IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF TEXAS
HOUSTON DIVISION

SCIENTIFIC DRILLING INTERNATIONAL, INC. and APPLIED TECHNOLOGIES ASSOCIATES, INC., Plaintiffs and Counterclaim Defendants,	§	CIVIL ACTION NO. 4:97-CV-3506
v.	§	HON. LYNN N. HUGHES
GYRODATA CORPORATION, Defendant and Counterclaim Plaintiff.	§	JURY TRIAL DEMANDED

DEFENDANT GYRODATA'S FIRST AMENDED ANSWER, AFFIRMATIVE DEFENSES, AND COUNTERCLAIMS

Defendant Gyrodata Incorporated ("Gyrodata") respectfully submits this amended answer, these affirmative defenses, and these counterclaims to the complaint of Plaintiffs Scientific Drilling International, Inc. ("SDI") and Applied Technologies Associates, Inc. ("ATA") (collectively, "SDI") against Gyrodata. The following numbered paragraphs correspond to SDI's complaint; however, anything in SDI's complaint not expressly admitted is denied:

1. Gyrodata is without information sufficient to form a belief about the state of ATA and SDI's incorporation or ATA's address; otherwise, Gyrodata admits the contents of paragraph 1 of the complaint.

2. Gyrodata admits the contents of paragraph 2 of the complaint.

3. Gyrodata maintains its headquarters and research, development, and manufacturing facilities in Houston. The remainder of paragraph 3 of the complaint is a legal conclusion requiring no response.

4. Gyrodata admits it has been charged with infringement of the ’869, the ’491, the ’533, the ’559, the ’405, and the ’336 patents, but denies that any infringement exists and denies that injunctive relief, damages, or attorney fees are warranted.

5. Gyrodata admits that this action claims to be an action for patent infringement under the patent laws of the United States, and if so, this Court has jurisdiction. Otherwise, Gyrodata denies the allegations of paragraph 5 of the complaint.

6. Gyrodata admits that venue is proper.

7. Gyrodata denies the allegations of paragraph 7. Though this purports to be a patent action, Gyrodata believes SDI filed this lawsuit as a pretext to conduct improper discovery and an attempt to reduce Gyrodata’s economic success in the market.

(a) Gyrodata admits that, on its face, U.S. Patent No. 4,199,869 (“the ’869 patent”) purports to have issued on April 29, 1980, to ATA as the assignee of Van Steenwyk, and is entitled “Mapping Apparatus Employing Two Input Axis Gyroscopic Means.” Gyrodata denies the patent was duly and legally issued.

(b) Gyrodata admits that, on its face, U.S. Patent No. 4,433,491 (“the ’491 patent”) purports to have issued on February 28, 1984, to ATA as assignee of Van Steenwyk, and is entitled “Azimuth Determination for Vector Sensor Tools.” Gyrodata denies the patent was duly and legally issued.

(c) Gyrodata admits that, on its face, United States Patent No. 4,471,533 (“the ’533 patent”) purports to have issued on September 18, 1984, to ATA as the assignee of Van Steenwyk, and is entitled “Well Mapping

System and Method with Sensor Output Compensation." Gyrodata denies the patent was duly and legally issued.

(d) Gyrodata admits that, on its face, United States Patent No. 4,593,559 ("the '559 patent") purports to have issued on June 10, 1986, to ATA as the assignee of Van Steenwyk, and is entitled "Apparatus and Method to Communicate Bidirectional Information in a Borehole." Gyrodata denies the patent was duly and legally issued.

(e) Gyrodata admits that, on its face, United States Patent No. 4,611,405 ("the '405 patent") purports to have issued on September 16, 1986, to ATA as the assignee of Van Steenwyk, and is entitled "High Speed Well Surveying." Gyrodata denies the patent was duly and legally issued.

(f) Gyrodata admits that, on its face, United States Patent No. 4,909,336 ("the '336 patent") purports to have issued on September 29, 1988, to Applied Navigation Devices as the assignee of David C. Brown and Fred L. Watson, and is entitled "Drill Steering in High Magnetic Interference Areas." Gyrodata denies the patent was duly and legally issued.

8. Gyrodata denies the allegations of paragraph 8.

(a) Gyrodata denies the allegations of paragraph 8(a). Particularly, Gyrodata denies that the '869 patent claims what SDI purports it to claim. Gyrodata denies that it makes or uses the apparatus as claimed in the '869 patent in the United States. Gyrodata denies that it uses the method claimed in the '869 patent in the United States.

(b) Gyrodata denies the allegations of paragraph 8(b). Particularly, Gyrodata denies that the ’491 patent claims what SDI purports it to claim. Gyrodata denies that it uses the method claimed in the ’491 patent in the United States.

(c) Gyrodata denies the allegations of paragraph 8(c). Particularly, Gyrodata denies that the ’533 patent claims what SDI purports it to claim. Gyrodata denies that it makes or uses the apparatus or method claimed in the ’533 patent in the United States.

(d) Gyrodata denies the allegations of paragraph 8(d). Particularly, Gyrodata denies that the ’559 patent claims what SDI purports it to claim. Gyrodata denies that it makes or uses the apparatus claimed in the ’559 patent in the United States.

(e) Gyrodata denies the allegations of paragraph 8(e). Particularly, Gyrodata denies that the ’405 patent claims what SDI purports it to claim. Gyrodata denies that it uses the method claimed in the ’405 patent in the United States.

(f) Gyrodata denies the allegations of paragraph 8(f). Particularly, Gyrodata denies that the ’336 patent claims what SDI purports it to claim. Gyrodata denies that it uses the method claimed in the ’336 patent in the United States.

9. Gyrodata denies that it has infringed, much less willfully infringed, any of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patents.

10. Gyrodata denies the allegations of paragraph 10.

11. Gyrodata denies the allegations of paragraph 11.

12. The rest of the complaint is a prayer, for which no particular response is required. Gyrodata does, however, deny that ATA and SDI are entitled to any of the relief they seek. Gyrodata also denies that ATA and SDI are entitled to any injunctive relief or that any of the requirements of injunctive relief have been met here.

AMENDED AFFIRMATIVE DEFENSES

First Affirmative Defense: Noninfringement

13. Gyrodata does not infringe and has not infringed, either directly or indirectly, does not and has not contributed to infringement, and does not and has not induced the infringement of any valid claim of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patents.

Second Affirmative Defense: Estoppel

14. All claims in the complaint are barred by the equitable doctrine of estoppel.

Third Affirmative Defense: Laches

15. All claims in the complaint are barred by the equitable doctrine of laches. All damages, if any, occurring more than six years before the filing of this suit are barred, as are any claims of injunctive relief.

Fourth Affirmative Defense: Prosecution History Estoppel

16. ATA and SDI are estopped from construing the claims of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patents in a way that would cover any of Gyrodata’s products or processes by reasons of statements made to the United States Patent and Trademark Office (“USPTO”) during the prosecution of the applications that led to the issuance of those patents.

Fifth Affirmative Defense: Patent Invalidity

17. The claims of the '869, the '491, the '533, the '559, the '405, or the '336 patents are invalid for failure to comply with the requirements of Sections 102, 103, and 112 of Title 35 of the United States Code.

Sixth Affirmative Defense: Prior Sale or Public Use

18. All claims in the complaint are barred by the doctrine of prior sale or public use under Title 35 of the United States Code, Section 102(b).

Seventh Affirmative Defense: Doctrine of Reverse Equivalents

19. Gyrodata has not infringed any of the claims of the '869, the '491, the '533, the '559, the '405, or the '336 patents under the doctrine of reverse equivalents, even if the claims of any of these patents literally read upon some of the accused products because Gyrodata's products have so changed that they are not the same as the claimed inventions of these patents.

Eighth Affirmative Defense: Unenforceability

20. Gyrodata cannot be liable for any infringement of the '869, the '491, the '533, the '559, the '405, or the '336 patents because each of these patents is unenforceable due to inequitable conduct.

(a) The '869 patent. The '869 patent is unenforceable under the doctrine of inequitable conduct. On information and belief, during an interference declared by the Board of Patent Interferences and Appeals on or about November 18, 1982, one of the named inventors, Donald Van Steenwyk, and/or others substantively involved in prosecuting the interference, including ATA's patent attorney William Haefliger and his associates, misrepresented the conception and/or reduction to practice dates for the invention claimed by the

’869 patent with the intent to deceive the USPTO. This misrepresentation was material because conception and/or reduction to practice are issues that were critical to priority in the interference proceeding. If SDI had lost the interference proceeding, SDI would have lost its rights to the ’869 patent because that patent would no longer have been valid. SDI made a material misrepresentation with the intent to deceive the USPTO, and this intent is evidenced by inconsistent dates of conception and reduction to practice SDI has given to the USPTO on the one hand and to Gyrodata in this litigation on the other hand.

(b) The ’491 patent. The ’491 patent is unenforceable under the doctrine of inequitable conduct. Upon information and belief, ATA named inventors Paul W. Ott, Harold J. Engebretson, Phillip M. LaHue, and/or Brett H. Van Steenwyk, with possible assistance from ATA’s patent counsel, William Haefliger, withheld from the USPTO evidence of the September 1979 sale of the invention of claim 1 of the ’491 patent years before SDI’s attempt to patent it. This sale was to Eastman Whipstock and/or others and occurred more than one year before SDI filed the application that led to the issuance of the ’491 patent. Each of the inventors and their counsel were involved in the provision of data to Eastman Whipstock and were thus fully aware of the sale. Each was under a duty to disclose the prior sale to the examiner during his examination of the ’491 patent. Evidence of this sale and the offer(s) for sale preceding the sale was material information because this is information a reasonable examiner would consider important in deciding whether to issue the ’491 patent. SDI withheld any mention of the sale, and associated offers for sale, with the intent to deceive the USPTO into granting the ’491 patent.

(c) The ’559 patent. The ’559 patent is unenforceable under the doctrine of inequitable conduct. Upon information and belief, Mr. Harold Engebretson concealed from the USPTO material prior art from September 1982, including, among other things, a technical paper published by Sandia National Laboratories that described Sandia’s Wellbore Inertial Navigational System (“WINS”). On September 8, 1982, a group of engineers from Sandia National Laboratories filed an application for a patent disclosing a WINS. That application eventually issued as U.S. Patent No. 4,987,684 (“the ’684 patent”). Also in September 1982, Sandia held a seminar presenting a paper on WINS. ATA employee Paul Ott attended the presentation and took copies of the Sandia papers back to ATA. Ott gave these papers to ATA employee/consultant Hal Engebretson, who read the Sandia paper within a few months of that presentation. Three years later, on March 7, 1985, Engebretson and ATA co-inventors David Brown and Fred Watson filed a patent application that later issued as the ’559 patent. Claim 1 of the ’559 patent describes a bi-directional communication system that is substantially the same as the one in the WINS. None of the inventors nor their counsel, William Haefliger, disclosed the Sandia paper or the ’684 patent. These items of prior art were material because they disclosed the same limitations of claim 1 of the ’559 patent that the examiner considered to be not shown by prior art of record. ATA could not have made arguments propounded to the USPTO during the prosecution of the ’559 patent if the Sandia paper had been disclosed to the examiner. ATA concealed this material prior art with the intent to deceive the USPTO into issuing the ’559 patent.

(d) The ’405 patent. The ’405 patent is unenforceable under the doctrine of inequitable conduct. On information and belief, ATA inventor Donald Van Steenwyk withheld from the USPTO evidence of sales of the claimed invention of the ’405 patent on February 4, 1983, and July 15, 1983. Both sales were to Eastman Whipstock and/or others and occurred more than one year before the ’405 patent’s filing date of July 30, 1984. Donald Van Steenwyk and patent counsel William Haefliger were provided data regarding these sales to Eastman Whipstock and thus were fully aware of the sales. Each was under a duty to disclose the prior sale to the examiner during his examination of the ’405 patent. Evidence of these sales and the preceding offer(s) for sale was material because a reasonable examiner would consider evidence of pre-critical date sales of the claimed invention important in deciding whether to issue the ’405 patent. SDI withheld information regarding the sale, and associated offers for sale, with the intent to deceive the USPTO into granting the ’405 patent.

(e) The ’336 patent. The ’336 patent is unenforceable under the doctrine of inequitable conduct. During the prosecution of the application that issued as the ’336 patent, ATA employees and co-inventors David Brown and Fred Watson withheld another ATA patent, the ’533 patent, from the USPTO with the intent to deceive the examiner into allowing the ’336 patent. The ’533 patent, which issued on September 18, 1984, was assigned to ATA. Four years later, Messrs. Brown and Watson filed the application for the ’336 patent, which was also assigned to ATA. As a result of the assignment of both patents, ATA’s management, the inventors, and ATA’s patent counsel all were aware of the ’533 patent during the prosecution of the application for the ’336 patent. The inventors of the ’336 patent and their patent counsel all were required to disclose to the USPTO material prior art of which they were aware during the entire pendency of the application for the ’336 patent. The ’533 patent discloses every limitation of claim 1 of the ’336 patent and therefore anticipates claim 1 of the ’336 patent. Anticipating prior art is per se material, yet ATA withheld from the examiner the prior art anticipatory ’533 patent. Even if the ’533 patent does not fully anticipate the ’336 patent, the ’533 patent disclosed so many common limitations to claim 1 of the ’336 patent that a reasonable examiner would have considered the prior art ’533 patent important in determining whether the ’336 patent was obvious in light of the ’533 patent. ATA’s withholding of the ’533 patent was intentional because ATA was aware of the prior art’s existence and also knew of its materiality. For example, the withheld prior art ’533 patent discloses the same steering function for which ATA sought patent protection in the ’336 patent. ATA’s withholding of the ’533 patent from the USPTO was with the intent to deceive the examiner into allowing the ’336 patent.

(f) Best mode. The ’491, the ’553, the ’559, the ’405, and the ’336 patents are invalid under the doctrine of inequitable conduct. On information and belief, as of 1978, ATA contemplated a best mode for the angular sensor in carrying out its inventions, including the inventions later claimed by these patents. When ATA inventors filed the applications for the ’533 patent (March 9, 1981; inventors Donald Van Steenwyk, and Paul Ott), the ’491 patent (February 24, 1982; inventors Paul Ott, Harold Engebretson, Phillip LaHue, and Brett Van Steenwyk), the ’405 patent (July 30, 1984; inventor Donald Van Steenwyk), the ’559 patent (March 7, 1985; inventors David Brown, Harold Engebretson, and Fred Watson) and the ’336 patent (September 29, 1988; inventors David Brown and Fred Watson), the applications did not disclose that ATA considered a certain type of sensor to be the best mode angular rate sensor.[1] ATA and its inventors concealed ATA’s contemplated best mode from the USPTO with the intent to deceive. Instead of disclosing its contemplated best mode, ATA listed various modes that were not operable in oilfield applications at the times ATA filed their applications. The degree of specificity with which ATA disclosed the wrong types of angular rate sensors is evidence of ATA’s intent to deceive the USPTO and the public.

Ninth Affirmative Defense: Patent Misuse

21. All claims in the complaint are barred by the doctrine of misuse of patent.

Tenth Affirmative Defense: Patent Expiration

22. Gyrodata cannot be liable for any infringement that occurred after the expiration of any one of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patents.

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[1] The details regarding the specific types of sensors are not disclosed in this pleading pursuant to the Court’s January 31, 2000 Order Protecting Confidentiality. Docket no. 59.

Eleventh Affirmative Defense: Mitigation

23. All claims in the complaint are barred, or limited, by the failure of the plaintiffs to mitigate their losses, if any.

Twelfth Affirmative Defense: Unclean Hands

24. All equitable claims, including the claim for injunction, set forth in the complaint are barred by the equitable doctrine of unclean hands, as well as other equitable doctrines pled here.

Thirteenth Affirmative Defense: Standing

25. Either SDI or ATA lack standing to bring the present action.

GYRODATA'S COUNTERCLAIMS

Defendant/Counterclaim-Plaintiff Gyrodata brings these counterclaims against Plaintiff/Counterclaim-Defendants SDI and ATA:

The Parties

26. Gyrodata Incorporated is a Delaware corporation with its principal place of business at 1682 West Sam Houston Parkway North, Houston, Texas 77043.

27. On information and belief, Plaintiff SDI is a Nevada corporation having corporate headquarters at 1100 Rankin Road, Houston, Texas 77073. On information and belief, Plaintiff ATA is a California corporation with an office at 3025 Buena Vista Drive, Paso Robles, California 93446.

Jurisdiction and Venue

28. This Court has subject matter jurisdiction over Gyrodata's patent counterclaims pursuant to 28 U.S.C. §§ 1331, 1338, 2201, and 2202. This Court has jurisdiction over Gyrodata's trademark counterclaims brought under the Trademark

Laws of the United States, 15 U.S.C. §§ 1051-1127. Jurisdiction over the trademark counterclaims is pursuant to 15 U.S.C. § 1121 and 28 U.S.C. §§ 1331 and 1338(a).

29. This Court has personal jurisdiction over SDI and ATA, at least because they filed their claims for patent infringement in this Court, to which Gyrodata has responded with these counterclaims.

30. Venue is established by Gyrodata's presence in this judicial district. 28 U.S.C. §§ 1391 and 1400. These counterclaims do not require for their adjudication the presence of other parties of whom the Court cannot acquire jurisdiction.

COUNT ONE: DECLARATORY JUDGMENT

31. Gyrodata re-alleges and incorporates by reference paragraphs 1 through 30 above as though fully set forth here. This is meant to apply to all counterclaims.

32. This is a counterclaim for a declaratory judgment under Title 28 of the United States Code, Sections 2001 and 2002, and the patent laws of the United States under Title 35 of the United States Code.

33. An actual controversy exists between SDI and Gyrodata concerning the validity, enforceability, and infringement of the '869, the '491, the '533, the '559, the '405, or the '336 patents.

34. Gyrodata seeks a declaratory judgment for the following:

(a) That the '869, the '491, the '533, the '559, the '405, or the '336 patents, and each and every claim thereof, are invalid for failure to comply with the requirements of Sections 102, 103, and 112 of Title 35 of the United States Code.

(b) That all claims of the complaint are barred by the doctrine of prior sale or public use under Section 102(b) of Title 35 of the United States Code.

(c) That it has not infringed any of the claims of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patent under the doctrine of reverse equivalents, even if the claims of any of these patents literally read upon some of the accused products because Gyrodata’s products have so changed that they are not the same as the claimed inventions of these patents.

(d) That the ’869, the ’491, the ’533, the ’559, the ’405, and the ’336 patents are unenforceable due to plaintiffs’ inequitable conduct, as described in paragraphs 20(a)-(f) above, which Gyrodata incorporates hereinto by reference.

(e) That it has not infringed any of the ’869, the ’491, the ’533, the ’559, the ’405, or the ’336 patents.

COUNT TWO: TORTIOUS INTERFERENCE WITH EXISTING CONTRACT

35. Gyrodata voluntarily dismissed this claim without prejudice June 29, 2001.

COUNT THREE: BUSINESS DEFAMATION

36. Gyrodata voluntarily dismissed this claim without prejudice June 29, 2001.

COUNT FOUR: VIOLATION OF FOREIGN CORRUPT PRACTICES ACT

37. Gyrodata voluntarily dismissed this claim without prejudice June 29, 2001.

COUNT FIVE: VIOLATION OF SHERMAN ACT, 15 U.S.C. § 2

38. Gyrodata voluntarily dismissed this claim without prejudice June 29, 2001.

COUNT SIX: VIOLATION OF TEXAS FREE ENTERPRISE ACT

39. Gyrodata voluntarily dismissed this claim without prejudice June 29, 2001.

COUNT SEVEN: PATENT INFRINGEMENT OF U.S. PATENT NO. 4,800,981

40. The parties stipulated to dismissing this counterclaim with prejudice on November 7, 2007. Docket no. 362.

COUNT EIGHT: TRADEMARK INFRINGEMENT

41. This is an action for trademark infringement and unfair competition under the Trademark Act of 1946, as amended (The Lanham Act, 15 U.S.C. § 1051, *et seq.*). This claim arises from the unauthorized use of the trademark DROP GYRO in the Houston, Texas, area and throughout the United States, and in the advertising and sale of services in connection with the controlled directional drilling of oil wells.

42. Since at least as early as September 1997, Gyrodata has offered services in connection with the controlled directional drilling of oil wells using the trademark DROP GYRO.

43. Sometime during the year 2000, if not earlier, Counterclaim Defendants commenced using the trademark DROP GYRO for essentially the same services offered by Gyrodata.

44. Gyrodata claims an interest in and right to exclusive use of the trademark DROP GYRO, and derivations of this trademark in the United States. Thus Gyrodata, pursuant to 15 U.S.C. § 1125(a), complains of Counterclaim Defendants SDI and/or ATA's use of this trademark in their sale, offering for sale of services and/or uses in commerce of the words DROP GYRO, or any combination thereof. The false designation of origin and/or false and misleading descriptions of fact are likely to cause confusion or deceive customers as to any affiliation, connection, or association Counterclaim Defendants have with Gyrodata. These false designations also include any perceived origin, sponsorship or approval by Gyrodata of Counterclaim Defendants' goods, services or/or commercial activities.

45. As a consequence of Counterclaim Defendants' violation of 15 U.S.C. § 1125(a) [Section 43(a) of The Lanham Act], Gyrodata is entitled to all of the relief set forth in 15 U.S.C. § 1117.

46. Gyrodata seeks a permanent injunction against Counterclaim Defendants to enjoin them from any further violation of Section 43(a) of the Lanham Act by acts as described herein and to be shown at trial.

47. Gyrodata requests that Counterclaim Defendants be permanently enjoined from using the trademark DROP GYRO, or any confusingly similar word or phase, in connection with advertising and promotion, on product labels, in correspondence, as part of a web site, as a metatag, or in any other related commercial activity.

48. Gyrodata seeks damages from Counterclaim Defendants to the full extent of the law for its losses due to Counterclaim Defendants' violations of The Lanham Act.

49. Gyrodata requests that the Court declare this case to be exceptional and award Gyrodata its attorney fees and costs in this action.

50. Gyrodata seeks an award from the Court for pre-judgment and post-judgment interest on all damages, at the maximum rate allowed by law in the State of Texas.

COUNT NINE: PATENT INFRINGEMENT OF U.S. PATENT NO. 5,821,414

51. This is an action for patent infringement of United States Patent No. 5,821,414 ("the '414 patent"), entitled "SURVEY APPARATUS AND METHODS FOR DIRECTIONAL WELLBORE WIRELINE SURVEYING," that issued on October 13, 1998, to Gary Uttecht, Eric Wright, James Brosnahan, Koen Noy, Han Wei and Greg Neubauer. Each inventor is, or was, at the time of invention, an employee of Gyrodata and contractually committed to assign ownership of such patent to Gyrodata.

Gyrodata is the exclusive owner and holder of the ’414 patent. A true and correct copy of the ’414 patent is attached as Exhibit “A.” Counterclaim Defendants have infringed the ’414 patent under 35 U.S.C. § 271 by making, selling, offering for sale, or using the patented invention within the United States during the term of the ’414 patent without authority to do so.

52. In broad terms, the ’414 patent claims an apparatus and method for surveying wells comprising a gyroscope having a spin axis aligned with the instrument axis, and having two sensitive axes orthogonally related to the spin axis and to each other. Attitude references of the wellbore, with regard to the first determined location, are then determined while the tool is continuously traversing through the wellbore.

53. Upon information and belief, Counterclaim Defendants have willfully infringed the ’414 patent and will continue to do so unless enjoined by the Court. As a direct and proximate cause of Counterclaim Defendants’ infringement of the ’414 patent, Counterclaim Plaintiff has suffered and will continue to suffer financial loss and damage. As a result of Counterclaim Defendants’ willful infringement of the ’414 patent, Counterclaim Defendants should be required to pay Counterclaim Plaintiff treble the amount of damages, as provided under 35 U.S.C. § 284, and reasonable attorney fees as provided under 35 U.S.C. § 283.

COUNT TEN: PATENT INFRINGEMENT OF U.S. PATENT NO. 5,806,195

54. This is an action for patent infringement of United States Patent No. 5,806,195 (“the ’195 patent”), entitled “RATE GYRO WELLS SURVEY SYSTEM INCLUDING NULLING SYSTEM,” that issued on September 15, 1998, to Gary Uttecht, Eric Wright, James Brosnahan and Greg Neubauer. Each inventor is, or was, at the time of invention, an employee of Gyrodata and contractually committed to assign

ownership of such patent to Gyrodata. Gyrodata is the exclusive owner and holder of the ’195 patent. A true and correct copy of the ’195 patent is attached as Exhibit “B.” Counterclaim Defendants have infringed the ’195 patent under 35 U.S.C. § 271 by making, selling, offering to sell, or using the patented invention within the United States during the term of the ’195 patent without authority to do so.

55. Broadly, the ’195 patent claims a method for well borehole survey involving a sonde supporting *X* and *Y* accelerometers, and *X* and *Y* sensors on a rate gyro having a *Z* axis aligned with the sonde. On a slickline, or within a drill string, the sonde is used to measure four variables to enable well azimuth and inclination to be determined. Measuring depth enables a survey to be made.

56. Upon information and belief, Counterclaim Defendants have willfully infringed the ’195 patent and will continue to do so unless enjoined by the Court. As a direct and proximate cause of Counterclaim Defendants’ infringement of the ’195 patent, Counterclaim Plaintiff has suffered and will continue to suffer financial loss and damage. As a result of Counterclaim Defendants’ willful infringement of the ’195 patent, Counterclaim Defendants should be required to pay Counterclaim Plaintiff treble the amount of damages, as provided under 35 U.S.C. § 284, and reasonable attorney fees as provided under 35 U.S.C. § 283.

COUNT ELEVEN: PATENT INFRINGEMENT OF U.S. PATENT NO. 5,657,547

57. The parties stipulated to dismissing this counterclaim with prejudice on February 19, 2003. Docket no. 155.

PRAYER FOR RELIEF

58. Gyrodata asks this Court to enter judgment in its favor against SDI and ATA and grant the following relief:

(a) The relief specified in each count above,

(b) A declaration that Gyrodata has not infringed the claims of U.S. Patent Nos. 4,909,336; 4,611,405; 4,433,491; 4,471,533; 4,593,559; and 4,199,869;

(c) A declaration that the claims of U.S. Patent Nos. Nos. 4,909,336; 4,611,405; 4,433,491; 4,471,533; 4,593,559; and 4,199,869 are invalid;

(d) A finding that this case is an exceptional case and an award of attorneys' fees and costs to Gyrodata pursuant to 35 U.S.C. § 285; and

(e) Any and all other relief to which it may be justly entitled.

Respectfully submitted,

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CERTIFICATE OF SERVICE

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GYR60.017 53000

US005821414A

United States Patent [19]

Noy et al.

[11] **Patent Number: 5,821,414**

[45] **Date of Patent: Oct. 13, 1998**

[54] **SURVEY APPARATUS AND METHODS FOR DIRECTIONAL WELLBORE WIRELINE SURVEYING**

[76] Inventors: **Koen Noy; Eric Wright; Gary Uttecht; James Brosnahan; Han Wei; Greg Neubauer**, all of 1628 Westbelt N., Houston, Tex. 77043

[21] Appl. No.: **797,785**

[22] Filed: **Feb. 7, 1997**

[51] **Int. Cl.**[6] **E21B 47/00**; E21B 47/022

[52] **U.S. Cl.** **73/152.54**; 33/304

[58] **Field of Search** 33/304, 313, 324; 73/152.54

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,753,296	8/1973	VanSteenwyk .	
4,197,654	4/1980	VanSteenwyk et al. .	
4,199,869	4/1980	VanSteenwyk .	
4,238,889	12/1980	Barriac .	
4,265,028	5/1981	VanSteenwyk .	
4,293,046	10/1981	VanSteenwyk .	
4,297,790	11/1981	VanSteenwyk et al. .	
4,433,491	2/1984	Ott et al. .	
4,454,756	6/1984	Sharp et al.	73/152.54
4,459,760	7/1984	Watson et al. .	
4,542,647	9/1985	Molnar	73/152.54
4,812,977	3/1989	Hulsing	364/422
4,987,684	1/1991	Andreas et al. .	
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Primary Examiner—Michael Brock
Assistant Examiner—Jay L. Politzer
Attorney, Agent, or Firm—Gunn & Associates, P.C.

[57] **ABSTRACT**

A wellbore survey method and apparatus which includes a gyroscope, wherein the gyroscope has a spin axis, aligned with the instrument axis, and further having two sensitive axis orthogonally related to the spin axis and to each other. In addition, the wellbore survey apparatus contains a drive means, functionally connected with the gyroscope, to rotate the gyro about the instrument axis. The wellbore survey apparatus also contains a set of accelerometers, wherein the sensitive axis are aligned orthogonally to each other, and said drive means is functionally connected to the accelerometers to rotate the accelerometers about the instrument axis. Sensors determine the azimuthal direction of inclination of the wellbore at a first location therein and while traversing from said first location. Attitude references of the wellbore with regard to said first location are determined while the tool is continuously traversing through the wellbore.

39 Claims, 5 Drawing Sheets

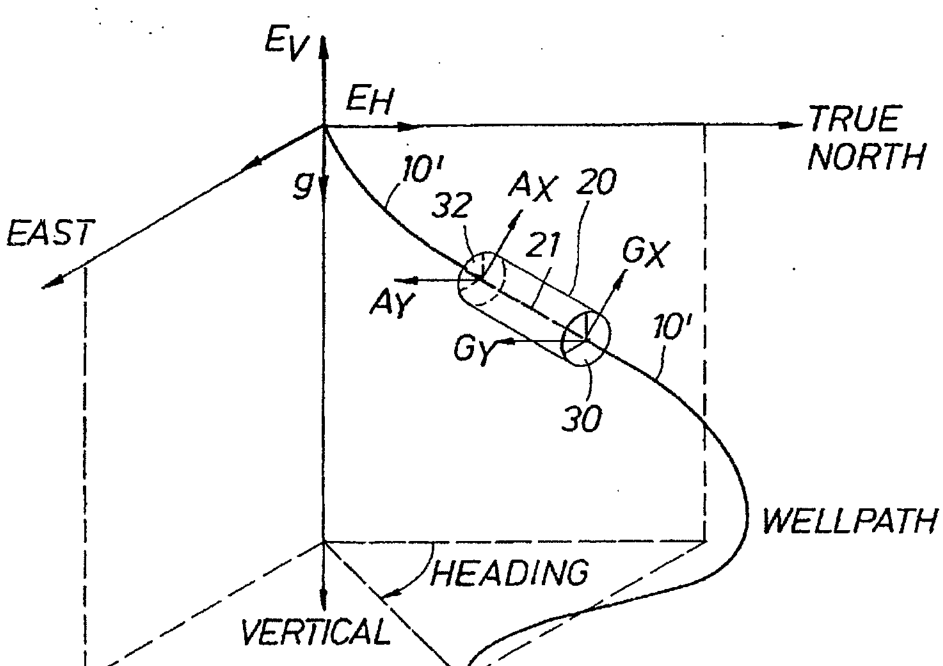


EXHIBIT "A"

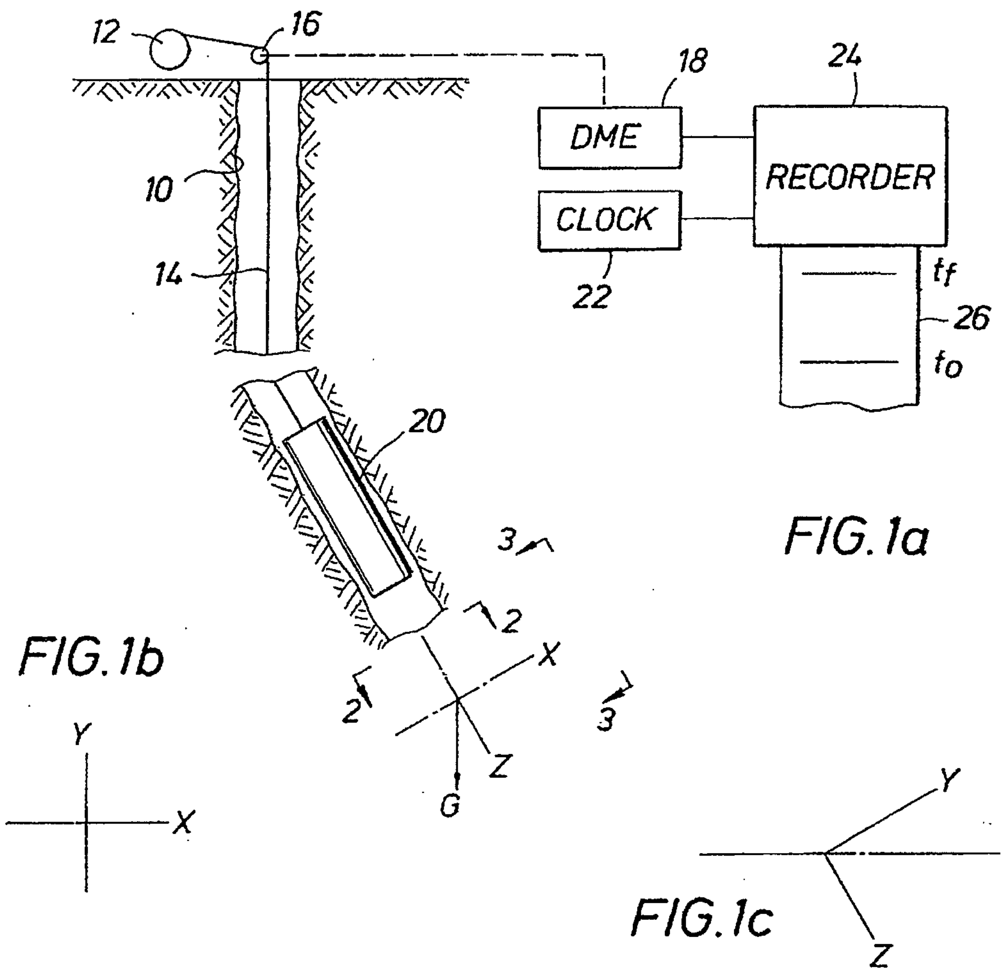


FIG. 1a

FIG. 1b

FIG. 1c

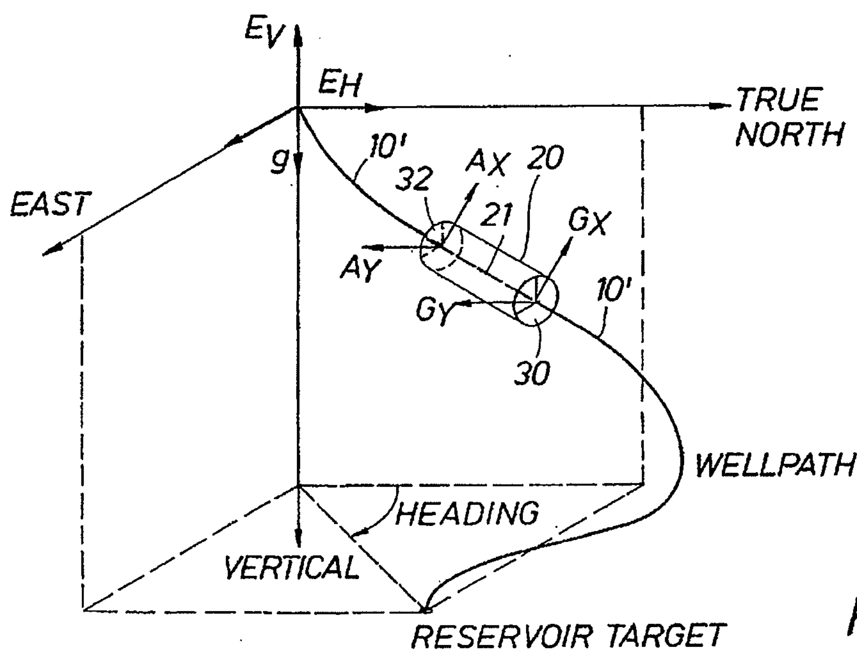


FIG. 2

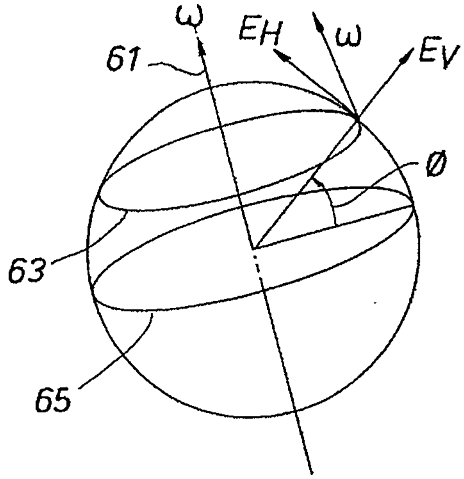


FIG. 3

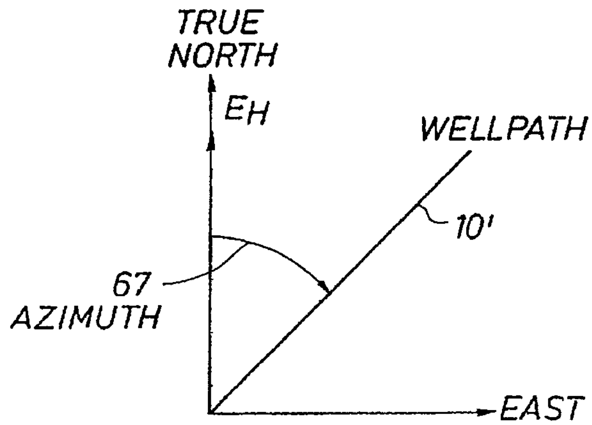


FIG. 4

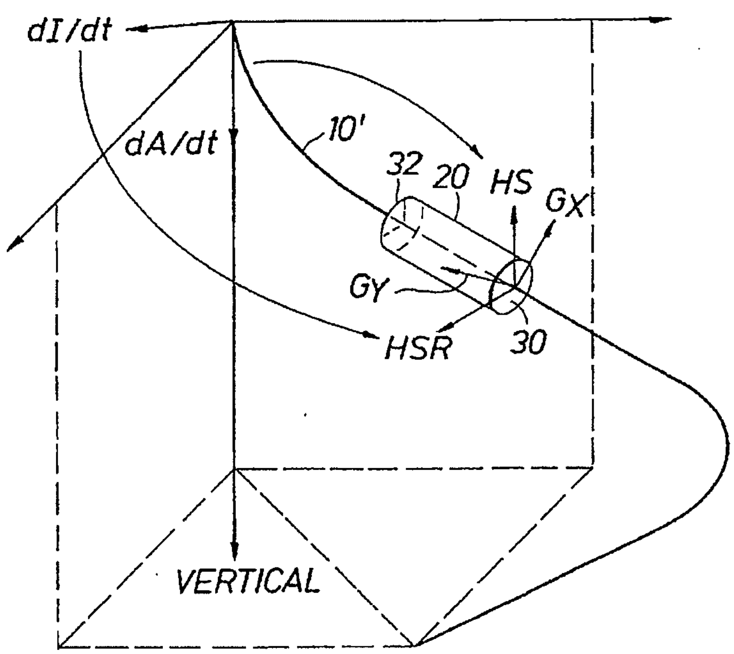


FIG. 5

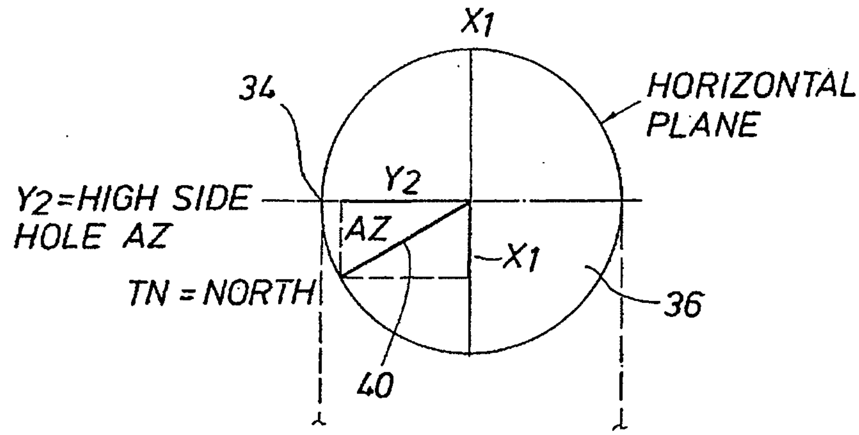

X1
34
HORIZONTAL PLANE
Y2
Y2=HIGH SIDE HOLE AZ
AZ
X1
TN = NORTH
36
40

FIG. 7

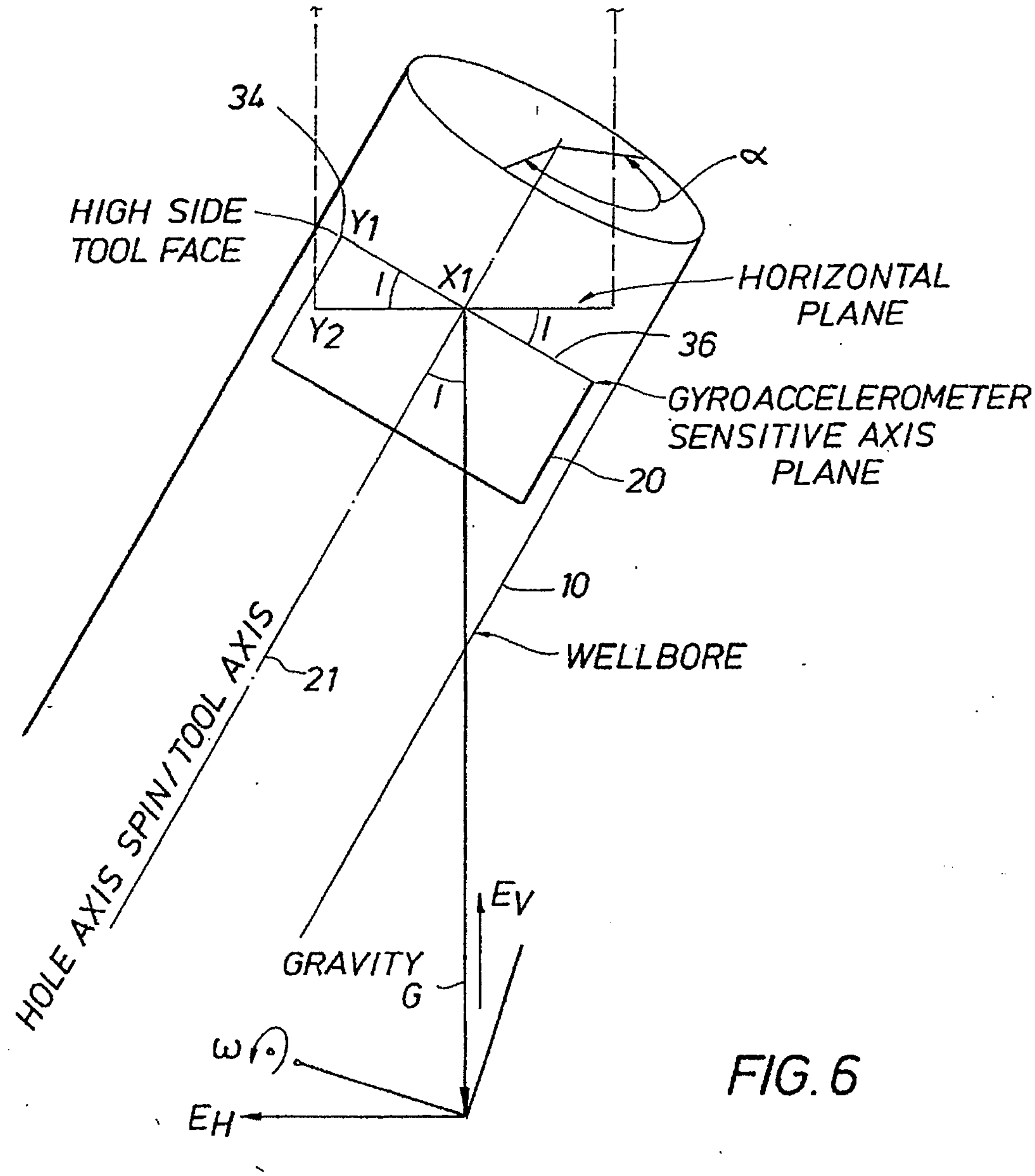

34
α
HIGH SIDE TOOL FACE
Y1
X1
I
HORIZONTAL PLANE
Y2
I
36
I
GYROACCELEROMETER SENSITIVE AXIS PLANE
20
10
WELLBORE
21
HOLE AXIS SPIN/TOOL AXIS
EV
GRAVITY G
ω
EH

FIG. 6

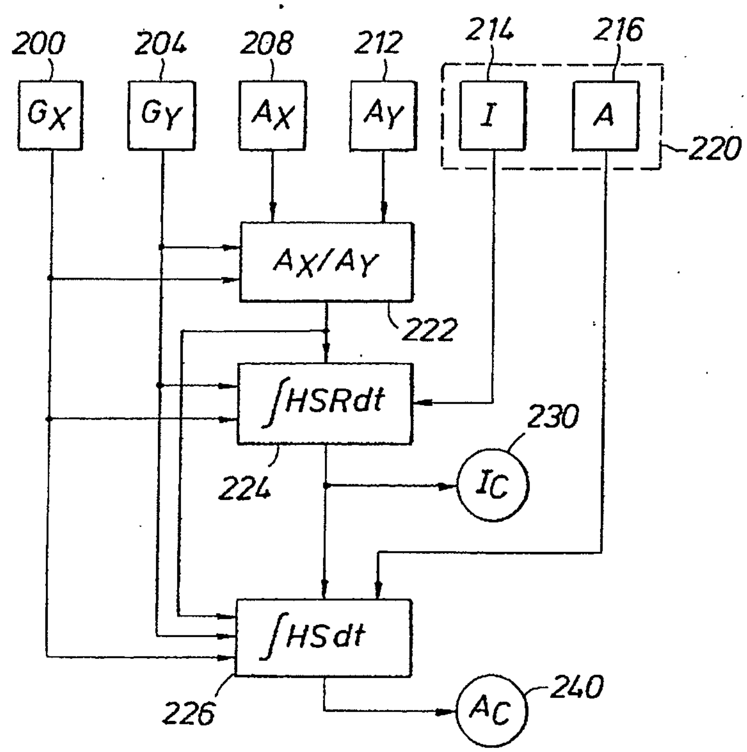
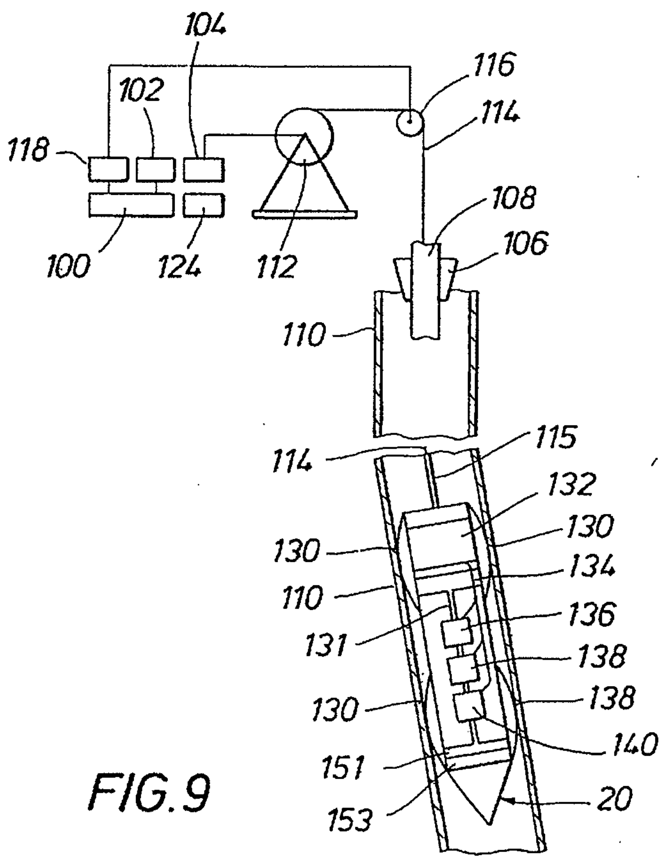

200
204
208
212
214
216
GX
GY
AX
AY
I
A
220
AX/AY
222
∫HSRdt
224
230
IC
∫HSdt
226
AC
240

FIG. 8


104
102
116
114
118
108
106
100
124
112
110
114
115
132
130
130
134
110
136
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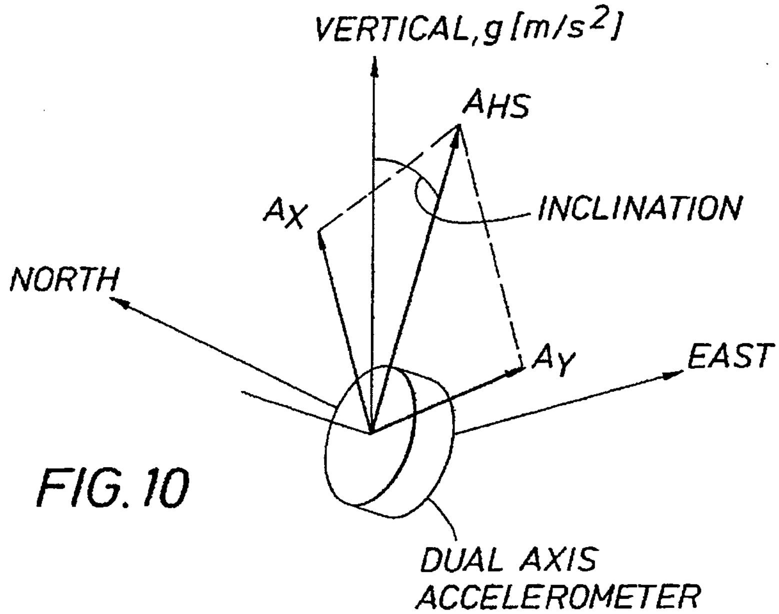
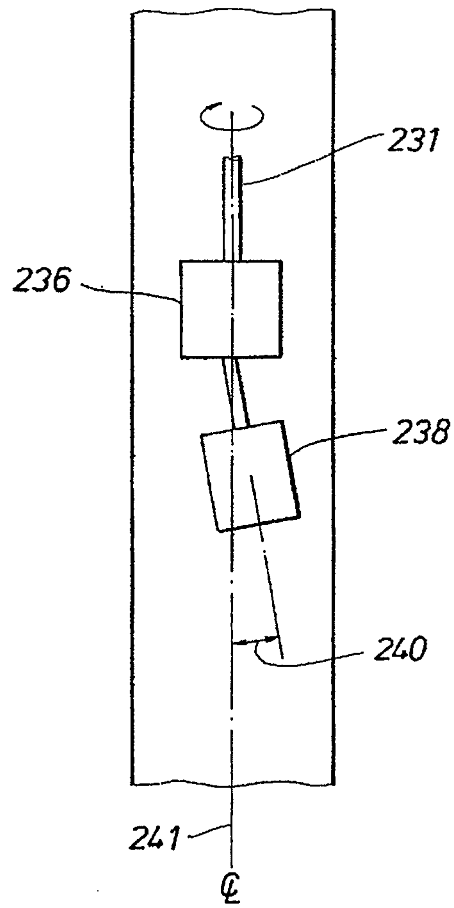
138
130
140
151
20
153

FIG. 9



VERTICAL, g [m/s²]
AHS
INCLINATION
AX
NORTH
AY
EAST
DUAL AXIS
ACCELEROMETER

FIG. 10



231
236
238
240
241
℄

FIG. 11

SURVEY APPARATUS AND METHODS FOR DIRECTIONAL WELLBORE WIRELINE SURVEYING

BACKGROUND OF THE DISCLOSURE

1. Field of the Invention

The present disclosure is directed to a wellbore survey method and apparatus, and more particularly to a survey system which enables mapping of the well borehole path while moving a survey instrument continuously along the well borehole by means of a wireline.

2. Background of the Art

Well borehole survey can be defined as the mapping of the path of a borehole with respect to a set of fixed, known coordinates A survey is required during the drilling of many oil and gas wells, and is of particular importance in the drilling of well which is deviated significantly from an axis perpendicular to the earth surface. Often two or three surveys will be required during the drilling process. In addition, a final survey is often required in a highly deviated well.

In drilling an oil well, it is rather easy to drill straight into the earth in a direction which is more or less vertical with respect to the surface of the earth. Indeed, regulatory agencies define a vertical well by tolerating a few degrees of deviation from the vertical. The interruption of the drilling operation and cost of the surveys is minimal in that situation. By contrast, highly deviated wells are required in a number of circumstances.

Onshore, it is necessary to drill a deviated well to enter formations at selected locations and angles. This may occur because of the faulting in the region. It is also necessary to do this around certain types of salt dome structures. As a further example of onshore, deviated drilling, a tremendous amount of interest has been developed in providing surveys of wells that have been deviated from a vertical portion toward the horizontal. Recently, a number of older wells drilled into the Austin chalk formation in the south central United States have played out and production has been lost. This has been a result of the loss of formation pressure. The Austin chalk producing strata is easily located and easily defined. It is however relatively thin. Enhanced production from the Austin chalk has been obtained by reentering old wells, milling a window in the casing, and reentry into the formation. The formation is typically reentered by directing the deviated well so that it is caught within the producing strata. In instances where the strata is perfectly horizontal with respect to the earth, that would require horizontal hole portion after curving into the strata. As a practical matter, the producing formations may also dip and so the last leg of the well may extend outwardly at some extreme angle such as 40° to 70°. Without being definitive as to the particular formation dip, such drilling is generally labeled horizontal drilling. The end result is that the borehole does not simply penetrate the formation, but is directed or guided follow the formation so that several hundred feet of perforations can then be placed to enable better production. To consider a single example, assume that the formation is 20' thick measured from the top to the bottom face. Assume as an example that the formation has a dip of 30°. By proper direction of the well during drilling, several hundred feet of hole can be drilled between the top and bottom faces of the formation. After drilling, but before casing has been completed, it is often necessary to conduct a concluding survey to assure that the production is obtained below the leasehold property. In addition, other surveys are required.

In offshore production, once a producing formation has been located, it is typically produced from a centrally positioned platform. Assume that the producing formation has an extent of four or five miles in lateral directions. Assume further that the formation is located at 5,000 feet or deeper. A single production platform is typically installed at a central location above the formation and supported on the ocean bottom. A production platform supports a drilling rig which is moved from place to place on the platform so that a number of wells are drilled. It is not uncommon to drill as many as 32 or more wells from a single production platform. From the inception, all the wells are parallel and extend downwardly with parallel portions, at least to a certain depth. Then, they are deviated at some angle. At the outer end of the deviated portion, vertical drilling may again be resumed. While a few of the wells will be more or less vertically drilled, many of the wells will be drilled with three portions, a shallow vertical portion, an angled portion, and a termination portion in the formation which is more or less vertically positioned. Again as before, one or two surveys are required during drilling, and a completion survey is typically required to be able to identify clearly the location of the well in the formation. Field development requires knowledge of the formation itself and also requires knowledge of the termination points of the wells into the formation. This means accurate and precise surveys are used to direct the wells in an optimum fashion to selected locations to get proper production from the formation.

The use of magnetic survey instrumentation is widely applied, but this technology has its limitations. For example, locally, magnetic survey instrumentation accuracy can be limited, since the earth's magnetic field strength and dip angles change, causing erroneous magnetic survey readings. Furthermore, magnetic survey accuracy can also be distorted due to non magnetic drill collars or so called "hot-spots". In addition, the magnetic survey accuracy can also be negatively affected by the presence of adjacent wells, from which the steel casing may severely influence the earth's magnetic field thereby generating erroneous magnetic readings within the well being surveyed. Other issues which affect the magnetic survey accuracy are the platform mass from which the survey is being conducted, geomagnetic interferences, and changes in the earth's magnetic field from one location to another location. Of course, these changes can be accurately measured, but in practice it is not a routine procedure and it further requires well trained field engineers and sophisticated instrumentation. Magnetic survey technology is also not applicable for use in wellbore which have been cased with steel casing.

The mapping apparatus, containing a rate gyroscope and accelerometers, remotely measures the earth's spin axis, and is lowered into the wellbore, while the system is held stationary at predetermined locations. In addition, the apparatus applies a rotary drive mechanism, functionally connected with the gyroscope and the accelerometers to rotate the gyroscope about its instrument or housing axis. Furthermore, the mapping apparatus contains a downhole power supply and data section for processing the sensor outputs to determine the heading direction of the wellbore at predetermined wellbore depths. This invention also discloses a method to measure azimuth very accurately regardless the wellbore deviation angle and latitude, while traversing continuously through a wellbore. A major advantage over U.S. Pat. No. 4,611,405 is the absence of a feed back controlled mechanism, i.e. the absence of a resolver means which is connected with a drive mechanism. In addition, the absence of a costly, power consuming feed back controlled mechanism reduces, significantly, development, operation and maintenance costs.

Survey instruments introduced in the 1980's featured rate gyroscopes and inclinometers in various configurations have been used for a number of years. A representative survey system of that sort is shown in U.S. Pat. No. 4,468,863 and also in U.S. Pat. No. 4,611,405. These instruments do not utilize a measure of the earth's magnetic filed, and can therefore be used in cased boreholes, and further overcome other previously discussed shortcomings of magnetic surveys. In these systems, a gyroscope is mounted with an axis of rotation coincident with the tool body or housing. The housing is an elongate cylindrical structure. Accordingly, the long housing is coincident with the axis of the well. That type system additionally utilizes X and Y axis accelerometers which define a plane which is transverse to the tool body thereby giving instrument inclination and orientation within the borehole. As the well deviates from the vertical, the axis of the gyroscope then is pointed in the correct azimuthal direction. By reading gyroscope movement, the azimuth can be determined and, when combined with the accelerometer measurements, the path of the borehole can be mapped in space.

In present day onshore and offshore drilling operations, highly deviated boreholes being drilled for reasons outlined above. High angles of deviation from the vertical often result in a rather small radius of curvature, or sharp bend in the borehole, thereby limiting the length and diameter of survey equipment that can traverse these bends. The prior art gyro/accelerometer systems discussed above, which are still widely used today, range in diameter up to 10⅝ inches and in length up to 40 feet. These dimensions introduce severe operational problems in traversing sharp or "tight" bends in today's highly deviated wells.

The prior art gyro/accelerometer systems are quite complex and expensive to fabricate and to operate. Still further, these systems must be stopped at discrete survey locations or "stations" within the borehole to obtain "point" readings. The survey instrument is stopped to permit a servo drive control system to restore one of the accelerometers to the horizontal. In effect, the gimbal or other support mechanism for the survey instrument is driven until the accelerometer is positioned in a horizontal plane. There are rather difficult calculations required to recognize the horizontal reference planes sought in that instance. The servo loop must be operated to seek that null position. Once that position is obtained, readings can be taken. This however requires stopping the equipment and permitting an interval of time while the servo loop accomplishes nulling. This requires taking a data point only at specified locations, so that a continuous curve representative of the borehole survey is merely an extrapolation of a number of discrete data points which are taken in space and which are formed into a curve utilizing certain averaging procedures. Furthermore, multiple stationary measurements greatly increases the cost of the survey in increased drilling rig time.

An object of the present invention is to provide a wellbore survey system which will operate in both open boreholes and boreholes cased with steel casing.

Yet another object of the invention is to provide accurate survey data over a wide range of borehole deviation ranging from essentially vertical boreholes to boreholes deviated from the vertical to angles of 90 degrees or more.

A further object of the invention is to provide a borehole survey system which can be conveyed along a wellbore and yield continuous borehole survey data without accuracy degradation in conjunction with quantifiable survey precision.

A still further object of the invention is to provide a survey instrument which is relatively short in length to negotiate short radius curves within the borehole.

Another object of the invention is to provide a smaller diameter survey instrument which can be pumped down the borehole.

Further objects of the invention are to provide a survey instrument which is rugged, reliable, relatively inexpensive to manufacture and operate, and which can be operated at relatively high temperatures.

There are other objects of the invention which will become apparent in the following disclosure.

SUMMARY OF THE INVENTION

The present disclosure provides a markedly improved wellbore survey system. The downhole survey instrument or "probe" utilizes a set of accelerometers which are mounted in the probe's cross borehole plane and mutually perpendicular to one another. In addition, the probe utilizes a dual-axis rate gyroscope, with its spin axis aligned with the axis of the probe. Two measurement principles, the gyrocompassing technique and the continuous survey mode, are employed to calculate wellbore direction as a function of depth. Both principles, and their application to the desired measurement, will be briefly summarized.

The gyrocompassing survey technique is employed to survey near vertical wellbore sections, and to measure the initial heading reference prior to switching to the continuous mode. During the gyrocompassing procedure, the probe is lowered into the wellbore by means of an electric wireline to measure the earth's gravity field and the earth's rate of rotation while the probe is held stationary at predetermined depths. The accelerometers measure the earth's gravity field. This allows computation of the instrument roll angle by determining the ratio of the output of the x-axis accelerometer over the output of the y-axis accelerometer. In addition, mathematical projection of the output of the x-axis accelerometer and the output of the y-axis accelerometer onto the highside direction enables computing the wellbore deviation angle. The azimuth angle is invariant to the earth's gravity field and therefore an additional sensor is used to determine the azimuth angle of the wellbore deviation angle. This is provided by the gyro readings as described in the following paragraph. The rate gyro sensor measures the earth's rate of rotation. Since the earth rotates at a fixed speed and these measurements are made at a given latitude, the vertical and horizontal earth rate vector components can also be derived. These components can then be projected into the sensitive gyro axis plane where the horizontal earth rate component references true north. The rate gyro, therefore, provides an azimuth reading referenced to a fixed point such as true north. By combining the output of the gyro sensitive axes and the accelerometer outputs, the well bore direction, inclination, and tool face can be determined. Depth is incorporated from the amount of wireline deployed to lower the probe within the borehole. Combining a series of survey stations downhole through a calculation method such as minimum curvature yields wellbore trajectory.

The continuous survey mode is based on measuring relative instrument rotations while the probe is continuously traversing through the borehole. After taking a stationary reference heading measurement in the gyrocompassing mode, new modeling procedures allow computation of probe azimuth and inclination changes about the highside and highside right directions, where the highside right direction is at right angles with respect to the highside direction. This is accomplished by mathematically projecting the probe azimuth and inclination changes into the gyro sensitive axis plane.

In order to calculate the actual wellbore path, the rate of rotation about the highside and highside right are integrated over time, yielding wellbore heading and inclination changes from the previously described reference procedure. In conjunction with depth, which is derived by continuously monitoring the amount of wireline deployed, the wellbore trajectory is generated.

An important advantage of the continuous mode is that, unlike gyrocompass surveying, continuous operation has no limitations in angle of inclination above 10 to 15 degrees.

Another obvious advantage of the continuous mode of operation is that the stopping and starting, and the time required to make station measurements, are avoided. Consider as an example that a survey of a well that has a length of 10,000 feet is required. Using the prior art station measurement technique, measurements should be taken at intervals not exceeding 100 feet. Using this criterion, one hundred measurements are required, wherein each measurement requires approximately one minute. Even if the top ten or twenty measurements are skipped because the top portion is fairly well known to be vertical, eighty to ninety station measurements are still needed. If the continuous mode survey of the present invention can eliminate eighty to ninety station measurements, a significant amount of time can be saved. Although time is required to establish a reference heading, and the continuous survey mode does require a finite amount of time, it is estimated that use of the present invention would result in a 25 to 50% reduction in interruption in the drilling process to obtain the survey. If one hour is saved per trip, rig time is reduced by one hour, and on land, that can have a value of easily $500.00 or more per hour. In an offshore drilling vessel, one hour of rig time may cost as much as $5,000–$10,000 per hour. Prices may vary up or down. It is therefore extremely beneficial to be able to run a survey without having to start and stop time and time again.

Another advantage of the present invention is that the quality of the data obtained from the survey is improved by a great amount over station measure surveys, in that measurements made in the continuous mode provide a continuous curve of the measurements. This then enables integration over the time interval of the survey. This permits a continuous survey to be provided. The present survey method and apparatus are probably more accurate than a survey furnished with discrete, stationary data points.

The present invention yields survey data which is not adversely affected by the angle of wellbore inclination. Furthermore, the probe of the present invention is relatively small in diameter, short in length, and can be reliably operated at relatively high temperatures.

In summary, the present disclosure sets out a survey method and apparatus which utilizes a rate gyro having a spin axis coincident with the shell or housing of the downhole instrument probe, which in turn is coincident with the axis of the well borehole. Two accelerometers positioned at right angles are mounted to define a transverse plane at right angles across the instrument. The probe housing is permitted to tumble or rotate in space in the continuous survey mode so that continuous movement including rotation of a random amount and direction is permitted. The output obtained from the system is a continuous data flow, i.e., a continuous well survey can then be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention are attained and can be understood in detail, more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings.

FIG. 1*a* shows a well survey instrument in accordance with the survey probe of the present disclosure positioned in a well borehole, and further shows deviated and essentially vertical portions of the borehole;

FIG. 1*b* is a view taken along the line 2—2 of FIG. 1*a* looking down the axis of the survey instrument probe housing and showing the X-Y plane at right angles with respect to the axis of the survey instrument;

FIG. 1*c* is a view taken along the X axis of FIG. 1*a* showing the tilt of the Y axis;

FIG. 2 illustrates gyrocompass surveying with the disclosed survey system, showing the earth's gravity and rotational vectors projected in the sensor axis plane to measure wellbore direction while the survey probe is stationary within the wellbore;

FIG. 3 illustrates the projection of the earth's rotation vector in the horizontal and vertical plane, as a function of latitude;

FIG. 4 shows the horizontal earth rate vector referencing true north;

FIG. 5 illustrates the survey system operation when the probe is moving continuously within the borehole, by integrating the highside and highside right measurements over time intervals;

FIGS. 6 and 7 jointly show relative position of the X-Y plane defined by the axis through the survey instrument probe body, and the projection of the X-Y plane into a plane by rotation about an axis;

FIG. 8 is a function diagram of the data processing steps used to convert parameters measured by the survey system into well mapping parameters of interest;

FIG. 9 illustrates the major elements of the downhole and surface components of the survey system;

FIG. 10 includes projection of both accelerometer axes onto the highside direction; and

FIG. 11 shows a bent axis arrangement for the accelerometer plane.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Before describing in detail the preferred apparatus and methodology of the invention, the several of the basic concepts employed in the invention will be presented as a foundation for more detailed disclosure.

Basic Apparatus and Measured Quantities

Attention is first directed to FIG. 1*a* of the drawings which is a simplified view showing a well during drilling and a well which requires a survey. To provide a context for the method and apparatus of the present disclosure, FIG. 1*a* shows a well borehole **10** which extends into the earth's surface and which has some measure of deviation. The amount of deviation is significant in many instances. To provide a suggested minimum, FIG. 1*a* will be described assuming that the well includes an upper portion which is more or less vertical and a central or lower portion which is inclined at an angle in excess of about 15°. Typically, the well is surveyed at some time during drilling, and especially when drilling a deviated well. Surveys typically are not required when the well is primarily vertical or when the well is relatively shallow. Sometimes, the type of survey made by the present system is not conducted in vertical wells. This type of survey carries a premium charge in comparison with lesser techniques preferred in the survey of vertical wells. Indeed, it may be sufficient merely to drill the well completely without this type of survey equipment should the well be totally vertical and relatively shallow. The present invention is best applied to deeper wells and whose which have deviated portions.

Typically, this well is surveyed before it has been cased from top to bottom. There may be a portion of casing equipment at the top part. Again, the casing may be present only through a few hundred or a few thousand feet of depth. In many instances, the well may be simply open hole. Whatever the circumstances, the present disclosure sets forth the well at a preliminary stage. The well of this disclosure is surveyed by providing a wireline supported instrument probe **20**. A drum **12** spools and deploys the wireline cable **14** on the drum thereby conveying the probe **20** along the borehole **10**. It is directed into the well through a pulley **16** at the surface, which is often referred to as a "measure" or "sheave" wheel. This pulley also serves as a guide wheel for directing the wireline cable **14** into the wellbore **10**, and also serves as an input device for depth measuring equipment (DME) **18** which measures the length of wireline **14** that extends into the wellbore **10**. At the bottom of the wireline **14**, the survey instrument probe **20** of the present disclosure is supported. The survey instrument **20** comprises an elongate cylindrical shell or housing. The equipment to be discussed below is supported on the interior.

The equipment shown in FIG. 1*a* additionally includes a clock **22** which provides data for a time based recorder **24**. That forms a printed record **26** of measured and computed wellbore survey data. The survey record **26** starts at t_o and runs to t_f. The time t_o therefore represents the beginning instant of the survey and t_f represents the end of the survey. The record **26** is a recording of survey data as a function of time, or can alternately be converted as a function of the depth of the survey instrument probe **20** along the borehole **10**, where depth is measured by the DME **18** by sensing the length of wireline **14** deployed within the borehole **10**.

FIG. 1*a* additionally shows a reference system which is tied to the instrument. The Z axis coincides with the elongate axis **21** of the housing **20** and also coincides with the axis of the borehole **10**. At the surface, the X and Y axes coincide with a horizontal plane which is transverse to the well borehole **10**. As will be understood, this reference system moves with the instrument. When the instrument **20** moves into the deviated portion, that repositions the reference system. In addition, FIG. 1*a* shows the gravity factor which is represented by g. To the left and right of the probe instrument package **20**, the X and Y axes define the plane which is horizontal at the surface but which is otherwise tilted depending on the inclination of the survey instrument **20**. By viewing the instrument along the X axis as shown in FIG. 1*b*, the Y axis is shown at an inclined angle above the horizontal as illustrated in FIG. 1*c*.

Measurement Principles

As mentioned previously, two measurement principles, the gyrocompassing technique and the continuous survey mode, are employed to calculate wellbore trajectory as a function of depth. These measurement principles, and their application to the desired measurement, will be briefly summarized.

Gyrocompassing Survey Technique

The gyrocompassing survey technique is employed to survey near vertical wellbore sections. Furthermore, the gyrocompassing survey technique is used to measure the initial heading reference prior to switching to the continuous mode. During the gyrocompassing procedure, the probe **20** is lowered into the wellbore **10** by means of the electric wireline **14** to measure the earth's gravity field and the earth's rate of rotation while the probe is held stationary at predetermined depths. X and Y accelerometers, denoted as a pair by the numeral **32**, measure the gravity field, g, with respect to the axis **21** of the instrument probe **20** as shown in the schematic, three dimensional prospective FIG. **2**. The measured quantities are the orthogonal vectors Ax and Ay shown in FIG. **2** The azimuthal orientation of the probe **20** within the borehole **10** defines the "highside tool face", see the accelerometer vectors in the plane at right angles to the housing axis in FIGS. **6**, **7** and **10**. An accelerometer measures acceleration (in this particular invention the earth's gravity field). The vector combination of the two accelerometers enables measurement of the instrument axis roll or the tool face angle of the instrument. This is performed by determining the ratio of the x-axis accelerometer output over the y-axis accelerometer output. In addition, the accelerometer outputs enable one to determine how far the instrument is deviated from vertical. In other words, the accelerometers define the inclination of the wellbore at a measured depth. In order to do so, the x-axis accelerometer output and the y-axis accelerometer output are projected onto the highside of the crossborehole plane of the instrument. The angle between the projected highside gravity component and the earth's gravity field define the inclination of the wellbore at that particular measured depth. See FIGS. **6**, **7** and **10** for visual clarification.

This allows the computation of the inclination of the probe **20**, therefore the inclination of the borehole **10** at the position of the probe along the well path **10'**, to be measured. The computation is performed by means of mathematical projection of the gravity field vector g into the accelerometer sensitive axis plane defined by A_x and A_y. It is apparent that the accelerometer readings alone are not sufficient to map the path **10'** of the borehole in three-dimensional space, since the heading azimuth of the borehole, shown in FIG. **2**, is not known. This is provided by the gyro readings as described in the following paragraph.

The rate gyro sensor **30** measures the earth's rate of rotation, defined by the vector ω, identified by the numeral **61** in FIG. **3**. Since the earth rotates at a fixed speed and these measurements are made at a given latitude **63**. The vertical and horizontal components of the earth rate vector components ω, defined as E_H and E_V, respectively, can be derived as shown in FIG. **3**. Note that the component E_V forms an angle ϕ with the plane **65** defining the earth's equator, therefore defining the latitude of the well borehole. The components E_H and E_V can then be projected into the sensitive gyro axis plane, (G_y, G_x) where G_y and G_x are the angular rate outputs of the gyro **30**, and where the horizontal earth rate component E_H references true north as shown in FIG. **4**. The rate gyro, therefore, provides a reading of the azimuth **67** of the well path **10'**, referenced to a fixed direction such as true north.

By combining the output of the gyro sensitive axes (G_y, G_x) and the accelerometer outputs A_x, A_y, the well bore direction, inclination, and tool face highside can be determined. Depth is incorporated from the amount of wireline **10** deployed from the drum **12** to lower the probe **20** within the borehole **10**. Combining a series of survey stations downhole through a calculation method such as minimum curvature yields wellbore trajectory path **10'**.

Continuous Survey Mode

The continuous survey mode is based on measuring relative instrument rotations while the probe **20** is continuously traversing through the borehole **10**. After taking a stationary reference heading measurement in the gyrocompassing mode, new modeling procedures allow computation of probe azimuth and inclination changes, dA/dt and dI/dt, respectively, about the highside (HS) and highside right (HSR) directions, where the HSR direction is at right angles with respect to the HS direction. This is accomplished by mathematically projecting dA/dt and dI/dt into the gyro sensitive axis plane (Gy, Gx), as shown in FIG. **5**.

In order to calculate the actual wellbore path, the rate of rotation about HS and HSR are integrated over time, yielding wellbore heading and inclination changes from the previously described reference procedure. In conjunction with depth, which is derived by continuously monitoring the amount of wireline **14** deployed, the wellbore trajectory **10'** is generated.

Operation, Data Processing, and Results

Recall that the system is operated in the gyrocompassing mode with the survey probe stationary in order to obtain a reference azimuth A and a reference inclination I. In the subsequent continuous mode of operation, the survey probe is conveyed along the borehole, the variation of inclination and azimuth, with respect to the reference inclination and azimuth is measured, and the path or trajectory of the wellbore in three-dimensional space is computed from these measured rates of change. The operation, data processing, and results obtained in both modes of operation will be disclosed in detail.

Gyrocompassing Mode

As shown in FIG. **1a** of the drawings, the portion of the well which is substantially straight does not require the expensive type survey which is conducted by the present disclosure. Accordingly, the survey instrument **20** need not be run in that portion. It is better to survey that portion of the well with the gyro compass system only. It is also better to run the survey in the highly inclined portion. FIG. **1a** shows the instrument probe **20** in the radically inclined portion of the well. The survey instrument of the present disclosure is especially effective at inclined angles in excess of about 20° or perhaps even 15° up to above 90°. In a vertical well, the accelerometers (at right angles to gravity) do not provide an output data. Inclination is needed to prompt accelerometer readings. A maximum inclination is not defined. In other words, at that juncture the instrument probe **20** is almost laying in a horizontal wellbore **10**. Moreover, the survey instrument and procedure of the present disclosure is best carried out while collecting four data streams from the survey instruments in the survey probe **20**. The gyro sensor **30** provides a rate gyro signal. As the Z axis of the gyro is forced from coincidence with the vertical, angular rates are generated. These are rates normally expressed in angular rotation per unit time such as degrees/min. There are two components of the angular rotation rate. The axis of the gyro **30** will be tilted with angular tilt being measured as it is rotated from a true vertical position. Imposing a reference system on the gyro in the perfect upright position, one component of information is the angular rate or G_x and a similar angular deflection is G_y. The two measurements are both needed because it would be a rare circumstance in which deflection were totally in only the X or Y dimensions.

Therefore the output of the gyro instrument **30** within the survey probe **20** is G_x and G_y. As will be understood, the gravity vector is represented by the vector g. The accelerometers **32** form the output signals A_x and A_y. There is no need to deploy an accelerometer along the Z axis and hence there is no data A_z. If Z axis data is needed, it can be alternately obtained from the wireline movement, and that information as needed is available from the DME data.

In FIGS. **6** and **7** jointly, the gravity vector g again is shown. FIG. **6** shows in abbreviated fashion the case or housing **20**. It has imposed on it the designation at **34** indicating the highside of the tool face. This is the uppermost point on the housing **20** in a transverse plane with respect to the tool axis. The point **34** is located in a plane **36** at right angles to the hole axis and spin axis **21** of the survey probe **20**. This plane is defined in the X and Y dimensions. In FIG. **6**, it is shown from the side, but at an angle dependent on the angle of deviation of the well. This permits rotation of the plane **36** to the horizontal as shown in the full line representation in FIG. **6**, and which is projected into FIG. **7** by the dotted line representation. The highside point **34** is rotated into the horizontal plane shown in FIG. **7**. Recall that the gyro **30** has two axes which are maintained in alignment with the X and Y accelerometer axes. Recall also that horizontal earth rate vector E_H can be readily resolved into vector components. This is shown in part in FIG. **7** where the vector **40** is resolved into X and Y components. This is the vector that is indicative of true north and includes the vectoral components resolved in FIG. **7**. When that rotation is made, thereby resulting in the projection of the true north vector in the horizontal plane as shown in FIG. **7**, the true north vector can then be seen.

The present system forms data which yields the true north measurement which is then converted into the azimuth as shown in FIG. **7**. This is the previously discussed reference azimuth A obtained with the system operating in as a station measurement the gyrocompassing mode.

Operation should be considered now. If the probe **20** is suspended in a vertical wellbore, the accelerometer outputs which are A_x and A_y are insensitive to gravity. When the well is deviated as shown in FIG. **1a** by an amount sufficiently large to define two components, it is possible to represent at least the X and Y components of the gravity vector g so that vector components can be resolved in the X-Y plane. These are represented as A_x and A_y which are added as vector components to obtain two measures of the gravity vector. The vector addition of components A_x and A_y yields the direction of the highside (HS) of the instrument in the borehole **10** at the position of the probe **20**.

Mathematical projection of the output of the x-axis accelerometer and the output of the y-axis accelerometer onto the highside direction provides the projected gravity component sensed by the instrument. The angle between the projected gravity component sensed by the instrument and the gravity direction equals the wellbore deviation angle when the instrument is stationary.

The multiple mode of operation is triggered in many ways, for example, by a switch, or by arbitrary depth selection or by computer operation. If several wells are drilled straight below a platform for 1,500 feet and then deviated to reach an underwater field, the first 1,500 feet of hole need not be surveyed. The continuous mode is switched on after 1,500 feet. Restated, no survey is needed for 1,500 feet and the time to is started then. This is implemented by turning on the power supply and data processor at t_o after 1,500 feet. A switch in the data processor is sufficient.

Continuous Mode Operation Once the reference azimuth and reference inclination values, A and I, have been measured with the probe **20** stationary, the continuous mode of operation is initiated. The gyro **30** is locked using a locking apparatus described in the following section. The computation of inclination I_c and azimuth A_c values in the continuous mode, with respect to corresponding reference values I and A measured in the stationary, gyrocompassing mode, is presented in block diagram form in FIG. **8**.

The accelerometer outputs A_x and A_y, represented by boxes **208** and **212**, are used to form the ratio A_x/A_y at the step represented by step **222**. The outputs G_x and G_y, represented by the boxes **200** and **204**, respectively, are combined with this ratio at step **222** to correct the ratio for any non gravity acceleration effects. The computation at step **222** yields the rate of roll over the HSR direction with respect to a reference rate of roll. This quantity is integrated over time, measured from a previously mentioned reference time to, which represents the initiation of the continuous mode operation, and combined with G_x and G_y at step **224** to yield a relative borehole inclination. This relative borehole inclination, when combined with the reference borehole inclination **214** stored in a memory device **220**, yields the desired borehole inclination I_c with the system operating in the continuous mode. The I_c output is represented at **230**.

Still referring to FIG. **8**, the relative borehole inclination, G_x and G_y, and A_x/A_y, are combined and integrated over time, measured from t_o at step **226**. This yields a continuous relative azimuth value measured with respect to A, the reference azimuth **216** stored within the memory **220**. The relative azimuth is combined with the reference azimuth A at step **226** to yield the desired azimuth reading A_c, represented at **240**, which in with the azimuth of the borehole computed with the survey system operating in the continuous mode of operation. As discussed previously, I_c and A_c are combined to yield a map of the borehole in three-dimensional space. All computations are preferably performed at the surface using a central processing unit defined in the following discussion of the system apparatus. To summarize, A_c and I_c are determined mathematically by integrating, over time, measured rates of change of inclination and azimuth with respect to measured, reference azimuth and inclination values. This approach greatly simplifies the downhole equipment required to obtain and accurate and precise map of the wellbore trajectory. The result is a smaller, more rugged survey instrument that those available in the prior art.

APPARATUS DETAILS

Attention is directed to FIG. **9** which shows the surface equipment and the downhole instrument probe **20** of the invention. These two basic subsections are connected physically and electronically by means of the wireline cable **114**.

The surface equipment will first be discussed. The depth measuring equipment (DME) **118** cooperates with a central processing unit (CPU) **100** and a recorder **124**. FIG. **9** also shows a surface interface **102** and a surface power supply **104** which provides power to the elements of the surface equipment. A drum **112** stores wireline cable **114**, and deploys and retrieves the cable within the borehole. The cable **114** passes over a measure or sheave well **116** and extends into the wellbore through a set of slips **106** around a pipe **108**. The wellbore is shown cased with casing **110**.

The instrument probe **20**, connected to one end of the wireline **114** by means of a cable head **115**, is guided within the casing **110** by a set of centralizing bow springs **130**. The probe **20** encloses an electronic assembly and power supply **132** which powers and controls other elements within the probe. A motor **134** rotates a gyro **136** by means of a shaft **131**. The motor **134** also rotates the accelerometer assembly, shown separately as an X axis component **138** and a Y axis component **140**, by means of the shaft **131**. The shaft **131** is terminated at the lower end by a bearing assembly **151** and a lock assembly **153** which fixes the shaft **131** when the drive motor **134** is turned off. Probe instrumentation is relatively compact so the length and diameter of the survey probe **20** are relatively small. Furthermore, the instrumentation within the probe **20** is relatively simple thereby yielding a very reliable well survey system. Other stated objects of the present invention are achieved as discussed in other sections of the above disclosure.

Attention is directed to FIG. **11** which shows a modified form of instrument. The illustrated portion includes a shaft **231** aligned on the housing centerline and which corresponds to the shaft **131** described with respect to FIG. **9**. The shaft rotates the gyro **236** in the same fashion but the next shaft portion is set at an angle. The angled shaft **239** rotates an accelerometer assembly **238** having the same accelerometers in it as embodiments mentioned earlier. The angle **240** is typically 10° to 30°, the preferred value being about 15°. The canted angle **240** provides an added data. The unprocessed output of the X and Y accelerometers provides two data streams which both can be resolved in two components, one being along the housing or tool axis or centerline **241** (see FIG. **11**) and the second resolved component at right angles to the centerline **241**. This angled mounting of the sensors **238** enhances performance by providing more data in vertical well portions.

While the foregoing is directed to the preferred embodiment, the scope can be determined from the claims which follow.

What is claimed is:

1. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing having an axis coincident therewith along a well borehole between first and second selected positions to form a survey between said first and second positions, wherein said first position is located within a non vertical section of said well borehole;

(b) positioning a rate gyro in said housing wherein said rate gyro forms rate gyro output signals indicative of measured angular rate between said first and second positions and taking a set of measurements to initialize the gyro at the first position;

(c) positioning in said housing first and second accelerometers at a right angle therebetween wherein said accelerometers define a transverse plane to the axis of said housing; and forming accelerometer output signals from said first and second accelerometers indicative of values sensed thereby at said first position and during movement between first and second positions in said well borehole;

(d) forming stored gyro data representative of said rate gyro output signals, relative to a reference azimuth measured by said rate gyro with said sensor housing stationary at said first position, during movement between said first and second positions along the well borehole;

(e) forming stored accelerometer data representative of said accelerometer output signals, relative to a reference inclination measured by said accelerometers with said housing stationary at said first position, during movement between said first and second positions alone the well borehole; and

(f) converting said stored rate gyro data and said stored accelerometer data into a plot of well borehole azimuth between said first and second positions.

2. The method of claim 1 wherein said housing is an elongate cylindrical housing and including the step of moving said housing along the well borehole suspended from a cable and moving said housing in a continuous motion between said first and second positions.

3. The method of claim 1 wherein said rate gyro is initially oriented to define an axis thereof coincident with the axis of said housing, and forming resolved X and Y components of movement of said rate gyro in said housing while moving between said first and second positions.

4. The method of claim 1 wherein said housing is suspended on an elongate wireline in said well borehole and said wireline is moved upwardly or downwardly to move said housing in said well borehole and movement of said housing is measured as a function of time to depth.

5. The method of claim 1 wherein said rate gyro is provided with first and second rate sensors at right angles for forming said rate gyro signals in X and Y axes with respect to the Z axis of the rate gyro, and further including the step of positioning the rate gyro so that the Z axis thereof coincides with said housing, and subsequently calculating azimuth from said rate gyro.

6. The method of claim 1 wherein said first and second positions are in a well borehole inclined by a specified angle from the vertical.

7. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing having an axis coincident therewith along a well borehole between first and second selected positions to form a survey between said first and second positions, wherein said first position is located within a non vertical section of said well borehole;

(b) positioning a rate gyro in said housing wherein said rate gyro forms output signals to initialize the gyro and also indicative of measured angular rate at said first position and between said first and second positions;

(c) positioning in said housing first and second accelerometers at a right angle therebetween wherein said accelerometers define a transverse plane to the axis of said housing, and forming outputs from said first and second accelerometers indicative of values sensed thereby at said first position and during movement between first and second positions in said well borehole and relative to a reference inclination at said first position;

(d) converting, data representative of the outputs of said rate gyro and said accelerometers during movement between said first and second positions along the well borehole to determine well borehole inclination; and

(e) recording a plot of well borehole inclination to form a plot between said first and second positions.

8. The method of claim 7 wherein said housing is suspended on an elongate wireline in said well borehole and said wireline is moved upwardly or downwardly to move said housing in said well borehole and movement of said housing is measured as a function of time and depth to form a record thereof.

9. The method of claim 7 wherein said first and second positions are in a well borehole inclined by a specified angle from the vertical.

10. The method of claim 7 wherein said housing is an elongate cylindrical housing and including the step of moving said housing along the well borehole suspended from a cable and moving said housing in a continuous motion between said first and second positions to obtain azimuth and depth between said fist and second positions.

11. The method of claim 10 wherein said rate gyro is initially oriented to define an axis thereof coincident with the axis of said housing, and forming resolved X and Y components of movement of said rate gyro in said housing while moving between said first and second positions.

12. The method of claim 7 wherein said rate gyro is provided with first and second rate sensors at right angles for forming gyro rate output signals in X and Y axes with respect to the Z axis of the rate gyro, and further including the step of restoring the rate gyro so that the Z axis thereof coincides with said housing, and subsequently calculating well borehole azimuth with respect to a reference azimuth measured with said rate gyro and with said sensor housing stationary at said first position.

13. The method of claim 12 wherein said first and second positions are in a well borehole inclined by a specified angle from the vertical.

14. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing having an axis coincident therewith along a well borehole between first and second selected positions to form a survey between said first and second positions, wherein inclination of said well borehole at said first position is greater than about 15 degrees;

(b) positioning a rate gyro in said housing wherein said rate gyro forms output signals to initialize the gyro and also indicative of measured angular rate;

(c) positioning in said housing first and second accelerometers at a right angle therebetween wherein said accelerometers define a transverse plane to the axis of said housing; and forming outputs from said first and second accelerometers indicative of values sensed thereby during movement between first and second positions in said well borehole with respect to a reference inclination at said first position;

(d) forming stored data representative of the outputs of said rate gyro with respect to a reference azimuth at said first position and said accelerometers during movement between said first and second positions along the well borehole to determine well borehole azimuth and inclination; and

(e) recording a plot of well borehole azimuth and inclination between said first and second positions.

15. The method of claim 14 wherein said housing is an elongate cylindrical housing and including the step of moving said housing along the well borehole suspended from a cable and moving said housing in a continuous motion between said first and second positions.

16. The method of claim 14 wherein said rate gyro is provided with first and second rate sensors at right angles for forming gyro rate output signals in X and Y axes with respect to the Z axis of the rate gyro, and further including the step of positioning the rate gyro so that the Z axis thereof coincides with said housing to direct said housing axis along said borehole, and determining azimuth from said rate gyro.

17. The method of claim 14 wherein said first and second positions are in a well borehole inclined by a specified angle from the vertical.

18. The method of claim 14 wherein said rate gyro is initially oriented to define an axis thereof coincident with the

axis of said housing, and forming resolved X and Y components of movement of said rate gyro in said housing while moving between said first and second positions.

19. The method of claim 18 wherein said housing is suspended on an elongate wireline in said well borehole and said wireline is moved upwardly or downwardly to move said housing in said well borehole and movement of said housing is measured as a function of time to form a record thereof.

20. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing along a well borehole between first and second selected positions to form a survey between said first and second positions, wherein inclination of said well borehole at said first position is greater than about 15 degrees;

(b) positioning a rate gyro in said housing wherein said rate gyro forms orthogonal output signals to initialize the gyro and also indicative of measured angular rate;

(c) positioning in said housing first and second accelerometers at a right angle therebetween wherein said accelerometers define a transverse plane to the axis of said housing;

(d) measuring a reference azimuth and a reference inclination at said first position and computing and storing data representative of the outputs of said rate gyro relative to said reference azimuth and said accelerometers relative to said reference inclination during continuous, unstopped movement between said first and second positions along the well borehole; and

(e) converting the stored data into a plot of well borehole azimuth between said first and second positions.

21. The method of claim 20 wherein said housing is an elongate cylindrical housing and including the step of moving said housing along the well borehole in a continuous motion between said first and second positions.

22. The method of claim 21 including the step of measuring housing rotation during movement, and projecting the measured housing rotation to a reference plane to fix in relative space one of said accelerometer outputs.

23. The method of claim 22 including the step of creating a Z axis output from accelerometer data.

24. The method of claim 22 including the step of setting the reference plane to obtain a reference horizontal plane relative to gravity.

25. The method of claim 22 including the step of projecting the gyro output data into a horizontal plane for measuring inclination from the gyro data.

26. An apparatus comprising:

(a) an elongate housing having an axis along the length thereof;

(b) a motor in said housing for rotating a shaft extending along said housing;

(c) a rate gyro supported by said housing and axially aligned within said housing and connected to said shaft for rotation thereby;

(d) a pair of accelerometers defining an X and Y plane wherein said pair are at right angles, and are rotated by said motor shaft;

(e) a signal processor connected to said rate gyro and said pair of accelerometers to process signals therefrom from a survey of a well borehole, wherein said signal processor

(i) forms a ratio of X and Y components of outputs of said accelerometers projected onto said X and Y planes, and

(ii) combines X and Y outputs from said rate gyro with a function of said ratio thereby correcting said ratio for any non gravity acceleration effects and yielding a relative borehole inclination; and

(f) a control for said signal processor to initialize operation so that said processor forms a survey between first and second locations in said well borehole, wherein inclination of said well borehole at said first location is greater than about 15 degrees.

27. The apparatus of claim 26 wherein said control and said signal processor form a survey of the well borehole beginning from a specified angle with respect to the vertical and relating said relative borehole inclination thereto.

28. The apparatus of claim 26 wherein said control responds to an angular change with respect to vertical in excess of a selected angle.

29. The apparatus of claim 26 wherein said gyro is rotated about said housing axis and said pair of accelerometers defines a plane at a non normal angle with respect to said axis.

30. The apparatus of claim 29 wherein said motor shaft is coincident with said housing axis at said rate gyro to mount said gyro for axial rotation, and said shaft is angled to said pair to define a non normal plane for said pair with respect to said housing axis.

31. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing along a well borehole between first and second selected positions to form a survey between said first and second positions, wherein said first position is located within a non vertical section of said well borehole;

(b) positioning a rate gyro in said housing wherein said rate gyro forms orthogonal output signals to initialize the gyro and also indicative of measured angular rate;

(c) positioning in said housing first and second accelerometers at a right angle therebetween wherein said accelerometers define a transverse plane to the axis of said housing;

(d) measuring gravity induced signals from said first and second accelerometers at the first position and determining therefrom a vector component describing the first position wherein the component includes well borehole inclination;

(e) measuring at the first position a vector component describing housing azimuth;

(f) moving the housing along the well borehole from the first to a second position in the well borehole;

(g) storing data representing the inclination and azimuth between first and second positions;

(h) measuring a reference azimuth and a reference inclination at said first position and computing and storing data representative of the output of said rate gyro relative to azimuth;

(i) storing data representative of said accelerometers relative to inclination; and

(j) converting the stored data into a plot of well borehole azimuth between said first and second positions.

32. The method of claim 31 including the step of measuring linear travel of said housing along the well borehole between the first and second positions.

33. The method of claim 31 including the step of measuring housing rotation as indicated by signals from said accelerometers.

34. The method of claim 31 including the step of measuring data from said rate gyro indicative of relative rotation of said housing in space from said first position.

35. A method of conducting an oil well survey along a well borehole comprising the steps of:

(a) moving an elongate sensor housing along a well borehole between first and second selected positions along the well borehole to form a borehole survey between said first and second positions, wherein said first position is located within a non vertical section of said well borehole;

(b) measuring angular rate of the housing on movement between said first and second positions;

(c) placing first and second accelerometers at a right angle in said housing wherein said accelerometers define a transverse plane to axis of said housing;

(d) measuring gravity induced signals from said first and second accelerometers at the first and second positions;

(e) determining the well borehole inclination;

(f) determining a vector component describing housing azimuth;

(g) moving the housing along the well borehole from the first to a second position in the well borehole;

(h) storing data representing the inclination and azimuth between first and second positions; and

(i) converting the stored data into a plot of well borehole azimuth between said first and second positions after initializing the stored data to form a reference at said first position.

36. The method of claim 35 including the step of measuring linear travel of said housing along the well borehole between the first and second positions.

37. The method of claim 36 including the step of measuring housing rotation as indicated by signals from said accelerometers.

38. The method of claim 37 including the step of measuring data from said rate gyro indicative of relative rotation of said housing in space from said first position.

39. A method of conducting an oil well survey comprising the steps of:

(a) positioning a sensor housing in a well borehole to conduct a survey;

(b) positioning a gyro in said housing wherein said gyro forms orthogonal output signals responsive to gyro operation with housing movement along said well borehole movement;

(c) positioning two orthogonal accelerometers in a plane transverse to said housing to form accelerometer output signals;

(d) defining from said orthogonal accelerometer signals tool high side at a first time, wherein said sensor housing is located within a non vertical section of said well borehole at said first time;

(e) determining at an initialized first time the position of the gyro as indicated by the output signals of the gyro;

(f) moving the housing along the well borehole from the first time to a second time; and determining between said first and second times rotation of the housing around an axis along the well borehole in response to said output signals.

* * * * *

US005806195A

United States Patent [19]

Uttecht et al.

[11] **Patent Number: 5,806,195**

[45] **Date of Patent: *Sep. 15, 1998**

[54] **RATE GYRO WELLS SURVEY SYSTEM INCLUDING NULLING SYSTEM**

[76] Inventors: **Gary Uttecht; James Brosnahan; Eric Wright; Greg Allen Neubauer**, all of 1628 Westbelt North, Houston, Tex. 77043

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,657,547.

[21] Appl. No.: **877,159**

[22] Filed: **Jun. 17, 1997**

Related U.S. Application Data

[63] Continuation of Ser. No. 358,867, Dec. 19, 1994, Pat. No. 5,657,547.

[51] **Int. Cl.**[6] **F21B 47/022**; G01C 19/38; G01C 9/00

[52] **U.S. Cl.** **33/304**; 33/302; 33/313

[58] **Field of Search** 33/304, 301, 302, 33/303, 312, 313, 114

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Primary Examiner—Christopher W. Fulton
Attorney, Agent, or Firm—Gunn & Associates P.C.

[57] **ABSTRACT**

A method for well borehole survey is set out. A sonde supports X and Y accelerometers and X and & sensors on a rate gyro having a Z axis aligned with the sonde. On a slickline, or within a drill string, the sonde is used to measure four variables, these being G_x and G_y, A_x and A_z. This enables well azimuth and inclination to determined. Measuring depth enables a survey to be made.

60 Claims, 2 Drawing Sheets

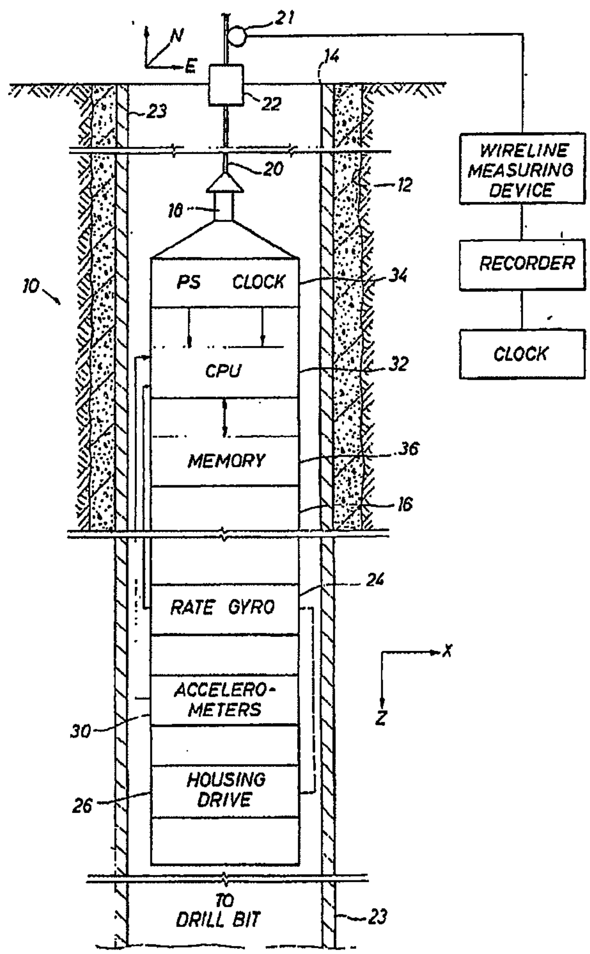
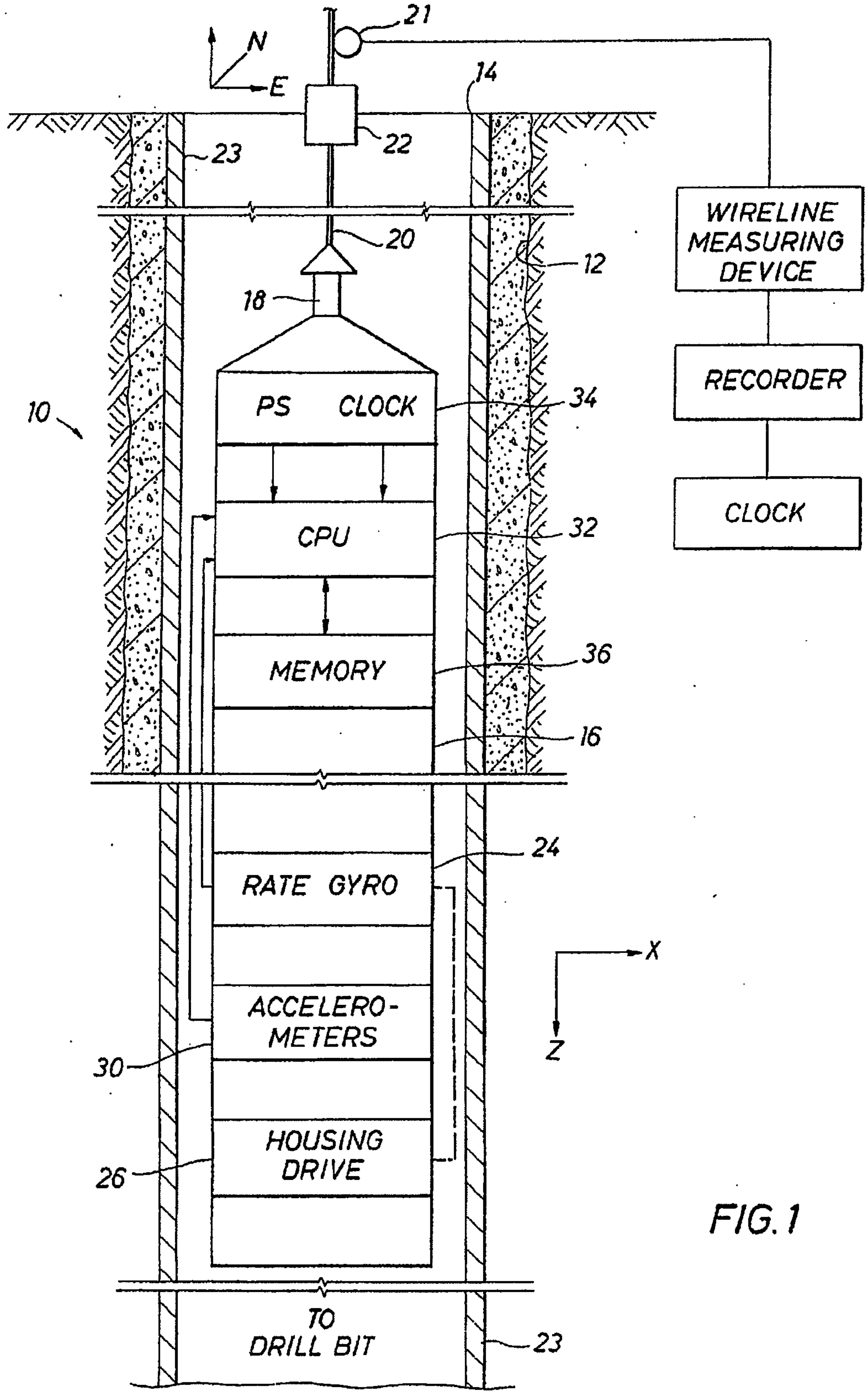


EXHIBIT "B"



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WIRELINE MEASURING DEVICE
20
12
18
RECORDER
PS CLOCK
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CLOCK
CPU
32
MEMORY
36
16
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RATE GYRO
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ACCELERO-METERS
Z
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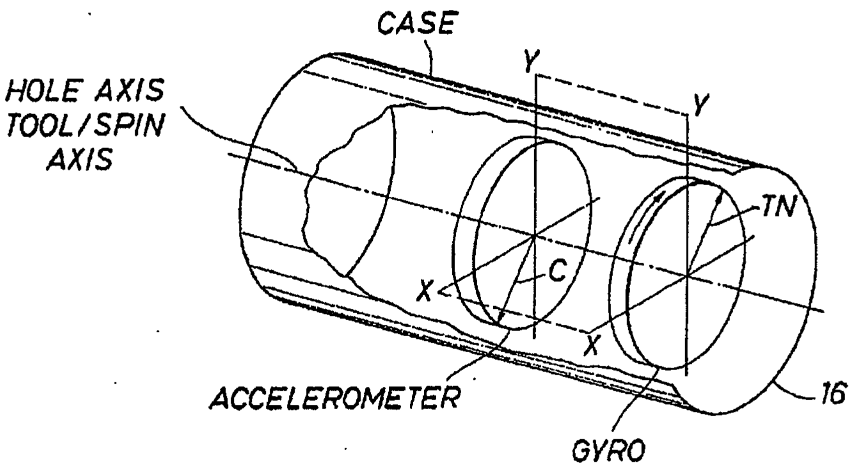
HOUSING DRIVE
26
TO DRILL BIT
23

FIG. 1

FIG. 2



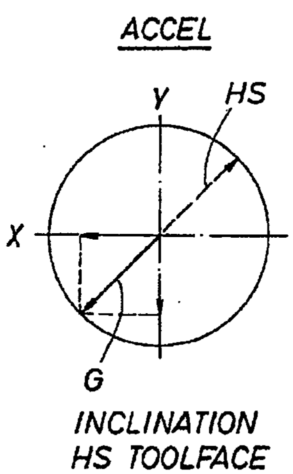


FIG. 3

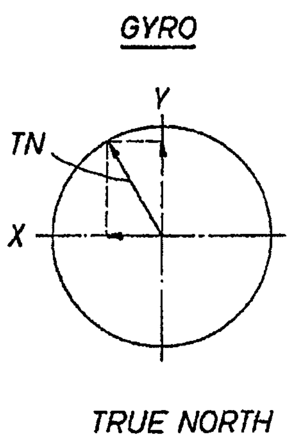


FIG. 4

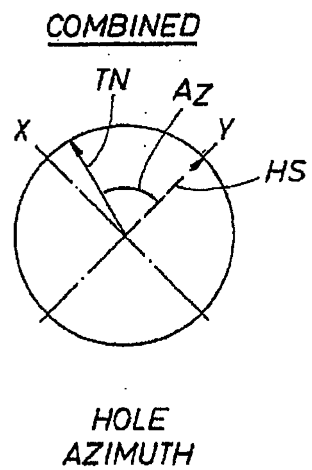


FIG. 5

RATE GYRO WELLS SURVEY SYSTEM INCLUDING NULLING SYSTEM

This application is a continuation of application Ser. No. 08/358,867 field Dec. 19, 1994, now U.S. Pat. No. 5,657, 547.

BACKGROUND OF THE DISCLOSURE

The present disclosure is directed to a rate gyro based survey device and a method of conducting a survey of a well borehole. In many instances, a well borehole is drilled which is substantially vertical. Rudimentary survey devices are used for such wells. By contrast, many wells are highly deviated. The well will define a pathway through space which proceeds from a centralized well head, typically clustered with a number of other wells, and extends in a serpentine pathway to a remote point of entry into a producing formation. This is especially the case with offshore platforms. Typically, an offshore platform will be located at a particular location. A first well is drilled to verify the quality of the seismic data. Once a producing formation is located, and is verified by the first well, a number of other wells are drilled from the same location. This is advantageous because it requires that the offshore drilling platform be anchored at a particular location. It is anchored at a given site and several wells are then drilled from that site. The wells drilled from a single site will enter the producing formation at a number of scattered locations. As an example, consider a producing formation which is 15,000 feet in length and width and which is located at a depth of 10,000 feet. From a single location approximately near the center, it is not uncommon to drill as many as 30 wells or more to the formation. Consider as an example an offshore location in about 200 feet of water where drilling is conducted into the single formation from a single platform location. After the first well has been drilled, a template is lowered to the mudline and rested on the bottom. The template typically supports several conductor pipes, typically arranged in a grid pattern such as 4×8. This provides a template with 32 holes in the template. Conductor pipes are placed in the holes in the template. Below that, a deviated well is drilled for most of the wells. Some of the wells are deviated so that they are drilled at an angle of perhaps only 30° with respect to the horizon as the wells are extended out laterally in a selected direction. The wells enter the formation at predetermined points. This means that each well has a first vertical portion, a bent portion below the conductor pipe, and then a long deviated portion followed by another portion which is often vertical. So to speak, the well is made of serial segments in the borehole.

A survey is necessary to determine the precise location of the well borehole. In most deviated wells, a free fall instrument typically is not used. Free fall survey instruments are used for fairly vertical wells. Where the vertical component is substantial and the lateral deviation is nil, survey instruments are readily available which can simply be dropped to obtain such data. Alternately, survey instruments are known which can be placed in the drill string at the time of retrieval of the drill string so that data is obtained as the drill string is pulled from the well borehole. This typically occurs when the drill bit is changed. The capture of accurate survey information is important, especially where the well is highly deviated. As an example, the well can be deviated where it extends at a 30° angle with respect to the horizon. It can have two or more large angular deflection areas. The well might terminate at a lateral location as much as 5,000 to 10,000 feet to the side of the drilling platform. Without regard to the lateral extent of the well borehole, and without regard to the azimuth or the depth of the well, it is important to obtain an accurate survey from such wells. In this instance, an accurate survey is required to enable drilling the well to the total depth desired and hitting the target entry into the producing formation. Typically, two or three surveys are required while drilling the well borehole. The surveys that are necessary enable correction to be undertaken so that the well can be further deviated to the intended location for the well.

In one aspect, the present disclosure sets forth a system which is able to be run on a slickline. The slickline is simply a support line to enable the sonde to be lowered to the bottom of the well borehole. The borehole path in space is located by the present system. In doing so, the sonde which encloses the equipment of the disclosure is lowered in either of two different fashions. In one instance, it can simply be lowered on the slickline and then left at the bottom of the drill string, and then is moved incrementally upwardly as the drill string is pulled. Pulling the drill string in necessary to change the drill bit which is periodically required. In that sequence, the device is lowered to the bottom of the drill string and is landed just above the drill bit. At that juncture of proceedings, the sonde cannot precede any further because it is captured within the drill string and is too large to pass through the openings in the drill bit. The drill bit is normally replaced by pulling the drill string. The drill string is pulled by removing the topmost joints of pipe. Typically, the derrick is sufficiently tall that three joints can be removed simultaneously. The three joints together comprise a stand which is placed in the derrick to the side of the rotary table. By this approach, the entire drill string is pulled incrementally moving the drill bit towards the surface for replacement. Each stand is approximately 90 feet in height. Therefore the drill bit is stationary for an interval sufficient to remove one stand, and these intervals are spaced at 90 feet in length. At each momentary stop in the process of removing the drill string, the drill bit is stopped and hence the sonde is stopped. This enables the device to obtain additional data. The data is measured at the stops while the survey is conducted.

In another procedure, the drill string is left in the well borehole. The sonde is lowered to the bottom of the well borehole on a slickline and is then pulled from the well borehole. In pulling, measurements are made by periodically stopping the sonde by stopping the slickline movement.

If the slickline gets in the way, it can be readily severed. A line cutting device is available which can be placed on the slickline and which is permitted to fall to the bottom of the slickline. The inertial upset which occurs when it strikes bottom is sufficient to cut the slickline and to enable retrieval of the slickline cutting apparatus and the slickline. This leaves the sonde in the drill pipe. It is left so that it can be retrieved along with the drill string. It is always found in the last joint of the drill stem (normally the bottom most drill collar) which is removed at the time that the drill string is pulled. As mentioned, pulling normally occurs during a trip to replace the drill bit.

The present disclosure sets forth an apparatus which particularly has an advantage in overcoming modest amounts of drift. It utilizes a rate gyro as well as two accelerometers. Both devices provide measurements in orthogonal directions. In the preferred construction of the device, measurements are made in the X and Y dimensions. By definition, the Z dimension is coincident with the center line axis of the cylindrical sonde. Therefore X and Y define a plane at right angles with respect to the Z axis. There is a scale problem which arises from the use of a rate gyro mixed with accelerometers. The sensitivity of a gyro is enhanced compared with accelerometers. Typically, the signals from the rate gyro are approximately two orders of magnitude more sensitive. This means that aging drift, temperature drift, drift as a result of vibration and the like are substantially amplified in the output signals from the rate gyro. One advantage of using a rate gyro is that the signal is so sensitive. It is however a detriment if the rate gyro signal is to be used in conjunction with signals from accelerometers. The present disclosure sets forth a mechanism in which the enhanced sensitivity of the rate gyro compared with the accelerometers is used to advantage. One aspect of this derives from a mechanism which rotates the rate gyro housing 180°. The housing is coincident with the axis through the tool so that the rate gyro is rotated about the Z axis. If the rotation is precisely 180°, then the X and Y outputs from the rate gyro will be reversed. They will be reversed precisely thereby yielding the same output data with a reversal in sign. If a value is obtained denoted as +X, and a second value is obtained which is denoted as −X, then the sum of these two values should be zero in a perfect situation, or should there be a minor amount of error in the system such as drift or other error, the difference in the two is dependent on the error, and the more precisely is two times error. This will be represented below as 2Δ Knowing this, the error Δ can be isolated, and can then be eliminated from the data. Not only is this is true for the X dimension, it is also true for the Y dimension. Therefore both errors can be overcome. This enable the presentation then of a rate gyro signal which is substantially free of that type of error.

The present disclosure takes advantage of onboard computing through a CPU which has provided with suitable power from operation by a power supply and which works with data which is input to the CPU. The data is written temporarily in memory. After a set of data is obtained, the set is then processed to reduce the amount of memory storage required. Speaking more specifically, in one aspect of the present disclosure, a set or ensemble of data is obtained. The number of measurements is represented by N where N is a whole number positive integer. The integer is typically a multiple of two so that data processing is simplified. In one aspect of the present disclosure, N is typically 64, 128, 256, ... As will be seen, these represent values of N where N is a multiple of two.

In summary, the present disclosure sets fourth a method and apparatus for obtaining survey data from a slickline supported tool which is maintained on the slickline or which is left in the drill string just above the drill bit. In both aspects, data is taken as the sonde which encloses the apparatus is pulled toward the surface either on the slickline or on removal of the drill string from the well borehole. In both instances, data is captured by making multiple measurements at a given depth in the well borehole whereby N data are collected and processed. The data are obtained from X and Y accelerometers and X and Y output sensors on a rate gyro. This provides four sets of data. The data are stored temporarily in memory until the N data are accumulated from the four sensors. The four sensors provide this data at one position, and then the rate gyro housing is rotated so that the data are provided from an alternate position. The alternate position is intended to be precisely equal and opposite. The second set of N data therefore provides data which ideally should subtract from the first set of data for the rate gyro. This enables nulling to substantially reduce the highly amplified effects of drift and the error in the rate gyro data. The N data are then averaged to provide four values two of which derived from the rate gyro and two of which are obtained from the accelerometers. The several data for each of the four sensors are statistically analyzed to provide the standard deviation. This is an indication of data quality.

DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention are attained and can be understood in detail, more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings.

It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may add to other equally effective embodiments.

FIG. **1** is a schematic diagram of the sonde of the present disclosure supported in a well borehole on a slickline and further shows a relative reference system for the sonde and a surface located reference system;

FIG. **2** is a perspective view of the sonde showing the X and Y orientation of the gyro and accelerometer sensors with respect to the Z axis which is coincident with the sonde housing;

FIG. **3** is an X and Y plot of the output signals of the accelerometers with respect to an X and Y coordinate system showing how he gravity vector G impacts the sensors and thereby provides useful data;

FIG. **4** is a view similar to FIG. **3** for the gyro showing how a vector is located with indicates true north; and

FIG. **5** is a combined coordinate system derived from FIGS. **3** and **4** jointly showing how true north cooperates with other measurements to thereby provide a indication of whole azimuth.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Attention is first directed to FIG. **1** of the drawings where the numeral **10** identifies the apparatus of the present disclosure. It is shown in a well borehole **12** which extends into the earth from a well head location **14**. At the well head, there is a reference system which is illustrated. At the surface, the reference system utilizes directional measurements namely those on a compass rose. Ideally it is oriented to true north. In other words, to the extent that magnetic north is different from true north at different locations on the earth, it is preferable to use true north. Often, magnetic north can be measured and a simple adjustment incorporated because the deviation between true north and magnetic north is well known. The compass defines the orthogonal measurements as mentioned, and that therefore defines the vertical dimension also. The three references of course describe an orthogonal coordinate system.

The tool **10** is constructed in a cylindrical shape and is enclosed within a shell or housing known as a sonde **16**. The sonde is for the protection of the apparatus located on the interior. The sonde at the upper end incorporates a fishing neck **18** for easy retrieval. It is incorporated so that a grappling type device can engage the fishing neck for retrieval. It is lowered into the well borehole on a slickline **20**. The slickline does not include an electrical conductor. In that instance, it would normally be termed as a wire line because it includes one or more electrical conductors. Rather, it is a small diameter wire of sufficient strength to support the survey tool **10**. The slickline extends to the surface. From the surface, the slickline is lowered into the well bore hole. Typically, this must be done through a blow out preventor to prevent pressure from blowing up through the well and out through the wellhead. The slickline, once the tool has been extended to the bottom of the well borehole, can be cut by placing a cutter device 22 on the slickline which travels to the bottom. When it is stopped, the inertial upset associated with that sudden stop causes a cutter mechanism inside the cutter 22 to sever the slickline. The slickline can then be retrieved with the apparatus 22 clamped on the lower end of the slickline. In one other aspect, FIG. 1 has been simplified simply by omitting the drill string from the drawing representation. As a practical matter, the tool of the present disclosure is normally lowered on the interior of a drill string 23. It is lowered to the bottom drill string closed at the lower end by a drill bit. As will be understood, it is necessary to obtain a survey from a partly drilled well borehole. In the drilling of a well borehole, the drill 23 supports the drill bit at the very bottom end of the drill string. The lowermost tubular member is typically a drill collar. At least one and sometimes as many as ten drill collars are incorporated.

The sonde 10 can be retrieved on the slickline 20 and measurements correlated to depth recorded by a measuring device having a measuring wheel contacted against the line 20. The measurement data is stored by a recorder as a function of time.

The drill string is normally extended in the well bore hole until the point in time that the drill bit has worn. The rate of penetration is normally measured and this is some indication that the drill string needs to be pulled to replace a worn drill bit. The life of a drill bit is typically reasonably well known. The life of the drill bit of course is somewhat dependent on the formation materials being drilled at the moment; in this aspect of the present disclosure, the drill bit is pulled with the drill string and is replaced with a new drill bit of a selected type for continued drilling in a particular type formation.

The present disclosure particularly features the sonde 16 which is a sealed housing for the apparatus. It is able to operate in a steel drill pipe because it is not dependent on magnetically induced measurements. In other words, it is not necessarily responsive to the magnetic field of the earth. In that instance, it would require that the bottom most drill collar be formed of some nonmagnetic material. Such drill collars are quite expensive and can be avoided through the use of the present apparatus.

As further shown in FIG. 1 of the drawings, there is a tool related reference system. The Z dimension is coincident with the central axis of the elongate cylindrical tool. X and Y are dimensions at right angles as before. The rate gyro which is supported in this apparatus is axially coincident with the central or elongate dimension of the sonde 16. The present apparatus utilizes a rate gyro 24. The rate gyro is enclosed in a suitable housing. The housing, sensors, and rotating member are apparatus which can be discussed in schematic form because it is a device well known in a number of application including oil well survey equipment. In other words, the rate gyro need only be shown in schematic form. It incorporates a housing which encloses the moving components. The housing itself is mounted for rotation about the Z axis, and a housing drive 26 is included. This drive rotates the housing precisely through 180° rotation. This rotation is about the Z axis or the axis of the sonde 16. The Z axis of the sonde is defined by the coordinate system previously mentioned, and hence rotation of the rate gyro about that axis provides measurements which will be discussed below taking into account the X and Y dimensions in the tool related coordinate system.

In FIG. 1 of the drawings, the accelerometers 30 are also indicated in schematic form. As further illustrated, the housing drive 26 is connected with rate gyro 24 to provide the above described rotation. The data from the four sensors, two accelerometers 30 and two sensors associated with the rate gyro 24, are all input to the CPU 32. The CPU is provided with a suitable power supply and a clock 34 for operation. A program in accordance with the teachings of the present disclosure is stored in memory 36, and the data that is created during test procedures is likewise written in memory. When retrieved to the surface, the memory can be interrogated, and the data removed from the sonde 10 for subsequent and separate processing.

To better understand the present apparatus, attention is momentarily directed to FIG. 2 of the drawings. As shown there, the sonde including the shell 16 is illustrated. In it, there are the two sets of sensors shown in symbolic form with particular emphasis on the X and Y coordinates for the two sets of sensors. As marked in FIG. 2, the X and Y dimensions are coincident. They differ in that the two sensor devices are offset along the length of the sonde. This offset does not impact the output data.

Going further with the structure shown in FIG. 2 of the drawings, there is imposed on the drawing the centerline axis through the shell 16 which forms the protective jacket of the sonde. Moreover the rate gyro which rotates in a plane transverse to the axis is likewise illustrated and a significant aspect of it is indicated, namely, the ability to locate true north. Likewise, the two accelerometers are able to locate the gravity vector which is indicated in FIG. 2 of the drawings. Going more specifically however to the symbolic representations which are sent forth in FIGS. 3, 4, and 5 considered jointly, it will be seen that the accelerometers provide two outputs. They will be represented symbolically as A_x and A_y. These are the two signals which are provided by the two accelerometers. In space, they define two resolved components of the gravity vector which is represented by the symbol G. As further shown in the drawings, the gravity vector which points toward the center of the earth defines an equal and opposite vector. That vector is represented by the symbol HS which refers to the high side of the tool face. The significance of that is understood with the explanation below.

FIG. 4 of the drawings shows the two output signals from the gyro which, as resolved components, defines a vector which points in the direction of true north represented by TN in FIG. 4. These representations shown in FIGS. 3 and 4 are combined in FIG. 5 of the drawings. True north is useful for orienting the measuring instrument 10 in space. Once that is known in conjunction with vector HS, the hole azimuth can be determined. That is represented by the vector A_z. The representations in FIGS. 3, 4, and 5 are significant in describing operation of the device of this disclosure.

One important feature of the present apparatus is brought out by the method of operation. Consider a first set of readings which is obtained by use of the survey tool which is shown in FIG. 1 of the drawings. Assume for purposes of discussion that the survey tool is lowered on a slickline to the bottom of a drill string and is left resting on the bottom the drill string just above the drill bit. At that location, the sonde is then located so that data can be obtained from a first location in the well borehole. Through the use of the present apparatus, measurements are obtained which are represented as A_x, A_y, G_x, and G_y. Preferably, many measurements are made, the number being represented by N, and they are recorded in memory. Assume for purposes of discussion that N data points is 128 or 256. Through the use of conventional statistical programs readily available, all of the data at a given tool depth in the well borehole is collectively analyzed and the standard deviation of the four variables is then obtained. The standard deviation is recorded along with the average value. While N data are obtained for all the four variables at a given depth, the data are reduced to single values so that each of the four variables are individually and uniquely represented.

As one example, assume that the sonde 10 is lowered to precisely 10,000 feet in the well borehole and a set of data is obtained. Assume also that N is 256. 256 entries are recorded in memory for each of the four variables. Then, the four variables are averaged and the standard deviation for each of the four is also obtained.

At this juncture, the data derived from the rate gyro includes averaged values of G_x and G_y. The next step is to rotate the gyro housing. Measurements again are made. These measurements are made after rotation and ideally are measurements which are equal and opposite the first measurements. The second set of N data is likewise averaged, and the standard deviation is again determined. The first average value for G_x is then compared with the second average value of $-G_x$. When the two are added, the two values should subtract to zero. In other words, the second set of data is subtracted from the first set of data from the rate gyro measurements.

One aspect of the present disclosure is that the N data are first captured with the housing in one position and then the housing is rotated and data again is obtained. Data from the second position is ideally equal and opposite for the X and Y sensors in the rate gyro. While the first data will represent G_x, the next data likewise will be G_x. The second set of data is averaged and again the standard deviation is obtained. The second set of data is subtracted from the first set for the rate gyro measurements. In other words, a difference signal is obtained which is G_x minus the second measurement of $-G_x$. Any small error which is obtained upon subtraction of the two values is primarily a function of error in the equipment. These error differences can be useful in evaluating the quality of the data.

The foregoing routine should be considered with respect to the position of the rate gyro system 10 in the well borehole. Data is preferably collected from the bottom to the top. To do this, at the time that a drill string is to be pulled on a trip to replace the drill bit, the measuring instrument 10 is pumped down the drill string supported on the slickline. When it lands at the bottom, the line is severed and retrieved so that it will not connect the several stands of pipe together. A first data is collected. This is collected while the drill bit is at bottom. This is accomplished when the drill string is not rotating. The averages are obtained for values of G_x, G_y, A_x, and A_y. In addition, the standard deviation for all four measurements is likewise obtained, thereby representing eight data, four being the average measurements and four being the standard deviation of those measurements. The housing is then rotated and the second set of measurements are obtained. These are the measurements of G_x and G_y. They are recorded for later subtraction, or they can be automatically subtracted by the CPU.

The collection of data requires a finite interval. The N(=256) measurements process is done in a few seconds. Earth movement continues while collecting the data long the well. The N measurements are taken at M depths.

The term M represents the number of measurements made at a specified depth along the well borehole. An example will be given below which involves 100 measurements or M=100.

The averaged measurements and deviation data are stored and are subsequently retrieved when the tool 10 is brought to the surface. Assume for purposes of description that the well is 9,000 feet in depth. The drill stem is made of stands of pipe so that data from 100 depths are obtained. The first set of N data are collected while the drill bit is on bottom and the second set of N data is collected after rotation of the gyro housing before the drill bit is raised by removal of the first stand of pipe. This can be continued indefinitely until the entire drill stem has been removed to enable bit replacement. This will create M data in the 9000 feet of borehole.

At each stopping place for the drill string where the drill string is suspended while another stand of pipe is removed from the drill string, the housing is rotated so that two sets of gyro data are obtained. This is repeated until the drill bit is brought to the surface. The measuring instrument 10 of the present disclosure is carried up the borehole in the bottom most drill collar resting on top of the drill bit. The sonde is then removed and connected to a suitable output cable to enable transfer of the measured data out of the sonde into another memory device. This enables the data to be further analyzed and used in plotting a survey of the well borehole.

As noted from the foregoing, one important advantage of the system is that N data are obtained with the housing positioned in one direction or orientation and then another set of N data are obtained with the housing rotated by 180°. This is done repetitively as the drill string is pulled.

The present system is not susceptible to distortions which arise from the incorporation of ferrous materials in the drill string. The present apparatus operates in ferrous pipe. This avoids the costly isolation step of installing an exotic alloy drill collar in the drill string. Such drill collar are relatively expensive. For example, a drill collar made of Inconel (an alloy trademark) is very expensive compared to a drill collar made of steel. The presently disclosed system avoids that costly requirement.

Consider now the steps necessary to construct a survey. For each depth, measurements from the four sensors (highly refined averages) were made at a particular elevation in the well borehole with a specified orientation of the tool in the well borehole. A careful and detailed survey can be obtained by this procedure using M sets of data where M is an integer representing the number of measurement sets of N data recorded at M locations in the well. The typical operation records data where M equals one with the drill bit on bottom. The next (M=2) is measured when the first stand of pipe is pulled.

In the foregoing, each of the M measurements stations are located spaced from adjacent stations by one stand of pipe or approximately 90 feet. This dimension is well known. The data collected thus has M sets of data where M represents the number of stops made in retrieving the drill string. This provides M finite locations along the pathway. The pathway can then represented in a three dimension plot of the well as a survey. The typical representation utilizes three variables which are depth in the well borehole. In addition, the inclination and azimuth of the well borehole can be determined. The three variables provide a useful representation of data which has the form of a survey as mentioned.

In another way of operation, the tool can be lowered in the well borehole to a desired depth, and the first of the M measurements is made with the drill bit at the bottom of the borehole and the sonde rested above the drill bit in the drill string. Then, the slickline is retrieved from the borehole by a specified measurement. If the well is 10,000 feet in depth, it is not uncommon to move the sonde 100 feet. In this instance, the M sets of measurements would be 100 or M=100. This enables operator control of the spacing of the data points along the survey. In a highly deviated well, the survey points may be quite close together. In a well which only deviates slightly, the survey points can be farther apart which permits a smaller value of M. In this particular instance, M and N can be selected by the operator. Loosely, they represent scale or spacing along the survey. As before, the survey typically is reported in the form of azimuth, inclination, and location along the well borehole. As noted with regard to FIGS. 3, 4 and 5, azimuth and inclination can be obtained from the data. Data quality is likewise obtained by noting the standard deviation. While the foregoing is directed to the preferred embodiment, the scope can be determined from the claims which follow.

We claim:

1. A method of performing a survey of a well borehole comprising the steps of:

(a) positioning within a well borehole an elongate sonde having a rate gyro therein rotating about an axis and forming an output indicative of north, wherein said rate gyro is supported by a housing rotatable between first and second positions separated by 180° of housing rotation, and
   (i) a first output indicative of north comprises N measurements is determined at said first sonde position,
   (ii) said housing is then rotated by 180° and a second output indicative of north comprising another N measurements is determined at said second sonde position, and
   (iii) N is an integer;
(b) combining said first and second outputs indicative of north to yield a measure of north in which systematic instrument error is reduced;
(c) positioning the sonde at spaced locations along a well borehole; and
(d) repeating step a) at each said spaced location.

2. The method of claim 1, wherein N is greater than 1 and said first output indicative of north is obtained from an average of said N measurements and said second output indicative of north is obtained from an average of said N measurements with said housing rotated 180°.

3. The method of claim 2 wherein rate gyro housing rotation occurs after N measurements are made, thereby enabling said N measurements to be made in a selected time interval and a second set of measurements to be made in a second selected time interval.

4. The method of claim 2 wherein each said spaced location is at evenly spaced locations along said well borehole so that the borehole survey has a desired set of data points.

5. The method of claim 1, wherein;
(a) said first output indicative of north is defined in a first X-Y quadrant which is orthogonal to the major axis of said elongated sonde;
(b) said second output indicative of north is defined in a second X-Y quadrant; and
(c) said first and second X-Y quadrants lie in a common plane and are azimuthally spaced at 180°.

6. The method of claim 1 wherein said sonde is lowered to the bottom of a drill string in the well borehole on a slickline and the slickline is retrieved leaving the sonde in said well borehole.

7. The method of claim 6 including the additional step of measuring the direction of said sonde along said well borehole at each said spaced location, and determining therefrom gravity direction at each said spaced location while tripping said drill string out of the borehole.

8. The method of claim 7 wherein said measurements of north and said gravity direction measurements are made spaced along said well borehole by the length of a stand of pipe in the drill string.

9. The method of claim 1 wherein said sonde is lowered to the bottom of said well borehole to enable a survey to be conducted, retrieving the sonde along the borehole, and making said measurements along the borehole said spaced locations.

10. The method of claim 9 wherein said sonde is stopped at said spaced locations along said well borehole and said measurements are made and stored in the sonde until retrieval to the surface.

11. A method of obtaining a survey in a well borehole subject to deviation from the vertical which comprises the steps of:

(a) positioning in a well borehole a rate gyro having an axis of rotation coincident with the major axis of a sonde which supports said rate gyro;
(b) moving said sonde along the well borehole and making two orthogonal signal measurements at spaced locations;
(c) combining said two orthogonal signals measurements to obtain a reference north measurement;
(d) reducing systematic instrument error ill said orthogonal signal measurements by making measurements differing by 180°;
(e) measuring the direction of gravity along the sonde during movement in the well borehole by making an additional two orthogonal signal measurement; and
(f) determining from said additional two orthogonal measurements at least two dimensions of the position of the sonde in the well borehole.

12. The method of claim 11 including the step of determining sonde depth within said well borehole.

13. The method of claim 12 including the step of determining well borehole azimuth for said survey.

14. The method of claim 13 including the step of determining well borehole inclination for said survey.

15. The method of claim 14 including the step of making said signal measurements recorded in memory within said sonde and retrieving the sonde to obtain data recorded in memory.

16. A method of performing a survey of a well borehole comprising the steps of:

(a) positioning within a well borehole an elongate sonde having a rate gyro therein rotating about an axis and forming an output indicative of north, wherein said rate gyro is supported by a housing rotatable between first and second positions separated by 180° of housing rotation, and
(b) making a first gyro measurement indicative of north;
(c) moving said gyro and making second, third and fourth measurements indicative of north and wherein
   (i) said first and said third measurements are at 180°;
   (ii) said second and said fourth measurements are at 180°; and
   (iii) said measurements are made after 90° rotation;
(d) summing said measurements indicative of north to yield a measure of north;
(e) reducing instrument error in said summation of north by combining said measurements;

(f) moving said sonde between spaced locations along a well borehole; and

(g) repeating steps (b)-(e) at each said spaced location.

17. The method of claim 16 wherein said first, second, third and fourth measurements are each defined by an average of N measurements, where N is an integer greater than 1.

18. The method of claim 17 wherein rate gyro housing rotation occurs after N measurements are made, thereby enabling said N measurements to be made in a selected time interval.

19. The method of claim 16 wherein each said spaced location is at evenly spaced locations along said well borehole so that the borehole survey has a desired set of data points.

20. The method of claim 16 wherein said sonde is lowered to the bottom of a drill string in the well borehole on a slickline and the slickline is retrieved leaving the sonde in said well borehole.

21. The method of claim 20 including the additional step of measuring the direction of said sonde alone said well borehole at each said spaced location, and determining therefrom gravity direction at each said spaced location while tripping said drill string out of the borehole.

22. The method of claim 21 wherein said measurements of north and said gravity direction measurements are made spaced along said well borehole by the length of a stand of pipe in the drill string.

23. The method of claim 16 wherein said sonde is lowered to the bottom of said well borehole to enable a survey to be conducted, retrieving the sonde along the borehole, and making said measurements along the borehole said spaced locations.

24. The method of claim 23 wherein said sonde is stopped at said spaced locations along said well borehole and said measurements are made and stored in the sonde until retrieval to the surface.

25. A method for measuring the position of a survey sonde in a well borehole, comprising the steps of:

(a) positioning a rate gyro in a well survey sonde;

(b) moving the sonde to a survey position in the well borehole;

(c) making a first and a second gyro reading at that survey position, wherein said first and second gyro readings provide information useful in determining north;

(d) positioning a pair of accelerometers at right angles in said sonde wherein one accelerometer is located in a plane at right angles to the major axis of said sonde;

(e) moving the sonde to a second survey position along the well borehole;

(f) making accelerometer measurements as the sonde moves along the well borehole; and

(g) determining from said gyro measurements and said accelerometer measurements the path of the well borehole in the earth.

26. The method of claim 25 wherein said sonde is lowered to the bottom of a drill string in the well borehole on a slickline and the slickline is retrieved leaving the sonde in said well borehole.

27. The method of claim 26 wherein said sonde is moved along the well borehole while tripping said drill string out of the borehole.

28. The method of claim 25 wherein said gyro measurements and said accelerometer measurements are made at spaced locations along said well borehole by the length of a stand of pipe in a drill string.

29. The method of claim 25 wherein said sonde is lowered to the bottom of said well borehole, retrieving the sonde along the borehole, and making said gyro and accelerometer measurements along the borehole said spaced locations.

30. The method of claim 29 wherein said sonde is stopped at said spaced locations along said well borehole and said gyro and accelerometer measurements are made and stored in the sonde until retrieval to the surface.

31. The method of claim 30 wherein said direction measurements are made at a plurality of spaced locations within said well borehole.

32. A method of performing a survey of a well borehole comprising the steps of:

(a) positioning within a well borehole an elongate sonde having a rate gyro therein rotating about an axis and forming an output indicative of north, wherein said rate gyro is supported by a housing rotatable between first and second positions separated by 180° of housing rotation, and wherein power to operate components within said sonde is supplied by a power supply within said sonde, and

(i) a first output indicative of north comprises N measurements is determined with said gyro in said first position,

(ii) said housing is then rotated by 180° and a second output indicative of north comprising another N measurements is determined with said gyro in said second position, and

(iii) N is an integer; and

(b) combining said first and second outputs indicative of north to yield a measure of north which contains reduced systematic instrument error.

33. The method of claim 32 wherein N is greater than 1 and said first output indicative of north is obtained from an average of said N measurements and said second output indicative of north is obtained from an average of said N measurements with said housing rotated 180°.

34. The method of claim 33 wherein rate gyro housing, rotation occurs after N measurements are made, thereby enabling, said N measurements to be made in a selected time interval and a second set of measurements to be made in a second selected time interval.

35. The method of claim 33 including the additional step of;

(a) providing two accelerometers within said sonde;

(b) measuring the inclination of said sonde within said well borehole using, the responses of said accelerometers; and

(c) determining therefrom gravity direction.

36. A method claim 35 including the additional steps of:

(a) making a third and a forth measurement, both of which are responsive to north and which are 180° apart and wherein

(i) said first and said third measurements are at 180°, and

(ii) said second and said fourth measurements are at 180°;

(b) summing, said measurements responsive to north to yield a measure of north; and

(c) reducing instrument error in said measurement of north by combining said first and third measurements responsive to north.

37. The method of claim 36 wherein said first and third measurements are made with said gyro, and said second and fourth measurements are made with one of said two accelerometers.

38. The method of claim 32 wherein;

(a) said first output indicative of north is defined in a first X-Y quadrant which is orthogonal to the major axis of said clongated sonde;

(b) said second output indicative of north is defined in a second X-Y quadrant; and

(c) said first and second X-Y quadrants lie in a common plane and are azimuthally spaced at 180°.

39. A method of obtaining a survey in a well borehole, comprising the steps of:

(a) positioning in a well borehole a rate gyro;

(b) obtaining direction measurements X, Y, −X and −Y from the response of said rate gyro, wherein X and −X differ by 180° and Y and −Y differ by 180°;

(c) obtaining a reference direction measurement from said direction measurements; and

(d) combining pairs of said direction measurements to reduce systematic instrument error in said reference direction measurement.

40. The method of claim 39 wherein;

(a) said rate gyro comprises at least one axis: and (b) said rate gyro is positioned such that X+90°=Y.

41. The method of claim 40 wherein each of said direction measurements are repeated N times at at least one spaced location within said well borehole.

42. The method of claim 41 where N is an integer greater than one.

43. The method of claim 39 wherein said reference measurement is true north.

44. The method of claim 39 wherein said reference measurement is a high side of a sonde containing said rate gyro.

45. A method for obtaining the orientation of a sonde within a well borehole, comprises the steps of:

(a) positioning a rate gyro having at least one axis within said sonde;

(b) with said gyro, making at least two orthogonal signal measurements at at least one location within said well borehole;

(c) obtaining a measure of true north from said two orthogonal signal measurements;

(d) measuring the direction of gravity at said at least one location within said well borehole; and

(e) determining from said at least two orthogonal signal measurements and said measure of gravity the azimuthal orientation of said sonde within said well borehole.

46. The method of claim 45 wherein said orientation of said sonde comprises the position of the high side of the sonde with respect to true north.

47. The method of claim 45 further comprising the steps of:

(a) moving said sonde along the well borehole;

(b) obtaining said measures of true north and of gravity at M spaced locations within said well borehole, where M is an integer greater than 1; and

(c) determining said azimuthal orientation of said sonde within said borehole at each said spaced location.

48. The method of claim 45 wherein said sonde is affixed to a second borehole instrument, and the orientation of said second borehole instrument within said borehole is obtained from said orientation of said sonde within said borehole.

49. The method of claim 45 wherein an additional two signal measurements are made and combined with said two orthogonal signal measurements to reduce systematic instrument error in said measure of true north.

50. The apparatus of claim 49 wherein said means for conveying said sonde comprises affixing said sonde to a borehole instrument which is conveyed by means of a wireline.

51. The apparatus of claim 50 wherein said sequence of data defines the azimuthal orientation of said borehole instrument within said well borehole.

52. The apparatus of claim 51 wherein said azimuthal orientation is defined with respect to said measure of true north.

53. An apparatus for measuring a sequence of data from within a well borehole, comprising;

(a) a sonde which is conveyed within said borehole, wherein said sonde comprises

(i) a rate gyro comprising at least one axis,

(ii) a power supply to operate said rate gyro,

(iii) a memory for recording response of said rate gyro, and

(iv) means for measuring the direction of gravity acting upon said sonde;

(b) a CPU for

(i) combining a first and a second measurement from said rate gyro to obtain a measure of true north,

(ii) combining a third and a fourth measurement from said rate gyro with said first and second measurements to reduce systematic instrument error in said measure of true north; and

(iii) combining said measure of gravity direction and said measure of true north to obtain said measured sequence of data; and

(c) means for conveying said sonde within said well borehole.

54. The apparatus of claim 53 wherein said means for conveying said sonde comprises a slick line.

55. The apparatus of claim 53 wherein said means for conveying said sonde comprises a drill string.

56. The apparatus of claim 53 wherein said means for conveying said sonde comprises the force of gravity.

57. The apparatus of claim 53 further comprising means for measuring the depth of said sonde within said well borehole.

58. The apparatus of claim 53 wherein said sequence of data defines a three dimensional path of said well borehole within the earth.

59. The apparatus of claim 53 wherein said sequence of data defines the azimuthal orientation of said sonde within said well borehole.

60. The apparatus of claim 59 wherein said azimuthal orientation is defined with respect to said measure of true north.

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