(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 March 2006 (02.03.2006)

PCT

(10) International Publication Number
WO 2006/023607 A1

(51) International Patent Classification:
G01F 1/36 (2006.01) *G01F 1/74* (2006.01)
G01F 1/44 (2006.01) *G01L 9/00* (2006.01)

(21) International Application Number: PCT/US2005/029334

(22) International Filing Date: 18 August 2005 (18.08.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/920,863 18 August 2004 (18.08.2004) US

(71) Applicant *(for all designated States except US)*: **BAKER HUGHES INCORPORATED** [US/US]; Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **PETER, Andreas**; Am Kriegersteg 27, 29997 Celle (DE).

(74) Agents: **RIDDLE, J., Albert** et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).

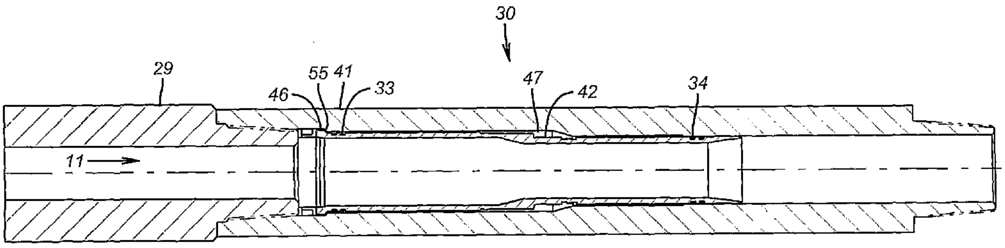
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

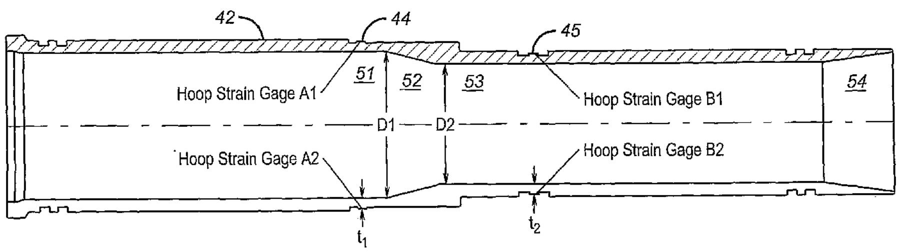
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FLOW METER USING STRAIN GUAGES TO MEASURE A PRESSURE DIFFERENTIAL





(57) Abstract: A system and method provides a flow measurement system for steady-state and transient flow. A housing contains a sleeve such that the sleeve is isolated from external mechanical loads. A flow measurement element, such as a venture or nozzle, is located in the sleeve. Strains along the sleeve caused by flow pressure changes through the flow element are detected and related to fluid flow rate.

WO 2006/023607 A1

FLOW METER USING STRAIN GAUGES TO MEASURE A PRESSURE DIFFERENTIAL

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to flow measurement of abrasive fluids and more particularly to a flow meter suitable for use in a drilling tubular.

Description of the Related Art

Drilling systems for oil and gas production commonly include a drilling fluid flowing down a tubular member in a borehole and back up to the surface. The drilling fluid serves several purposes known in the art, such as removing cuttings from the wellbore. The drilling fluid is a mixture of a liquid with solid particles in suspension. As is known in the art, some of the solids may be added to the liquid to control the viscosity and gel strength of the liquid, for example, to maintain the cuttings in suspension in the drilling fluid. Other solids, such as barite, may be added to control the hydrostatic pressure near the bottom of the wellbore, so as to control formation fluid flow into the wellbore. The drilling fluid inside the tubular member may be at relatively high pressure and be at flow rates in the range of 100 gpm to over 1000 gpm. Measurement of the flow rate of the drilling fluid in such a situation is problematic.

Common obstruction type flow meters, such as orifice plates, result in unacceptable pressure losses across the flow metering section. **Fig. 1** depicts a common venturi type meter where the flow is accelerated through the gradually reducing conically tapered nozzle section to the minimum area at the throat section. The accelerated flow has a related static pressure drop between the entrance pressure port and the throat pressure port with the pressure drop being determinable from Bernoulli's equation, well known to those skilled in the art. The fluid flow expands and diffuses in the gradually tapered diffuser section such that as much as 75% of the pressure drop is recovered. The pressure differential between the entrance and the throat may be detected by a differential pressure transducer known in the art. The system as described in **Fig. 1**, however, has serious drawbacks when used in a drilling fluid flow system. For example, when the flow meter is located in a vertical orientation, the solids in the drilling fluid have a tendency to settle out in and clog the fluid lines leading from the pressure ports to the differential pressure sensor. In addition, the sensing pressure ports create a flow disturbance that leads to locally accelerated erosion caused by the particles in the drilling fluid impinging on the port.

Thus, there is a demonstrated need for a flow meter that is suitable for use in abrasive fluid flow and is resistant to clogging and erosion.

SUMMARY OF THE INVENTION

In one aspect, the present invention provides a system for measuring a fluid flow comprising a housing adapted to be inserted in a flowline. A sleeve is adapted to fit into the housing. The sleeve has a flow measuring element disposed therein such that the flow element generates a pressure difference across the flow element related to a flow rate of the fluid flow therethrough. A first seal and a second seal act cooperatively with the sleeve and the housing to form a sealed volume between a portion of the sleeve and the housing. A first strain sensor is attached to the sleeve at a first predetermined location and generates a first signal related to a fluid pressure in the sleeve upstream of the flow element. A second strain sensor is located on the sleeve at a second predetermined location spaced apart axially from the first strain sensor and generates a second signal related to a fluid pressure in the sleeve at the second predetermined location. The difference between the first signal and the second signal is related to a flow rate of the fluid inside the sleeve.

In another aspect, a method for measuring a fluid flow comprises inserting a housing in a flowline. A sleeve is adapted to fit into the housing. The sleeve has a flow measuring element disposed therein such that the flow element generates a pressure difference across the flow element where the pressure difference is related to a flow rate of the fluid flow through the sleeve. A first seal and a second seal act cooperatively with the sleeve and the housing to form a sealed volume between a portion of the sleeve and the housing. A first strain sensor is attached to the sleeve at a first predetermined location and generates a first signal related to a fluid pressure in the sleeve at the first predetermined location. A second strain sensor is located on the sleeve at a second predetermined location spaced apart axially from the first strain sensor and generates a second signal related to a fluid pressure in the sleeve at the second predetermined location. The difference between the first signal and the second signal is related to a flow rate of the fluid inside the sleeve.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following detailed description of the embodiments, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

Figure 1is a sketch of a prior art flow measuring device;

Figure 2 is a sketch of a drilling system having a flow measurement system according to one embodiment of the present invention;

Figure 3 is a sketch of one embodiment of a flow measurement system;

Figure 4 is a sketch of a sleeve component used in one embodiment of the present invention;

Figure 5 is a schematic of a circuit used in conjunction with one embodiment of the present invention;

Figure 6 is a schematic of a sleeve having a replaceable flow measurement element used in one embodiment of the present invention; and

Figure 7 is schematic of a multi-component sleeve used in one embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

In one embodiment, see **Fig. 2**, and described herein as an example and not as a limitation, a drilling operation has a derrick **10** for supporting a drill string **3** in a borehole **2**, also called a wellbore. Supported in derrick **10** is a top drive **29** for rotating drill string **3**. Drill string **3** comprises multiple sections of drill pipe **1** connected together by threaded connections **4**. A bottomhole assembly **9** is attached to the bottom end of drill string **3** and has a drill bit **8** attached to a bottom end thereof. Drill bit **8** is rotated to drill through the earth formations. Bottomhole assembly **9** comprises multiple sections of drill collars **6** and may have a measurement while drilling (MWD) system **7** attached therein, above bit **8**. Drill collar sections **6** and MWD system **7** are connected through threaded connections **5**. Measurement while drilling, and/or logging while drilling (LWD), systems are well known in the art. Such systems commonly measure a number of parameters of interest regarding the drilling operation, the formations surrounding the borehole **2**, and the position and direction of the drill bit **8** in the borehole **2**. Such systems may include downhole processors (not shown) to provide open or closed loop control, in conjunction with a steerable system (not shown), of the borehole **2** path toward a predetermined target in a subterranean formation. In an alternative embodiment, a kelly drive (not shown), of a kind known in the art, may be used to rotate drill string **3**.

Drilling fluid **11**, commonly called drilling mud, is pumped by pump **16** through the drill string **3**, exits the bit **8** and returns back to the surface in the annulus **12** between drill string **3** and borehole **2**. Drilling flow rates may commonly range from the order of 100 gpm to in excess of 1000 gpm, depending, at least to some extent, on the borehole size and the ability of the fluid to remove the cuttings from the borehole. Drilling fluid discharge pressure of pump **16** is commonly in the excess of 1000 psi.

As is known in the art, MWD system **7** may transmit data obtained by sensors in MWD **7** by transmitting encoded pressure signals in drilling fluid **11** to a surface sensor **30**, where the encoded pressure signals are detected. A number of devices are known in the art for creating such pulses. In one common device, a positive pressure signal is generated by partially impeding a portion of the flow of drilling fluid **11**. In another device, a negative pressure signal is generated by partially venting a portion of the flow of drilling fluid **11** from inside the drill string **3** to the annulus **12**. In these examples, the positive and negative reference is relative to the overall static pressure level in the drilling fluid **11** as it flows through the drill string **3**. In yet another common arrangement, a continuous wave is generated that propagates to the surface. In each device, a pressure signal is generated that propagates through the drilling fluid **11** in drill string **3** to a surface sensor **30** where it is detected and transmitted electrically to a processor **15** for decoding and interpretation. Commonly, surface sensor **30** is a pressure sensor that detects the pressure pulse that propagates to the surface. One skilled in the art will realize that the pressure pulse induced in the drilling fluid flow has a related flow velocity change determined by the relationship quantifying the water hammer effect, see U.S. Patent 4,262,343 to Claycomb. The pressure change-velocity change relationship is of the form:

$$\Delta P = \rho C \, \Delta V \qquad (1)$$

where,

ΔP= the magnitude of the pressure pulse,

ρ= the fluid mass density;

C= the acoustic velocity of the fluid, also called the sound speed of the fluid;

and

ΔV= the change in the fluid velocity.

In one embodiment of the present invention, surface sensor **30** is a flow meter as shown in **Figs. 3** and **4**. Housing **41** is attached to the bottom end of top drive **29**. The other end of housing **41** is adapted to attach to drill string **3** (see **Fig. 2**). Alternatively, housing **41** may be inserted in the high pressure flow line between pump **16** and top drive **29**. Housing **41** has a land **55** adapted to contact upset **46** on sleeve **42** and position sleeve **42** in housing **41**. Seals **33** and **34** seal the ends of sleeve

42 to housing **41** and prevent the intrusion of drilling fluid **11** into the volume **47** between sleeve **42** and housing **41**. The volume **47** contains a gas, for example air, at substantially atmospheric pressure. External mechanical loads on housing **41**, such as bending and tension, are substantially isolated from sleeve **42**.

Sleeve **42** is dimensioned such that the volume **47** is formed by a predetermined gap between the outer diameters of sleeve **42** and the corresponding inner diameters of housing **41**. The dimensions of sleeve **42** and housing **41** are selected, using techniques known in the art, such that under the maximum expected internal pressure of drilling fluid **11**, sleeve **42** does not expand to contact housing **41** along the length between seals **33** and **34**.

The internal surface of sleeve **42** forms flow measuring element such as a venturi type section for determining the flow rate through sleeve **42**. Sleeve **42** has an entrance region **51** of diameter D1, a conically reducing tapered nozzle section **52** that tapers to a straight section **53** of diameter D2. As one skilled in the art will appreciate, from the classical Bernoulli relationship, as flow passes from section **51** to section **53**, at a substantially constant flow rate, the fluid velocity will increase and the fluid static pressure will decrease. The difference in pressure between section **51** and section **53** is related to the volumetric flow rate of the fluid. Changes in internal pressure cause changes in the hoop strains and stresses in sleeve **42** that can be detected and related to flow. The flow is allowed to expand in diffuser section **53** such that a major portion of the pressure difference is recovered in the downstream flow. Different sizes of sleeve **42** may be used for different flow ranges. In addition, should sleeve **42** exhibit erosive wear, it is easily replaced. The internal surface of sleeve **42**, or a portion thereof may be coated with abrasion and/or erosion resistant coatings, for example tungsten carbide coatings.

Strain gages **A1** and **A2** are mounted on a diameter **44** on sleeve **42**. Gages **A1** and **A2** are mounted substantially **180** degrees apart, as shown. Likewise gages **B1** and **B2** are mounted on diameter **45** on sleeve **42**. In one embodiment, lands **44** and **45** are each dimensioned such that hoop strains caused by an equal internal pressure are equal at the two lands. For example, the wall thickness t_1 may be greater than thickness t_2 because the diameter of section **51** is greater than that of section **53**, as one skilled in the art will appreciate.

Fig. 5 shows one embodiment for detecting the pressure differential for use with resistance type the strain gages. Gages **A1, A2, B1, B2** are connected electrically by wires and feedthroughs (not shown) in a wheatstone bridge **60**, where $\mathbf{U_0}$ is the excitation voltage applied to the bridge and **U** is the output of the bridge that is related to the pressure differential between section **51** and section **53**. The use of such an arrangement is known in the art. Note that such a bridge provides temperature compensation because all gages experience substantially the same temperature and thermal expansion. Bending moments acting on the sleeve are compensated because gages on opposite sides of the sleeve are located in opposite arms of the bridge and cancel each other. Static internal pressure inside the sleeve is substantially compensated for as all gages are strained similarly by the internal pressure. Therefore, the output voltage, **U**, is an indication of the pressure difference between sections **51** and **53** that is related to volumetric flow of the fluid through sensor **30**. Output **U** may be connected to control module **63** that contains signal conditioning circuits **61** and processor **62** for converting the output to usable information. Control module **63** also contains circuits to provide power to strain sensors A1, A2, B1, B2. Processor **62** may be a computer with memory and permanent storage capability of a kind known in the art.

In an alternative embodiment, see **Fig. 6**, sleeve **162** is adapted to fit into housing **41** previously described. In this embodiment, a flow element, such as nozzle **120**, is inserted in sleeve **162** and drilling fluid **11** flows therethrough. Nozzle **120** has a predetermined entrance region **152** that accelerates the fluid flow from the entrance section **151** to the throat section **153** and discharges the flow into the exit section **154**. As one skilled in the art will appreciate, the flow in the exit section encounters a substantial pressure loss such that there is a measurable pressure differential between entrance section **151** and exit section **154**. Such a device is similar to commonly used flow nozzle measuring devices. This pressure differential can be related to the flow rate using standard techniques. The pressure differential can be detected by strain gages located at lands **144** and **145** using techniques previously described. Sleeve **162** allows the thickness of lands **144** and **145** to be equal, thereby simplifying calibration. Nozzle **120** may have an abrasion and/or erosion resistant coating deposited on its flow exposed surfaces. Alternatively, nozzle **120** may be manufactured of a material that is resistant to erosion and/or abrasion by drilling fluid **11**. Such materials include, but are not limited to, ceramics and tungsten carbide.

In another embodiment, see **Fig. 7**, sleeve **242** is adapted to fit into housing **41** of **Fig. 3**. Sleeve **242** comprises sections **201**, **202**, and **203** that are connected together by threaded connections **205** and **206**. Alternatively, connections **205** and **206** may be comprise any suitable mechanical connection, such as, for example, brazing, welding, and shrink fitting. Seals (not shown) are inserted in grooves **210A,B** and **211 A,B** and act cooperatively with housing **41** to provide isolated volumes (similar to volume **17** of **Fig. 3**) between sections **201, 203** and housing **41**. Measurement lands **244** and **245** are disposed on sections **201** and **203**, respectively, and have strain gages A1,A2 and B1, B2 mounted, respectively, thereon. Flow **11** passes through sleeve **242** and is accelerated from section **251** through the conically converging region **252** and passes into section **253**. The strains imposed on gages A1,A2 and B1, B2 by the flow are detected and related to the flow of fluid **11**, as described previously. The multi-component nature of sleeve **242** allows for ease of replacement for changing flow ranges and/or for replacing worn sections. Any of the sections **201, 202, 203** may be manufactured of an erosion resistant material and/or be coated with an erosion resistant material, as described previously.

In another alternative embodiment, the volume between any of the sleeves previously described and their associated housing contains a liquid, for example, an oil. The liquid is substantially incompressible and can, therefore, transmit forces from the sleeve to housing **41**, and, therefore, the sleeve does not need to be able to hold the static pressure of the drilling fluid. The static pressure of the drilling fluid is transmitted from the sleeve to housing **41**. The wall thickness of such a sleeve can be made much thinner in this embodiment. Deformations of the sleeve due to the static internal pressure are very low, and substantially the same at lands the strain gage locations. These deformations therefore create almost no signal from the strain gages. Deformations of the sleeve, in response to the pressure differential, are much larger than in the before mentioned embodiments, because of the reduced sleeve wall thickness. The resulting signal from the strain gages is therefore also much larger and easier to detect.

The flow sensors described above, use resistance strain gages for detecting strains at predetermined locations along a sleeve. Alternatively, any suitable strain sensing device may be used, including, but not limited to, piezoelectric elements, piezoresistive elements, capacitive devices, and fiber optic strain sensing devices.

As discussed previously, pressure signals encoded and transmitted by the drilling fluid **11** also manifest themselves as velocity and flow fluctuations that are related to the pressure fluctuations by **Eq. 1**. The flow fluctuations can be detected by the flow sensor described by **Figs. 3-7** and can be used to decode the signals transmitted from downhole.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible. It is intended that the following claims be interpreted to embrace all such modifications and changes.

What is claimed is:

1. A system for measuring a fluid flow comprising:

- a housing adapted to be inserted in a flowline;
- a sleeve adapted to sealably fit into said housing such that a predetermined gap exists between said sleeve and said housing and wherein said sleeve is substantially isolated from mechanical loads on said housing; and
- a flow measuring element disposed in the sleeve such that the flow element generates a pressure difference across said flow element related to a flow rate of the fluid flow therethrough.

2. The system of claim 1, further comprising a first seal and a second seal acting cooperatively with said sleeve and said housing to form a sealed volume between a portion of said sleeve and said housing.

3. The system of claim 1, further comprising a first strain sensor attached to said sleeve at a first predetermined location and generating a first signal related to a fluid pressure in said sleeve upstream of said flow measuring element, and a second strain sensor mounted on the sleeve at a second predetermined location spaced apart axially from said first strain sensor and generating a second signal related to a fluid pressure in the sleeve at the second predetermined location, wherein the difference between the first signal and the second signal is related to the flow rate of the fluid inside the sleeve.

4. The system of claim 1, wherein the flow measuring element is one of (i) a venturi element, and (ii) a nozzle element.

5. The system of claim 1, wherein the flow measuring element has a wear resistant coating applied to an inside surface of the flow measuring element.

6. The system of claim 1, wherein the flow measuring element comprises multiple sections.

7. The system of claim 2, wherein the first seal and the second seal are made of an elastomeric material.

8. The system of claim 2, wherein the sealed volume contains a fluid chosen from the group consisting of (i) a gas at substantially atmospheric pressure, and (ii) a liquid.

9. The system of claim 3, wherein the first strain sensor and the second strain sensor are resistance strain gages.

10. The system of claim 3, wherein the first strain sensor and the second strain sensor are piezoelectric elements.

11. The system of claim 3, wherein the first strain sensor and the second strain sensor are piezoresistive elements.

12. The system of claim 3, wherein the first strain sensor and the second strain sensor are fiber optic strain sensors.

13. The system of claim 3, further comprising a control module containing circuits for powering said first strain sensor and said second strain sensor and detecting said first signal and said second signal.

14. The system of claim 13, wherein the control module further comprises a processor and memory acting under programmed instructions for relating the difference between said first signal and said second signal to the fluid flow in the sleeve.

15. The system of claim 1, wherein the fluid contains solid particles.

16. The system of claim 1, wherein the fluid is a drilling fluid.

17. The system of claim 3, wherein a first sleeve wall thickness at the first predetermined location and a second wall thickness at the second predetermined location are predetermined such that a first hoop strain at the first predetermined location is substantially the same as a second hoop strain at the second predetermined location when said first location and said second location are exposed to substantially equal internal pressure.

18. The system of claim 1, wherein the flow rate comprises a steady-state component and a time-varying component.

19. The system of claim 18, wherein the time-varying component is related to a predetermined signal transmitted in the drilling fluid.

20. The system of claim 19, wherein the predetermined signal is a mud pulse telemetry signal.

21. The system of claim 6, wherein at least one of the multiple sections is made of an erosion resistant material.

22. The system of claim 1, wherein the flow measuring element is integrally formed as part of the sleeve.

23. A method for measuring a fluid flow comprising:

- inserting a housing in a flowline;
- adapting a sleeve to sealably fit into said housing such that a predetermined gap exists between said sleeve and said housing; and
- disposing a flow measuring element in said sleeve such that said flow element generates a pressure difference across said flow measuring element related to a flow rate of the fluid flow therethrough.

24. The method of claim 23, further comprising providing a first seal and a second seal, both seals acting cooperatively with said sleeve and said housing to form a sealed volume between a portion of said sleeve and said housing.

25. The method of claim 23, further comprising attaching a first strain sensor to said sleeve at a first predetermined location and generating a first signal related to a fluid pressure in said sleeve upstream of said flow measuring element, and attaching a second strain sensor on the sleeve at a second predetermined location spaced apart axially from said first strain sensor and generating a second signal related to a fluid pressure in the sleeve at the second predetermined location, wherein the difference between the first signal and the second signal is related to a flow rate of the fluid inside the sleeve.

26. The method of claim 23, wherein the flow measuring element is one of (i) a venturi element, and (ii) a nozzle element.

27. The method of claim 23, wherein the flow measuring element has a wear resistant coating applied to an inside surface of the flow measuring element.

28. The method of claim 23, wherein the flow measuring element comprises multiple sections.

29. The method of claim 24, wherein the first seal and the second seal are made of an elastomeric material.

30. The method of claim 24, wherein the sealed volume contains a fluid chosen from the group consisting of (i) a gas at substantially atmospheric pressure, and (ii) a liquid.

31. The method of claim 25, wherein the first strain sensor and the second strain sensor are resistance strain gages.

32. The method of claim 25, wherein the first strain sensor and the second strain sensor are piezoelectric elements.

33. The method of claim 25, wherein the first strain sensor and the second strain sensor are piezoresistive elements.

34. The method of claim 25, wherein the first strain sensor and the second strain sensor are fiber optic strain sensors.

35. The method of claim 25, further comprising a control module containing circuits for powering said first strain sensor and said second strain sensor and detecting said first signal and said second signal.

36. The method of claim 35, wherein the control module further comprises a processor and memory acting under programmed instructions for relating the difference between said first signal and said second signal to the fluid flow in the sleeve.

37. The method of claim 23, wherein the fluid contains solid particles.

38. The method of claim 23, wherein the fluid is a drilling fluid.

39. The method of claim 25, wherein a first sleeve wall thickness at the first predetermined location and a second wall thickness at the second predetermined location are predetermined such that a first hoop strain at the first predetermined location is substantially the same as a second hoop strain at the second predetermined location when said first location and said second location are exposed to substantially equal internal pressure.

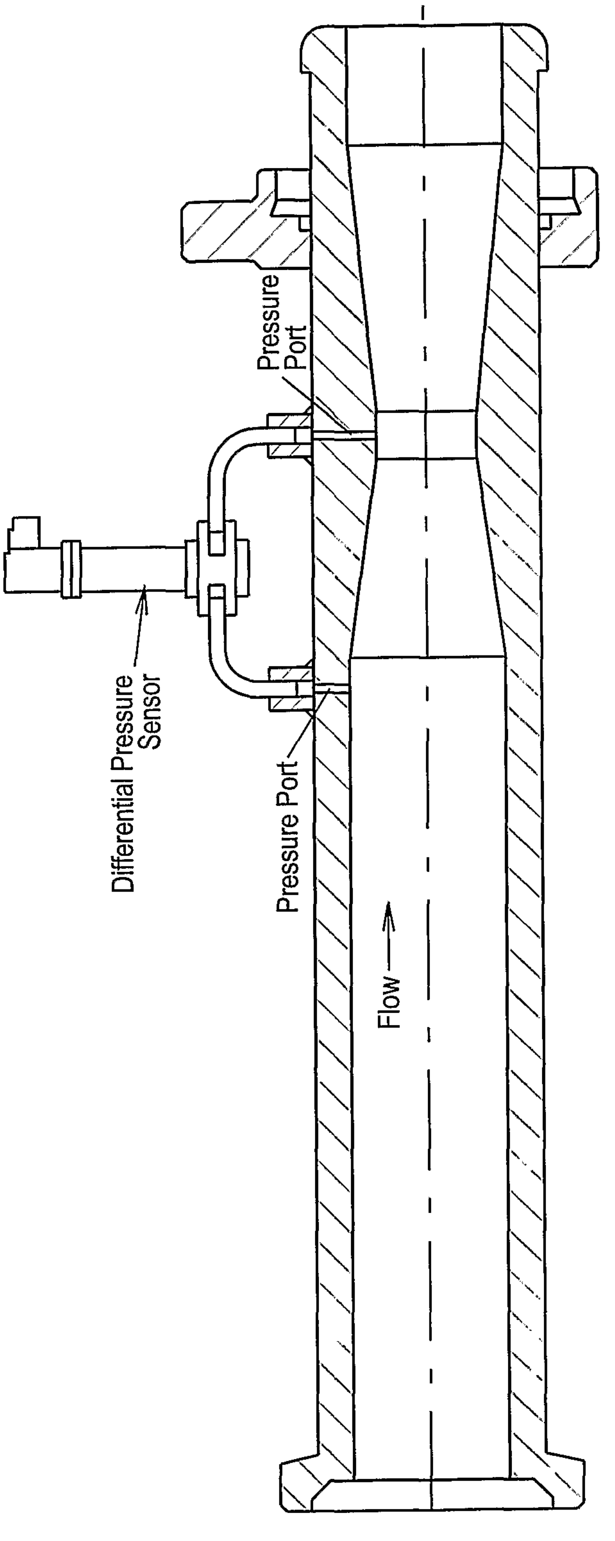
40. The method of claim 23, wherein the flow rate comprises a steady-state component and a time-varying component.

41. The method of claim 40, wherein the time-varying component is related to a predetermined signal transmitted in the drilling fluid.

42. The method of claim 41, wherein the predetermined signal is a mud pulse telemetry signal.

43. The method of claim 28, wherein the flow measuring element is made of an erosion resistant material.

44. The system of claim 23, wherein the flow measuring element is integrally formed as part of the sleeve.



(PRIOR ART)
FIG. 1

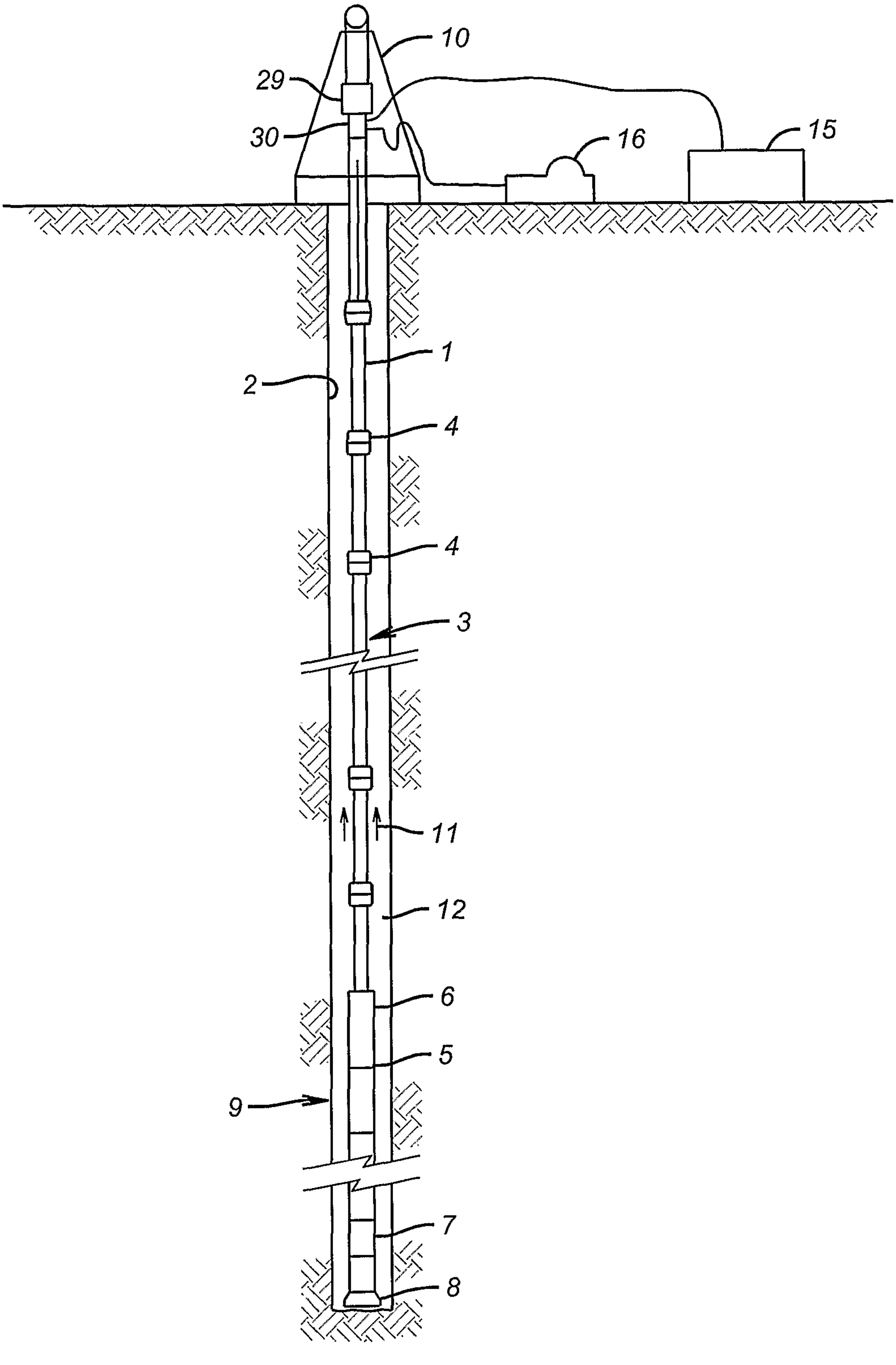


FIG. 2

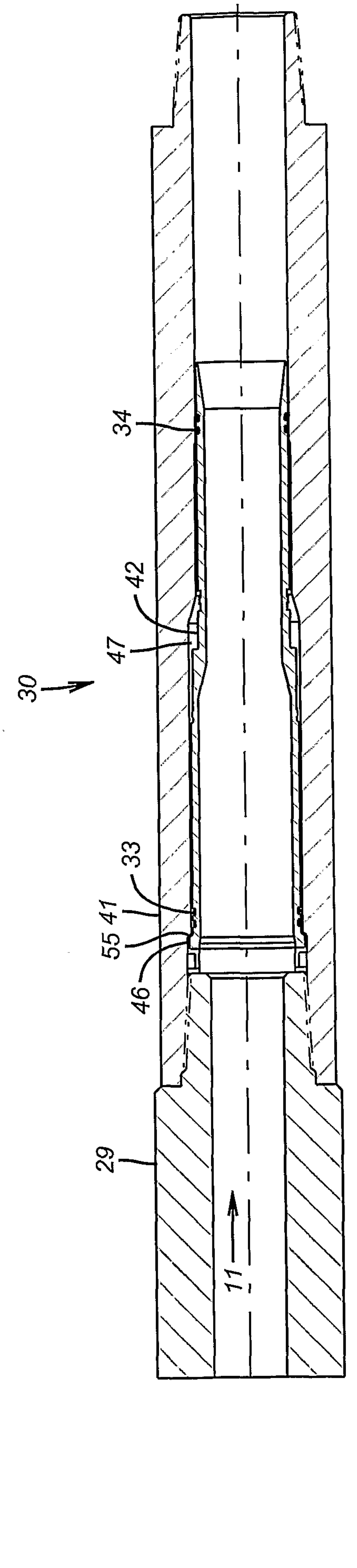

34
42
47
30
33
55
41
46
29
11

FIG. 3

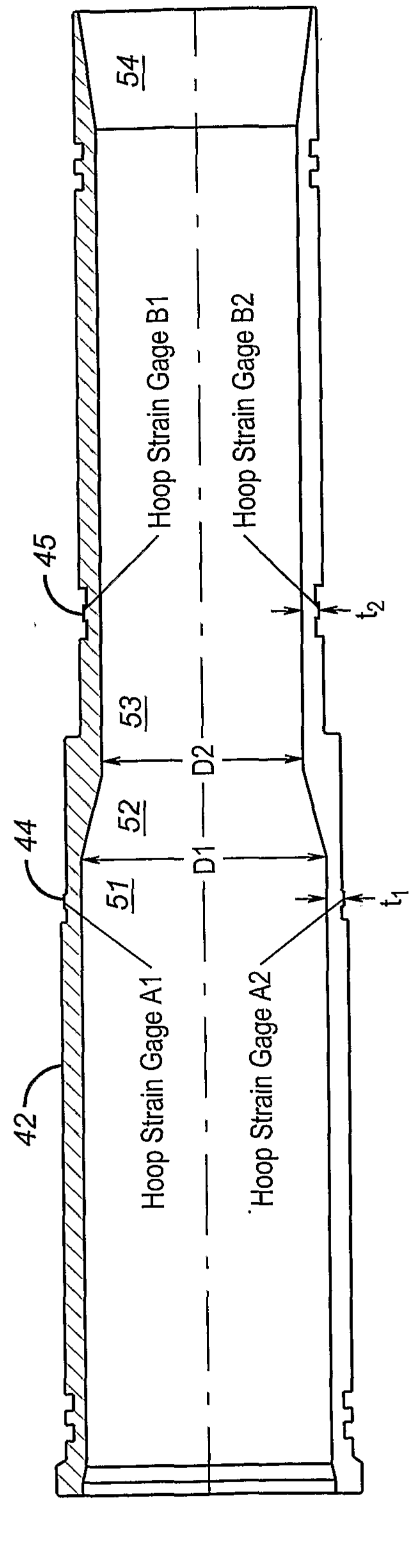

54
Hoop Strain Gage B1
Hoop Strain Gage B2
45
t_2
53
D2
52
D1
44
51
t_1
Hoop Strain Gage A1
Hoop Strain Gage A2
42

FIG. 4

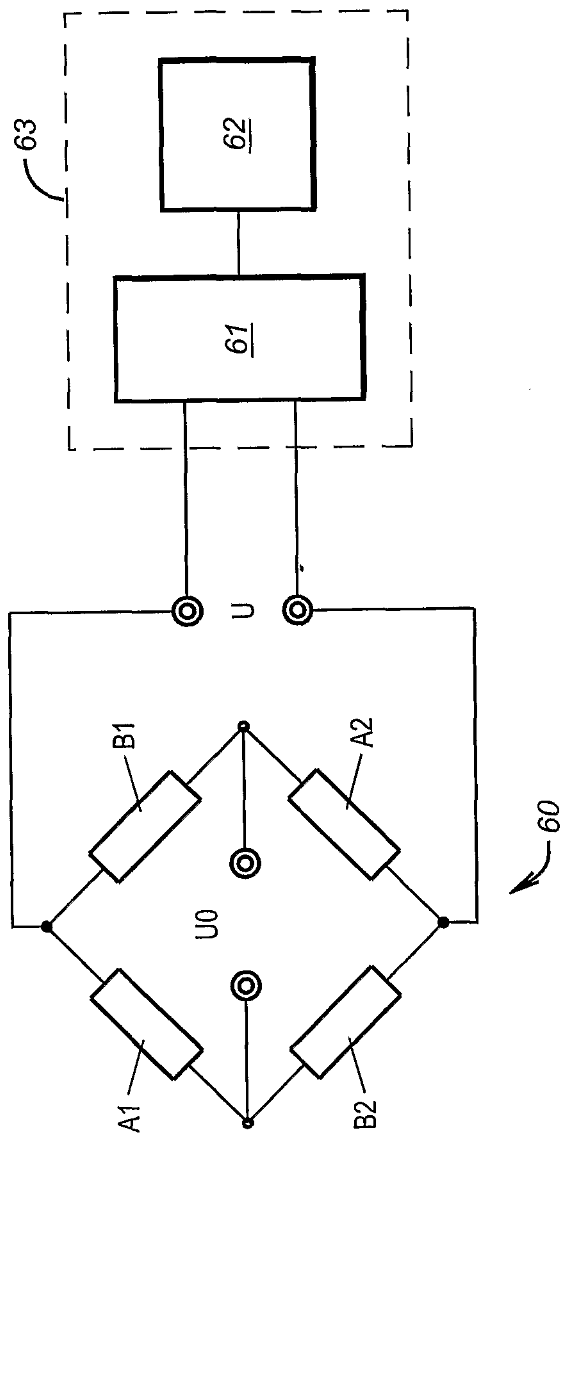


FIG. 5

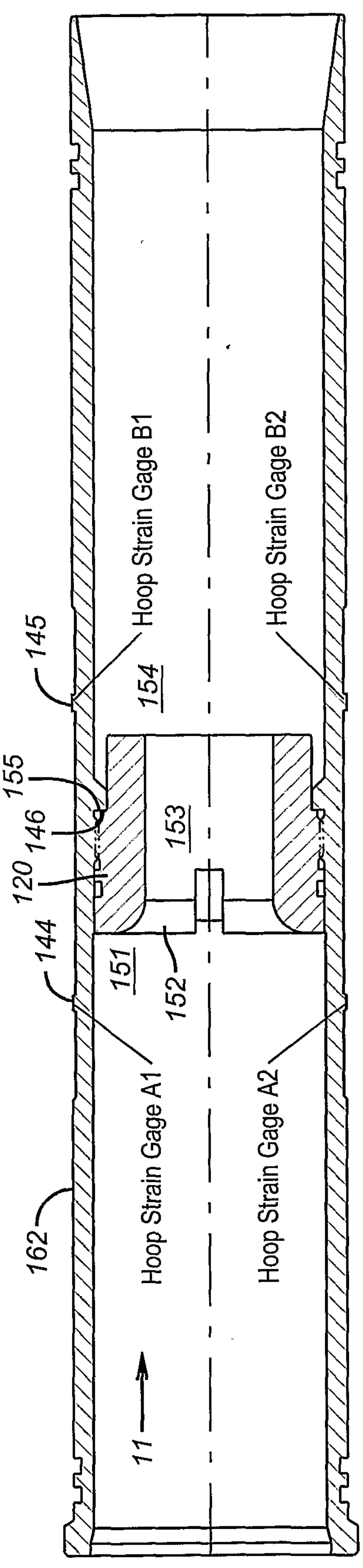

145
Hoop Strain Gage B1
Hoop Strain Gage B2
154
155
146
153
120
144
151
152
Hoop Strain Gage A1
Hoop Strain Gage A2
162
11

FIG. 6

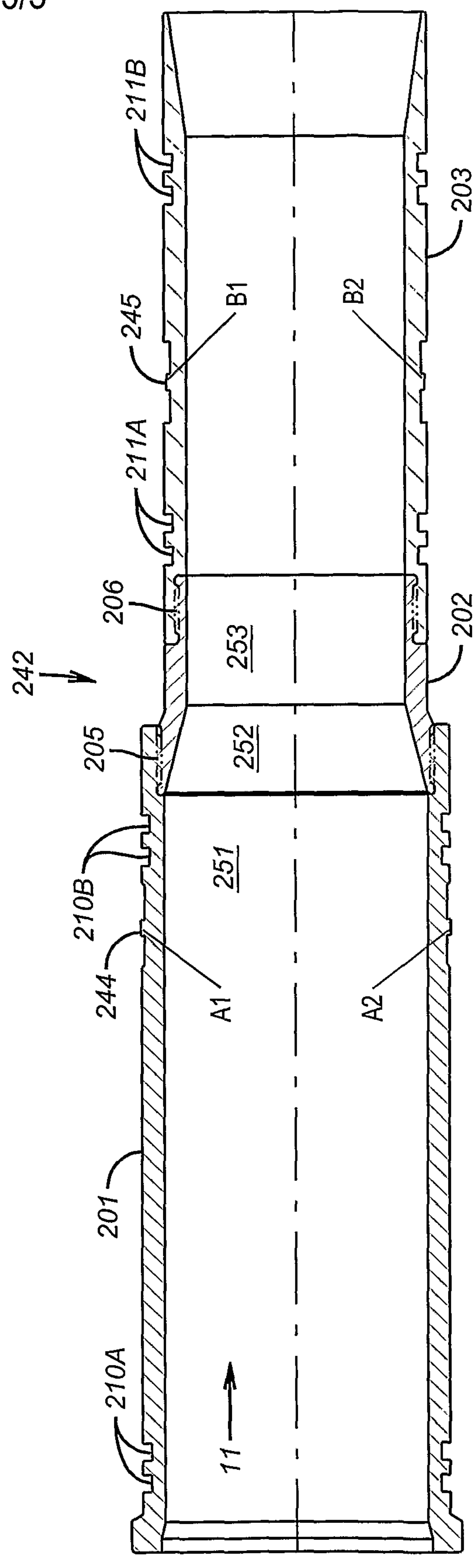

211B
203
245
B1
B2
211A
206
253
202
242
205
252
210B
251
244
A1
A2
201
210A
11

FIG. 7

INTERNATIONAL SEARCH REPORT

Application No
PCT/US2005/029334

A. CLASSIFICATION OF SUBJECT MATTER
G01F1/36 G01F1/44 G01F1/74 G01L9/00

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)
G01F G01L

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 16 48 173 A1 (JOHN ZINK COMP) 8 April 1971 (1971-04-08)	1,2,4-6, 15,16, 18-24, 26-28, 37,38, 40-44
	page 3, paragraph 3 - page 5, paragraph 1; figures 1-3	
Y		3,9-14, 25,31-36
Y	US 6 698 297 B2 (GYSLING DANIEL) 2 March 2004 (2004-03-02) column 3, line 26 - column 4, line 67; figure 1	3,9-14, 25,31-36

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in 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 but 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	Date of mailing of the international search report
20 December 2005	29/12/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Boerrigter, H

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

Application No
PCT/US2005/029334

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99/47895 A (ABB OFFSHORE SYSTEMS LIMITED) 23 September 1999 (1999-09-23) the whole document -----	1-44
A	US 6 354 147 B1 (GYSLING DANIEL L ET AL) 12 March 2002 (2002-03-12) column 15, line 33 - column 16, line 57; figures 19-20-21 -----	3,25
A	US 4 706 501 A (ATKINSON ET AL) 17 November 1987 (1987-11-17) the whole document -----	3,25

INTERNATIONAL SEARCH REPORT

Application No
PCT/US2005/029334

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 1648173	A1	08-04-1971	NONE			
US 6698297	B2	02-03-2004	AU	2003241039	A1	19-01-2004
			CA	2489944	A1	08-01-2004
			WO	2004003484	A2	08-01-2004
			GB	2405485	A	02-03-2005
			US	2004000197	A1	01-01-2004
WO 9947895	A	23-09-1999	AU	2847699	A	11-10-1999
			GB	2335494	A	22-09-1999
US 6354147	B1	12-03-2002	AU	4961699	A	17-01-2000
			MX	PA00012769	A	24-04-2002
US 4706501	A	17-11-1987	AU	552602	B2	12-06-1986
			AU	7739681	A	27-05-1982
			CA	1174323	A1	11-09-1984
			DE	3172259	D1	17-10-1985
			EP	0052957	A1	02-06-1982
			NO	813758	A	24-05-1982