages orthogonally positioned within a ring configuration within said load cell; and

a second Wheatstone bridge comprising four strain guages orthogonally positioned within a ring configuration within said load cell;

a plurality of temperature sensors positioned within said drill collar wall and arrayed to measure temperatures at locations comprising said drill collar's outside diameter, said drill collar's inside diameter, and said load cells;

a triaxial vibration sensor positioned within said drill string proximate to said load cells;

a magnetometer array positioned within said drill string in physical association with said triaxial vibration sensor;

a first pressure transducer positioned within said drill string in fluid communication with an annular volume surrounding said drill string within said borehole; and

a second pressure transducer positioned within said drill string in fluid communication with an internal bore of said drill string;

wherein said plurality of independent load cells provide for redundant maesurements of weight-on-bit, torque-on-bit, and bending-on-bit forces, said plurality of temperature sensors provide for measurements of temperature gradients so as to correct said load cell measurements, said triaxial vibration sensor and said magnetometer array provide for measurements of drill string motion to provide for finding and tracking drill string rotational orientation within the borehole, and said pressure transducers provide for measurement of pressure variations so as to correct said load cell measurements.

2. The sensor device of Claim 1 wherein said strain guages comprise foil strain guages covered with a protective coating and located on an inside diameter of a ring member element of said load cells.

3. The sensor device of Claim 1 wherein said plurality of load cells number four, are ring-shaped in configuration, and are press-fit into circular recesses positioned within said drill collar wall.

4. The sensor device of Claim 1 further comprising a read-out port in a side wall of said drill collar for electrical connection between conductors associated with said load cells, said temperature sensors, said pressure transducers, said

triaxial vibration sensor, and said magnetometer array, and an external data collection device.

5 The sensor device of Claim 1 wherein an internal wall of said drill collar is thermally insulated from a drilling fluid used in operation of said drill string within said borehole.

6. The sensor device of Claim 1 wherein said drill collar wall is thermally insulated from a drilling fluid used in operation of said drill string within said borehole.

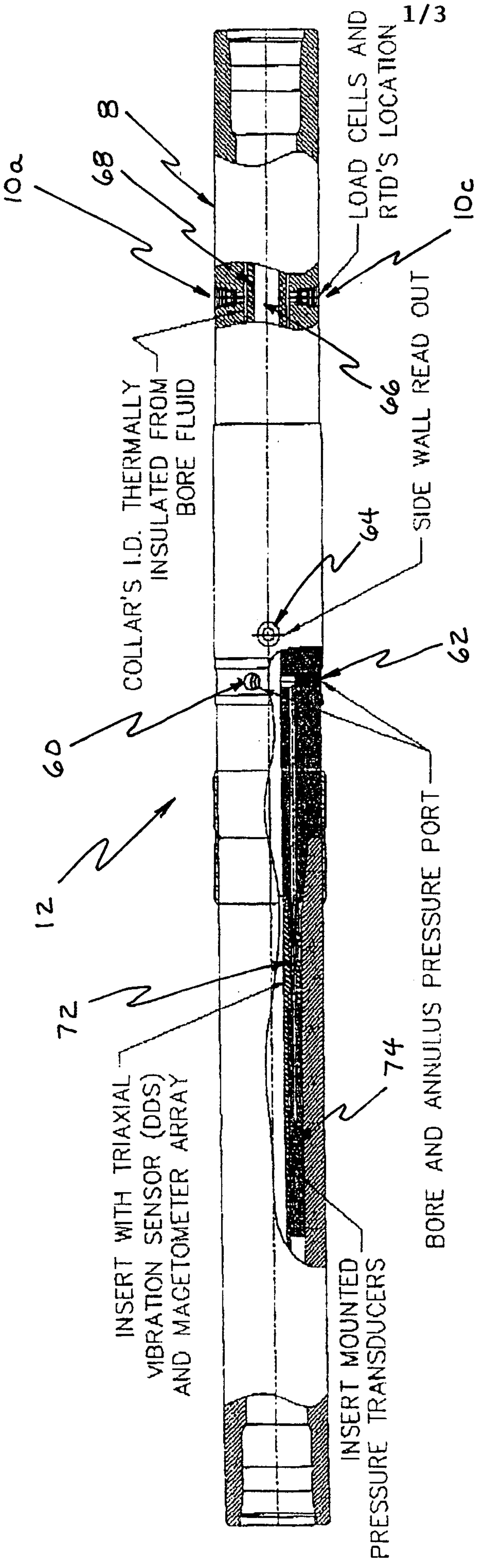


FIGURE 1 TOP LEVEL SCHEMATIC FOR DES APPARATUS

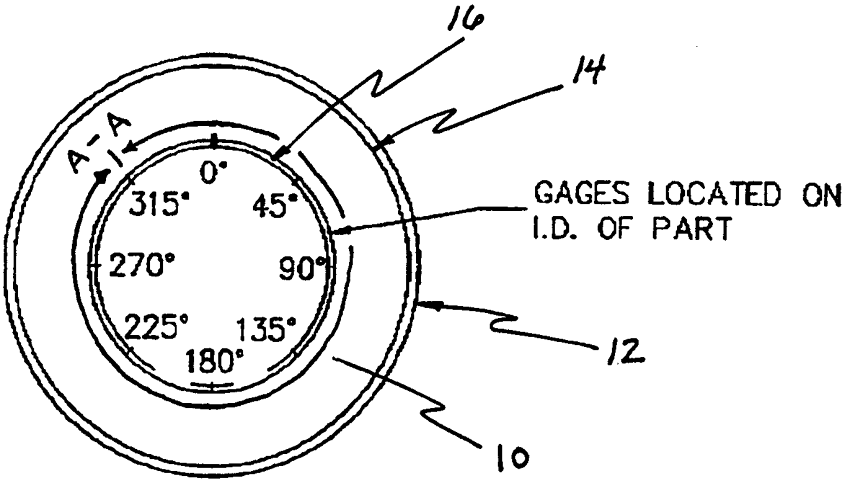


FIGURE 2a

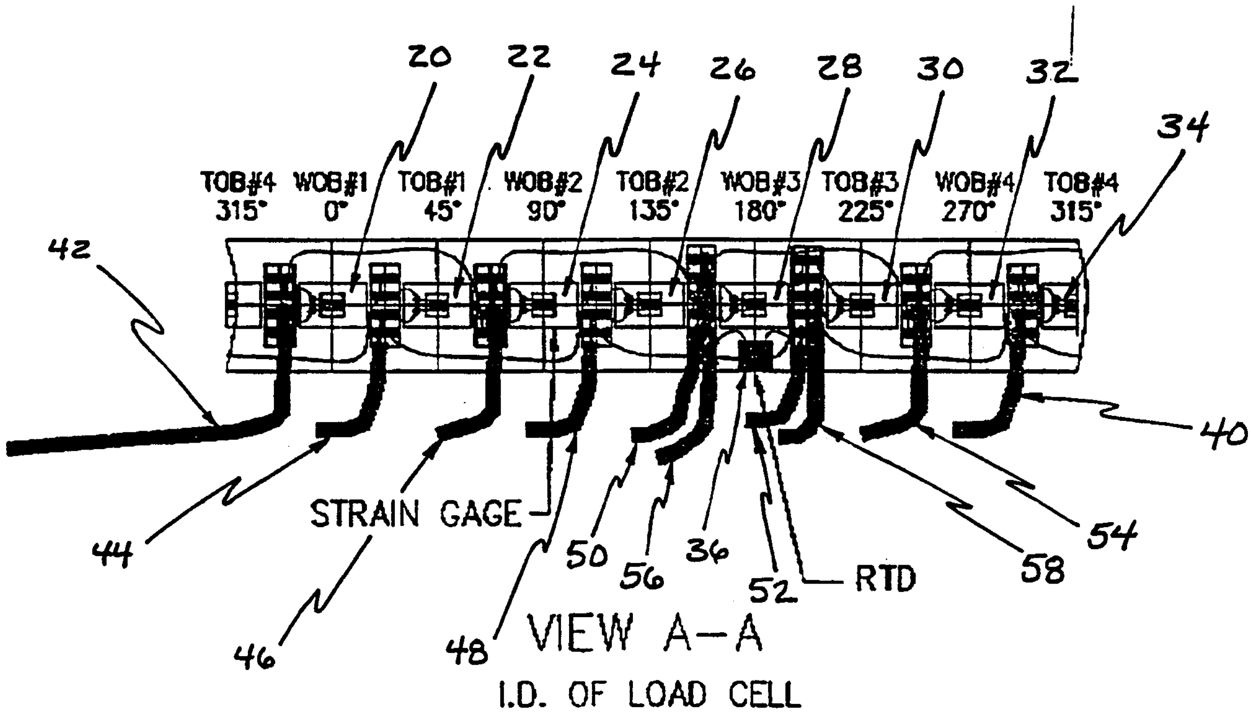
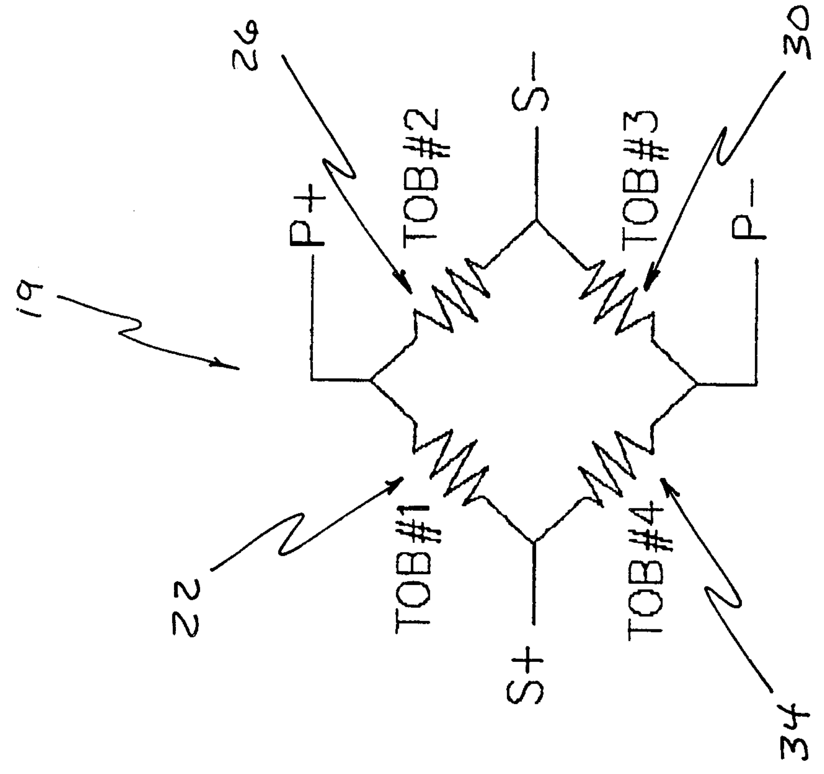
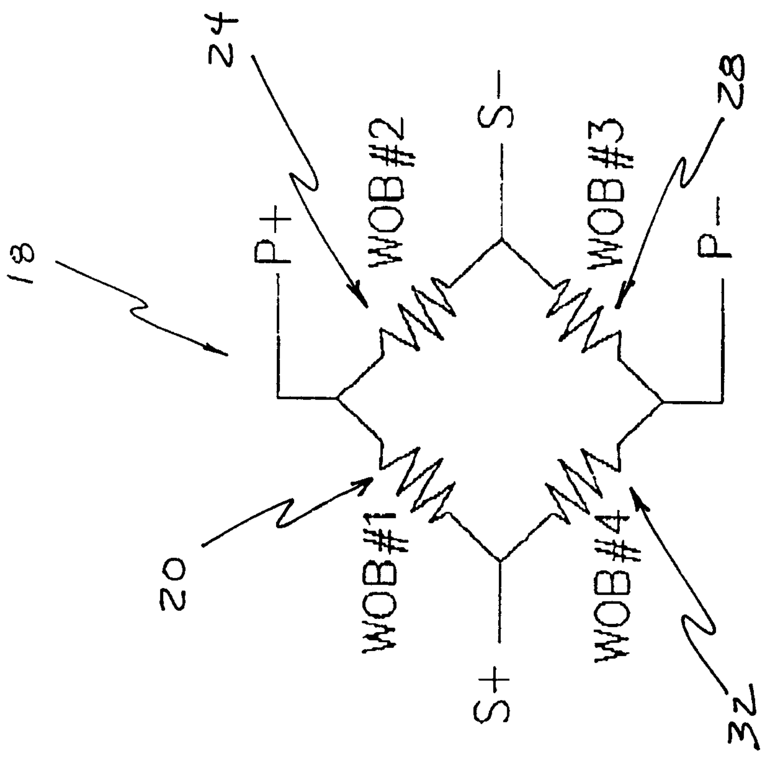


FIGURE 2b



TOB WHEATSTONE BRIDGE SCHEMATIC

FIGURE 3b



WOB WHEATSTONE BRIDGE SCHEMATIC

FIGURE 3a

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/29572

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :E21B 47/12, 47/00, 44/00; G01V 01/40, 03/00;
US CL :073/152.01, 152.47, 152.52; 175/50, 45; 166/250.07, 254.20
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)

U.S. : 073/152.01, 152.46, 152.47, 152.52, 152.16; 175/50, 45, 40,48; 166/250.07, 254.20, 250.01, 250.16

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

None

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

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,662,458 A (HO) 05 May 1987 (05-05-1987), see entire document.	1, 3, 5-6
A	US 4,821,563 A (MARON) 18 April 1989 (18-04-1989), see entire document.	1, 3
A	US 4,958,517 A (MARON) 25 September 1990 (25-09-1990), see entire document.	1-3
A	US 5,679,894 A (KRUGER et al.) 21 October 1997 (21-10-1997), see entire document.	1-6
X	US 5,467,083 A (MCDONALD et al.) 14 November 1995 (14-11-1995), see entire document.	1-4

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 28 APRIL 2000	Date of mailing of the international search report 23 MAY 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer DAVID JOHN WIGGINS Telephone No. (703) 305-4884

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/29572

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,903,245 A (CLOSE et al.) 20 February 1990 (20-02-1990), see entire document.	1
A	US 5,812,068 A (WISLER et al.) 22 September 1998 (22-09-1998), see entire document.	1, 3-6
X	US 5,386,724 A (DAS et al.) 07 February 1995 (07-02-1995), see entire document.	1-3, 5-6
X	US 3,884,071 A (HOWETH et al.) 20 May 1975 (20-05-1975), see entire document.	1, 3-4
A	US 3,817,345 A (BAILEY et al.) 18 June 1974 (18-06-1974), see entire document.	1

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

USPTO APS STN/CAS search terms: drilling downhole or subterranean; borehole or wellbore; oil, petroleum or natural gas; load cell; vibration or seismic; sensor, detector, gauge, or probe; temperature or pressure; magnetometer or gravitometer; logging; stress, strain or load; Wheatstone Bridge.