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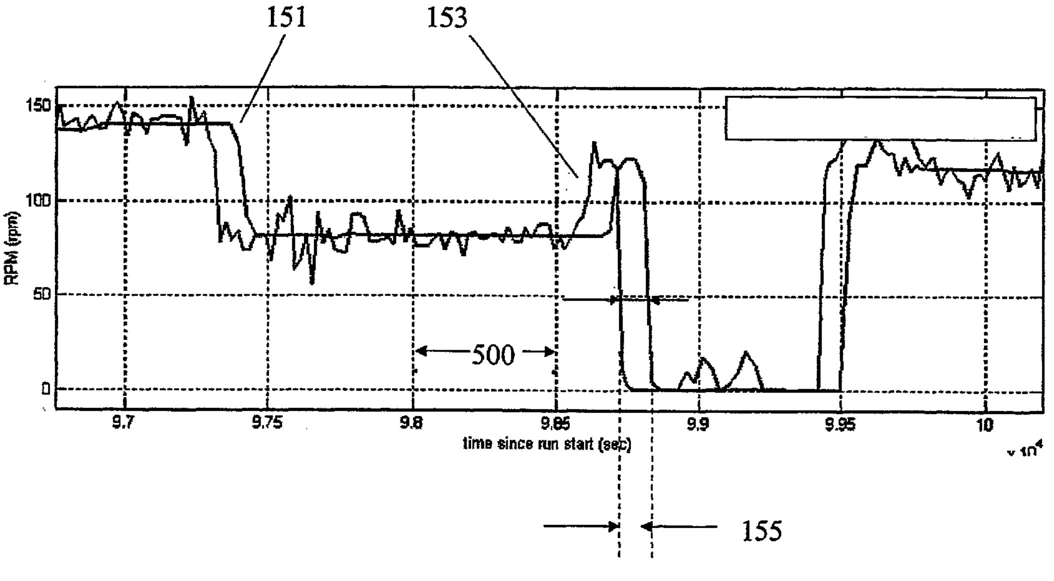

(57) Abstract: Differences in times of a time clock at the surface and a downhole time clock are determined using a correlation technique. These differences can be used to provide better correspondence between downhole formation evaluation (FE) sensor measurements and drilling measurements, as well as between different FE sensors.

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APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

TIME AND DEPTH CORRECTION OF MWD AND WIRELINE MEASUREMENTS USING CORRELATION OF SURFACE AND DOWNHOLE MEASUREMENTS.

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BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] This invention is related to methods for determining a depth at which measurements are made by a downhole assembly based on surface estimates of the depth and surface and downhole measurements.

2. Description of the Related Art

[0002] In the rotary drilling of wells such as hydrocarbon wells, a drillbit located at the end of a drillstring is rotated so as to cause the bit to drill into the formation. The rate of penetration (ROP) depends upon the weight on bit (WOB), the rotary speed of the drill and the formation and also the condition of the drillbit. The earliest prior art methods for measuring ROP were based on monitoring the rate at which the drillstring is lowered into the well at the surface. However because the drill string, which is formed of steel pipes, is relatively long, the elasticity or compliance of the string can result in the actual ROP being different from the rate at which the string is lowered into the hole. Consequently, the depth of the bottomhole assembly (BHA) that includes the drillbit is different from that which is estimated from surface measurements alone.

[0003] The BHA typically includes several formation evaluation (FE) sensors that make measurements of formation properties. These include, for example, density, porosity, resistivity, and seismic velocities. Similar measurements may also be made after the well has been drilled by conveying logging instruments on a wireline or coiled tubing. Determination of properties of the formation is based upon evaluation of a suite of logs that are properly aligned in depth.

[0004] Due to their nature, all data from MWD tools are referenced to time, i.e. it is presumed to be known *when* every measured value was taken. For applications involving correlating different logs, it is necessary to know *where* the measurement was taken. To find out *where* it is necessary to know the wellbore profile, i.e., the wellbore location in space. The wellbore profile may be determined using suitable survey instruments such as accelerometers and/or gyroscopes.

[0005] It is also necessary to know the time-depth profile, i.e., where (with respect to the wellbore) the bit was located at each moment of time. Using the wellbore profile and the time-depth profiled, it is possible to place MWD measurements along the wellbore and hence in space.

[0006] The wellbore and time-depth profiles are known only with some finite accuracy. This affects the accuracy of the final logs. This is well known and there is much effort spent to ensure good quality surveys and depth measurements. There is another problem that has a strong impact on the accuracy of the final results. This problem arises due to the fact that the timestamps on MWD data come from the clocks in MWD tools, while surface measurements have timestamps from the surface computer clock.

[0007] If the tool clock does not produce the same time as the surface clock during the whole run, then any attempt to use time-depth profiles (which are based on surface time) to convert from *when* to *where* will result in erroneous output. The error depends on how big this mismatch is, and due to the non linearity of the time-depth transformation even small time mismatches can result in noticeable changes to the logs (especially time-based logs).

[0008] US 6,837,105 to *DiFoggio* et al. discloses the use of a downhole atomic clock for maintaining synchronization with a surface clock for seismic while drilling (SWD) applications. Atomic clocks based on an atomic transition of rubidium, cesium and/or hydrogen can have drifts as small as 3 μs per day. This kind of accuracy is necessary for SWD applications where errors of 1-2 ms in synchronization can be serious. For determination of a time-depth profile, as in the present invention, an accuracy 3μs is not necessary. Even for a high rate of penetration (ROP) of 100 m/hr, an error of 1 second translates into a depth error of less than 3 cm; for lower ROPs, the depth error is even smaller. Errors of the order of 3cm can be tolerated in correlation of different logs. Given the high cost of atomic clocks and the possible damage that can occur to them in the harsh drilling environment, it would be desirable to find alternate methods of determining proper alignment of logs.

[0009] US 5,581,024 to *Meyer* et al. established proper alignment of logs use of a downhole computer and buffer storage within a MWD downhole subassembly to process data from the response of a plurality of sensors of different type. Sensor measurements are made essentially simultaneously. First, the sensor responses are correlated to a common reference point and reference vertical resolution. This correlation is performed using downhole models of the sensor responses stored within a downhole memory associated with a downhole processor. In one embodiment, response models are computed theoretically or are determined from sensor responses measured in test facilities with known environmental conditions. These sensor response models are initially stored within the downhole memory. As an alternate embodiment, sensor response models are calculated while drilling using the downhole computer and sensor responses in portions of the borehole where conditions are known. These models are then stored in the downhole memory and subsequently used for correlation in the portions of the borehole in which conditions are unknown. The depth and resolution correlated sensor responses are then processed, using combination sensor response models stored within the first storage means along with downhole computing means to obtain logs of formation parameters of interest as a function of depth within the borehole which is preferably a depth reference point.

[0010] The modeling is necessary in *Meyer* due to the fact that different sensors have different resolution in depth. This adds to the complexity of the problem that must be solved. It would be desirable to have a relatively simple, inexpensive and rugged apparatus and method for determining the depth of a tool in a borehole. The present invention satisfies this need.

SUMMARY OF THE INVENTION

[0011] One embodiment of the present invention is a method of determining a difference between a first clock at a surface location and a second clock at a downhole location of a downhole assembly. First measurements of a first parameter of the downhole assembly are made at the surface location and a first time stamp is associated with the first measurements. Second measurements, similar to the first measurements, are made of the downhole assembly at the downhole location and a second time stamp is associated with the second measurements. The time difference is determined by matching a feature of the first measurements with a corresponding feature of the second measurements. The first and second measurements may be a rotational speed of a drillstring, a torque measurement and/or a pressure measurement. The determined time differences are used to correct formation evaluation and other downhole sensor measurements to a corrected time.

[0012] Another embodiment of the present invention is a measurement while drilling (MWD) system that includes a first clock at a surface location and a second clock on a bottomhole assembly (BHA) at a downhole location in a borehole in an earth formation. The second clock may have a time difference relative to the first clock. The system further includes a processor which determines the time difference from first measurements of a first parameter of the MWD system at the surface location and second measurements similar to the first measurements at the downhole location. The time difference is obtained by matching a feature of the first measurements with a corresponding feature of the second measurements. The first and second measurements may be of rotational speed or torque.

[0013] Another embodiment of the invention is a computer readable medium for use with a measurement while drilling (MWD) system. The MWD system includes a first clock at a surface location a second clock on a bottomhole assembly (BHA) at a downhole location in a borehole in an earth formation. The second clock has a time difference relative to the first clock. The medium includes instructions which enable determining the time difference from first measurements of a first parameter of the MWD system at the surface location and second measurements similar to the first measurements at the downhole location. The determination is done by matching a feature of the first measurements with a corresponding feature of the second measurements. The medium may be selected from the group consisting of (i) a ROM, (ii) an EPROM, (iii) an EAROM, (iv) a Flash Memory, and, (v) an Optical disk.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The present invention is best understood with reference to the accompanying figures in which like numerals refer to like elements and in which:

FIG. 1 (Prior Art) shows a schematic diagram of a drilling system having downhole sensor systems and accelerometers;

FIGS. 2a and 2b are plots of surface measurements and downhole measurements of rotational speed at two different times of drilling;

FIG. 3a is a plot of the time difference between the surface and downhole rotational speed as a function of drilling time;

FIG. 3b is a plot of the time difference between surface and downhole torque measurements as a function of drilling time;

FIGs. 4a and 4b show the data of Figs. 2a and 2b after correcting for the time shift;

FIG. 5 shows the method of conversion of time-based memory data to depth-based log;

FIG. 6 shows the correction of misalignment between FE measurements and drilling measurements using the determined time shift;

FIG. 7 shows the determination of time since drilled; and

FIG. 8 shows the errors in time based logs without applying the time corrections.

DETAILED DESCRIPTION OF THE INVENTION

[0015] FIG. 1 shows a schematic diagram of an exemplary drilling system **10** having a downhole assembly containing an acoustic sensor system and surface devices. This is a modification (discussed below) of the device disclosed in US Patent 6 088 294 to *Leggett* et al. As shown, the system **10** includes a conventional derrick **11** erected on a derrick floor **12** which supports a rotary table **14** that is rotated by a prime mover (not shown) at a desired rotational speed. A drill string **20** that includes a drill pipe section **22** extends downward from the rotary table **14** into a borehole **26**. A drill bit **50** attached to the drill string downhole end disintegrates the geological formations when it is rotated. The drill string **20** is coupled to a drawworks **30** via a kelly joint **21**, swivel **28** and line **29** through a system of pulleys **27**. During drilling operations, the drawworks **30** is operated to control the weight on bit and the rate of penetration of the drill string **20** into the borehole **26**. The operation of the drawworks **30** is well known in the art and is thus not described in detail herein.

[0016] During drilling operations a suitable drilling fluid (commonly referred to in the art as "mud") **31** from a mud pit **32** is circulated under pressure through the drill string **20** by a mud pump **34**. The drilling fluid **31** passes from the mud pump **34** into the drill string **20** via a desurger **36**, fluid line **38** and the kelly joint **21**. The drilling fluid is discharged at the borehole bottom **51** through an opening in the drill bit **50**. The drilling fluid circulates uphole through the annular space **27** between the drill string **20** and the borehole **26** and is discharged into the mud pit **32** via a return line **35**. Preferably, a variety of sensors (not shown) are appropriately deployed on the surface according to known methods in the art to provide information about various drilling-related parameters, such as fluid flow rate, weight on bit, hook load, etc.

[0017] A surface control unit **40** receives signals from the downhole sensors and devices via a sensor **43** placed in the fluid line **38** and processes such signals according to programmed instructions provided to the surface control unit. The surface control unit displays desired drilling parameters and other information on a display/monitor **42** which information is used by an operator to control the drilling operations. The surface control unit **40** contains a computer, memory for storing data, data recorder and other peripherals. The surface control unit **40** also includes models and processes data according to programmed instructions and responds to user commands entered through a suitable means, such as a keyboard. The control unit **40** is preferably adapted to activate alarms **44** when certain unsafe or undesirable operating conditions occur. The surface control unit also includes a surface clock (not shown).

[0018] Optionally, a drill motor or mud motor **55** coupled to the drill bit **50** via a drive shaft (not shown) disposed in a bearing assembly **57** rotates the drill bit **50** when the drilling fluid **31** is passed through the mud motor **55** under pressure. The bearing assembly **57** supports the radial and axial forces of the drill bit **50**, the downthrust of the drill motor **55** and the reactive upward loading from the applied weight on bit. A stabilizer **58** coupled to the bearing assembly **57** acts as a centralizer for the lowermost portion of the mud motor assembly.

[0019] The downhole subassembly **59** (also referred to as the bottomhole assembly or

"BHA"), which contains the various sensors and MWD devices to provide information about the formation and downhole drilling parameters and the mud motor, is coupled between the drill bit **50** and the drill pipe **22**. The downhole assembly **59** preferably is modular in construction, in that the various devices are interconnected sections so that the individual sections may be replaced when desired.

[0020] Still referring to **FIG. 1**, the BHA also preferably contains sensors and devices in addition to the above-described sensors. Such devices may include a device for measuring the formation resistivity near and/or in front of the drillbit **50**, a gamma ray device for measuring the formation gamma ray intensity and devices for determining the inclination and azimuth of the drill string **20**. The formation resistivity measuring device **64** is may be coupled above the lower kick-off subassembly **62** that provides signals, from which resistivity of the formation near or in front of the drill bit **50** is determined. A dual propagation resistivity device ("DPR") having one or more pairs of transmitting antennae **66a** and **66b** spaced from one or more pairs of receiving antennae **68a** and **68b** may be used. Magnetic dipoles are employed which operate in the medium frequency and lower high frequency spectrum. In operation, the transmitted electromagnetic waves are perturbed as they propagate through the formation surrounding the resistivity device **64.** The receiving antennae **68a** and **68b** detect the perturbed waves. Formation resistivity is derived from the phase and amplitude of the detected signals. The detected signals are processed by a downhole circuit that is preferably placed in a housing above the mud motor **55** and transmitted to the surface control unit **40** using a suitable telemetry system **72.**

[0021] The inclinometer **74** and gamma ray device **76** are suitably placed along the resistivity measuring device **64** for respectively determining the inclination of the portion of the drill string near the drill bit **50** and the formation gamma ray intensity. Any suitable inclinometer and gamma ray device, however, may be utilized for the purposes of this invention. In addition, an azimuth device (not shown), such as a magnetometer or a gyroscopic device, may be used to determine the drill string azimuth. Such devices are known in the art and are, thus, not described in detail herein. In the above-described configuration, the mud motor **55** transfers power to the drill bit **50** via one or more hollow shafts that run through the resistivity measuring device **64.** The hollow shaft enables the drilling fluid to pass from the mud motor **55** to the drill bit **50.** In an alternate embodiment of the drill string **20,** the mud motor **55** may be coupled below resistivity measuring device **64** or at any other suitable place.

[0022] The drill string **20** contains a modular sensor assembly, a motor assembly and kick-off subs. In a preferred embodiment, the sensor assembly includes a resistivity device, gamma ray device and inclinometer, all of which are in a common housing between the drill bit and the mud motor. Such prior art sensor assemblies would be known to those versed in the art and are not discussed further.

[0023] The downhole assembly of the present invention includes a MWD section which may contain a nuclear formation porosity measuring device, a nuclear density device and an acoustic sensor system placed above the mud motor **55** for providing information useful for evaluating and testing subsurface formations along borehole **26.** The present invention may utilize any of the known formation density devices. Any prior art density device using a gamma ray source may be used. In use, gamma rays emitted from the source enter the formation where they interact with the formation and attenuate. The attenuation of the gamma rays is measured by a suitable detector from which density of the formation is determined.

[0024] The porosity measurement device preferably is the device generally disclosed in U.S. Pat. No. 5,144,126, which is assigned to the assignee hereof and which is incorporated herein by reference. This device employs a neutron emission source and a detector for measuring the resulting gamma rays. In use, high energy neutrons are emitted into the surrounding formation. A suitable detector measures the neutron energy delay due to interaction with hydrogen and atoms present in the formation. Other examples of nuclear logging devices are disclosed in U. S. Pat. Nos. 5,126,564 and 5,083,124.

[0025] The above-noted devices transmit data to the downhole telemetry system **72,** which in turn transmits the received data uphole to the surface control unit **40.** The downhole telemetry also receives signals and data from the uphole control unit **40** and transmits such received signals and data to the appropriate downhole devices. The present invention preferably utilizes a mud pulse telemetry technique to communicate data from downhole sensors and devices during drilling operations. A transducer **43** placed in the mud supply line **38** detects the mud pulses responsive to the data transmitted by the downhole telemetry **72**. Transducer **43** generates electrical signals in response to the mud pressure variations and transmits such signals via a conductor **45** to the surface control unit **40.** Other telemetry techniques such electromagnetic and acoustic techniques or any other suitable technique may be utilized for the purposes of this invention. The BHA also includes a downhole processor and a downhole clock (not shown) at convenient locations.

[0026] In operation, MWD data are collected and stored in the downhole memory during the run. The following procedure has been commonly used in the past:

1. Synchronize all surface computers;
2. Before the run synchronize the tool clock to the surface computer;
3. Dump memory with the same computer after the run. During the dump procedure, the time of the surface computer is compared to the time of the tool and a found mismatch is saved along with the memory data;
4. This saved mismatch is used during processing of memory data as a default value for time correction; and
5. The timestamps of memory data is shifter by the specified value.

[0027] Unfortunately this way of "correcting" for a time mismatch does not provide a good correction, as the mismatch is not constant during the run. This can be easily observed by plotting the same parameter measured on the surface and downhole. By measuring the same parameter with the same resolution at the surface and downhole, the problem of resolution matching discussed in *Meyer* is avoided. **Fig. 2a** shows the surface measured rotational speed in RPM **151** and the downhole measured rotational speed **153.** As expected, the surface speed is quite uniform, but the downhole speed is somewhat irregular. The main cause for the irregularity is possible sticking and slipping of the drillstring inside the borehole. Torsional waves travel quite fast in the drill string and we should see changes in the downhole RPM within few seconds after RPM is changed on the surface. Such a difference is noted, and is indicated by the time **155** with a value of approximately 80 seconds. An accurate estimate of this time difference may be readily obtained by performing a cross-correlation of the smoothed downhole curve with the surface curve **151.** It should be noted that the use of surface and downhole measurements of RPM is for exemplary purposes only, and the method of the present invention is applicable for any two types of measurements that are similar to each other. In this regard, the term “similar’ is intended to mean having matching features.

[0028] Fig. 2b shows similar plots of surface rotational speed **151′** and downhole rotational speed **153′** later in the drilling of the same well. The estimated time shift **155′** is now only around 40 seconds. Note the difference in time scales between **Fig. 21** and

Fig. 2b. It is thus clear that the correction procedure outlined above would not work with a constant time shift.

[0029] Turning now to **Fig. 3a**, the results of using a time varying time shift based on a cross-correlation of the surface and downhole measurements of rotational speed from **Figs. 2a, 2b** are shown. The curve **201** is the determined time shift, **203** is a linear fit to **201** and **205** is the difference between the determined time shift and the linear fit Obviously there is some noise in the downhole measurements and therefore they should be approximated first by a smooth curve before using them for time correction. As a first approximation a linear time correction (linear time "stretching") is a good approximation. In an alternate embodiment of the invention, different smoothing, such as a higher order polynomial may be used. **Fig. 3b** shows similar results for torque measurements: **221** is the determined time shift between surface torque measurements and downhole torque measurements while **223** is a linear fit to **221.** The results are similar to those in **Fig. 3a.** Another measurement that can be used is the pressure. For example, when a drill pipe is being added to the drillstring, the mud pump is turned off. It takes a determinable time for the resulting pressure change to propagate down the borehole and reach the BHA. Any time difference over and above the determinable time is attributable to the clock.

[0030] As would be known to those versed in the art, the surface rotary speed is determined largely by the speed of the drive motor at the surface. The rotary speed downhole, on the other hand, is more affected by stick-slip effects and will thus be more erratic. As long as there is no bit bounce at the bottom, a smoothing is appropriate.

[0031] Turning now to **Fig. 4a,** the results of shifting the downhole speed measurements of **Fig. 2a** (earlier in the drilling) based on the linear shift **203** of **Fig. 3** are shown. The downhole speed **253** tracks the surface speed **251** quite well. Similarly, **Fig. 4b** shows the results of shifting the downhole speed measurements of **Fig. 2b** (later in the drilling) based on the linear shift **203** of **Fig. 3**. As in **Fig. 4a,** the time shifted downhole speed **253′** matches the surface speed **251′** quite well.

[0034] We next examine the effect of the time shift (of the order of one minute or so) on formation evaluation (FE) logs in depth. The FE logs are, as noted above, recorded in time and stored in a memory in the BHA. Referring to **Fig. 5,** an exemplary FE log **301** is shown. This is a function of time, and at a selected time such as **303,** the FE log has a value of **311.** The time-depth profile from surface measurements is depicted by **305.** In the example shown, there is a time period when the drillbit was backed up from the bottom of the hole as seen in the negative slope of **305.** At the time **303,** the surface measurements would indicate a depth of the drillbit denoted by **307.** The FE sensor, which is at a known distance above the drillbit would then be at the depth **309.** The value **311** is assigned to the FE curve at depth **309** to give the point **313.** Repeating this for other values **303** of the FE time produces the curve **321.**

[0035] Turning to **Fig. 6,** an exemplary FE log **351** (density, for this example) is shown as a function of depth using the method of **Fig. 5** and without applying the time shift estimated from **Fig. 3.** Also shown in **Fig. 6** are the weight on bit (WOB) **355,** the rotary speed (RPM) **357,** and the ROP **359.** The WOB, RPM and ROP all shown a layer at the depth interval denoted by **363** which corresponds to a significant change in drilling conditions. The drilling parameter logs have a scale chosen to make the comparison with the density logs clearer. The density change corresponding to this drilling change is shifted by about 6 ft. in the curve **351** relative to the change in drilling conditions. The density change was due to a shale stringer within a sand layer.

[0036] After applying the time shift to the FE-time curve and converting it to depth gives the curve **361.** There is now a good match between the depth of the stringer seen on the density curve and the change in drilling conditions **363** due to the stringer. Similar observations may be made about a second stringer **365** that can be seen in **Fig. 6.**

[0037] The mismatch is exacerbated if, as is common practice, FE logs are examined at the wellsite in the form of time displays. The correction of the logs to a common time base is first discussed with reference to **Fig. 7.** Suppose that an MWD data point is measured at some time $\mathbf{t_m}$ **(403)**. Using the time-depth profile **409** one can find depth of the bit $\mathbf{d_{bit}}$ **405** at time $\mathbf{t_m}$. Formation evaluation (FE) sensors are some meters behind the bit. Subtracting sensor offset from $\mathbf{d_{bit}}$ one will find the depth of the sensor $\mathbf{d_s}$ **407** when measurement was done. Using $\mathbf{d_s}$ one can find time $\mathbf{t_p}$ **401** when bit was at this depth.

Difference between $\mathbf{t_m}$ and $\mathbf{t_p}$ **(421)** is called time since drilled (TSD) and is used to plot FE data alongside drilling data on time-based logs. Of course, the TSD value is not a constant during the run and is computed for each data point. The FE log **411** is thus converted to **413.** The results of this conversion of an FE log and a comparison with drilling logs in time is discussed next.

[0038] Shown in **Fig. 8** is the FE log displayed in time **451** without and with **453** the time shift. The curve **455** is the WOB, **457** is the drilling activity code, **459** is the RPM and **459** is the ROP. Looking at the figure, it would not be clear whether the "spike" **471** is a spike in the measurement due to noise (which it is not), or whether it is a lithology change (which it is).

[0039] It should be noted with respect to **Fig. 6** that in the example shown, the ROP is highly correlated with the WOB. US 6769407 to *Dubinsky* et al., having the same assignee as the present invention and the contents of which are incorporated herein by reference, teaches a method of determining ROP from downhole accelerometer measurements. Accordingly, the method of the present invention is not limited to correlating downhole RPM measurements with surface RPM measurements, and other downhole measurements, such as ROP determined from accelerometer measurements may also be used.

[0041] By using the method of the present invention, the FE sensor measurements in depth can be properly aligned with sensor measurements made with wireline logging tools or with measurements made using sensors conveyed on a slickline. This greatly facilitates the interpretation of formation properties by having redundant measurements and/or additional measurements between MWD, wireline and slickline sensors. Slickline measurements have the same clock problems as MWD measurements since the downhole clock and sensors are isolated from the surface system and do not even have the limited telemetry capabilities of MWD systems. The proper alignment in depth of measurements made with different sensors at different times having possibly different resolution and different depths of investigation makes it possible to use the method disclosed in US 6344746 to *Chunduru* et al, having the same assignee as the present invention and the contents of which are incorporated herein by reference.

[0042] In some situations, different FE sensors may be at different parts of the BHA and have different time clocks with different drifts. The method described above provides a framework which makes it possible to compare the FE sensor data not only with drilling data but also with each other.

[0043] The processing of the data to apply the various corrections may be accomplished in whole or in part by a downhole processor and in whole or in part by a surface processor or a combination of a. Implicit in the control and processing of the data is the use of a computer program implemented on a suitable machine readable medium that enables the processor to perform the control and processing. The machine readable medium may include ROMs, EPROMs, EAROMs, Flash Memories and Optical disks.

[0044] While the foregoing disclosure is directed to the preferred embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

CLAIMS

What is claimed is:

1. A method of determining a difference between a first clock at a surface location and a second clock at a downhole location of a downhole assembly, the method comprising:

    (a) making first measurements of a first parameter of the downhole assembly at the surface location and associating a first time stamp with the first measurements;

    (b) making second measurements, similar to the first measurements, of the downhole assembly at the downhole location and associating a second time stamp with the second measurements; and

    (c) determining the time difference by matching a feature of the first measurements with a corresponding feature of the second measurements.

2. The method of claim 1 wherein the downhole assembly comprises a bottomhole assembly (BHA) conveyed on a drillstring and the first parameter is at least one of (i) a rotational speed of the drillstring, (ii) a torque, and, (iii) a pressure.

3. The method of claim 2 wherein the second measurements comprise a measurements of at least one of (i) a rotational speed of the drillstring, (ii) a torque, and, (iii) a pressure..

4. The method of claim 2 wherein the second measurements comprise a rate of penetration (ROP) of the drillstring.

5. The method of claim 4 further comprising determining the ROP using accelerometer measurements.

6. The method of claim 1 wherein the matching further comprises performing a cross-correlation of the first and second measurements

7. The method of claim 1 further comprising determining the time difference at a plurality of drilling times.

8. The method of claim 7 further comprising:

(i) making measurements with a formation evaluation (FE) sensor of a property of the earth formation, the FE sensor being associated with the second clock; and

(ii) converting the FE measurements to drilling depth using the determined time difference at the plurality of drilling times.

9. The method of claim 8 further comprising:

(i) making measurements with an additional FE sensor of an additional property of the earth formation, the additional FE sensor being associated with a third clock having an additional difference of time relative to the first clock; and

(ii) converting the additional FE measurements to drilling depth using the additional time difference at the plurality of drilling times.

10. The method of claim 8 further comprising evaluating the earth formation by jointly processing the converted FE measurements in conjunction with measurements made using sensors on at least one of (i) a wireline, and, (ii) a slickline.

11. The method of claim 7 further comprising:

(i) making measurements with a formation evaluation (FE) sensor of a property of the earth formation, the FE sensor being associated with the second clock; and

(ii) converting the FE measurements to drilling time using the determined time difference at the plurality of drilling times.

12. The method of claim 8 further comprising determining a lithology of an earth formation from the converted FE measurements.

13. A measurement while drilling (MWD) system comprising:
    (a) a first clock at a surface location;
    (b) a second clock on a bottomhole assembly (BHA) at a downhole location in a borehole in an earth formation, the second clock having a time difference relative to the first clock; and
    (c) a processor which:
        (A) uses first measurements of a first parameter of the MWD system at the surface location and second measurements, similar to the first measurements at the downhole location; and
        (B) determines the time difference by matching a feature of the first measurements with a corresponding feature of the second measurements.

14. The system of claim 13 further comprising a drilling tubular which conveys the BHA into the borehole.

15. The system of claim 13 wherein the first parameter is at least one of (i) a rotational speed of a drillstring, (ii) a torque, and, (iii) a pressure.

16. The system of claim 15 wherein the second measurements comprise at least one of (i) a rotational speed of the drillstring, (ii) a torque, and, (iii) a pressure..

17. The system of claim 15 wherein the second measurements comprise a rate of penetration (ROP) of the drillstring.

18. The system of claim 17 further comprising an accelerometer which gives an output indicative of the ROP,
wherein the processor further determines the ROP using the output of the accelerometer.

19. The system of claim 13 wherein the processor performs the matching by further performing a cross-correlation of the first and second measurements

20. The system of claim 13 wherein the processor further comprising determines the time difference at a plurality of drilling times.

21. The system of claim 20 further comprising a formation evaluation (FE) sensor which makes measurements of a property of the earth formation, the FE sensor being associated with the second clock,
and wherein the processor further converts the FE measurements to drilling depth using the determined time difference at the plurality of drilling times.

22. The system of claim 20 further comprising a formation evaluation (FE) which makes measurements of a property of the earth formation, the FE sensor being associated with the second clock
and wherein the processor further converts the FE measurements to drilling time using the determined time difference at the plurality of drilling times.

23. The system of claim 21 wherein the processor further determines a lithology of an earth formation from the converted FE measurements.

24. A computer readable medium for use with a measurement while drilling (MWD) system, the MWD system comprising:
(a) a first clock at a surface location; and
(b) a second clock on a bottomhole assembly (BHA) at a downhole location in a borehole in an earth formation, the second clock having a time difference relative to the first clock;
the medium comprising instructions which enable:
determining from first measurements of a first parameter of the MWD system at the surface location and second measurements similar to the first measurements at the downhole location, the time difference by matching a feature of the first measurements with a corresponding feature of the second measurements.

25. The medium of claim 24 wherein the medium is selected from the group consisting of (i) a ROM, (ii) an EPROM, (iii) an EAROM, (iv) a Flash Memory, and, (v) an Optical disk.

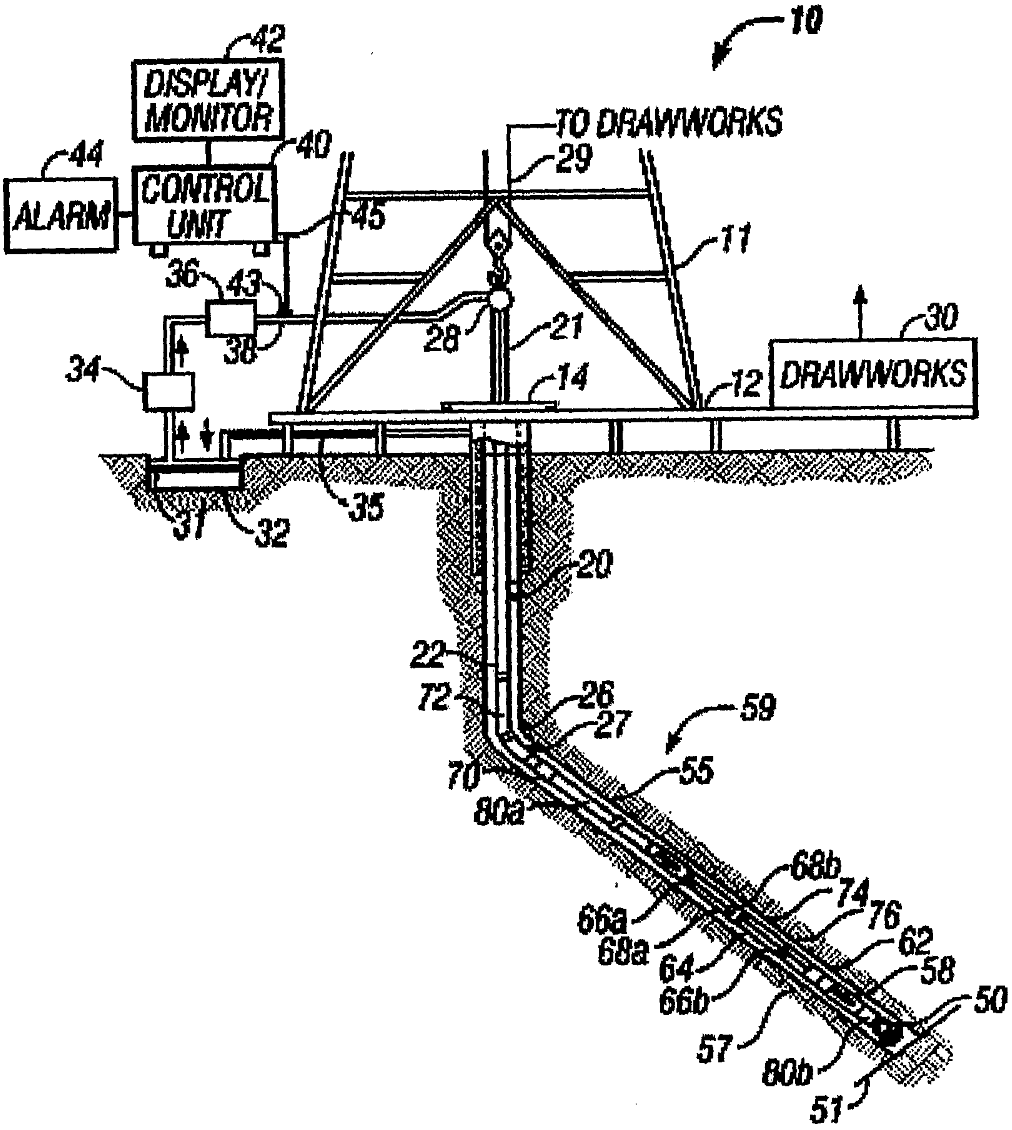

FIG. 1

Prior art

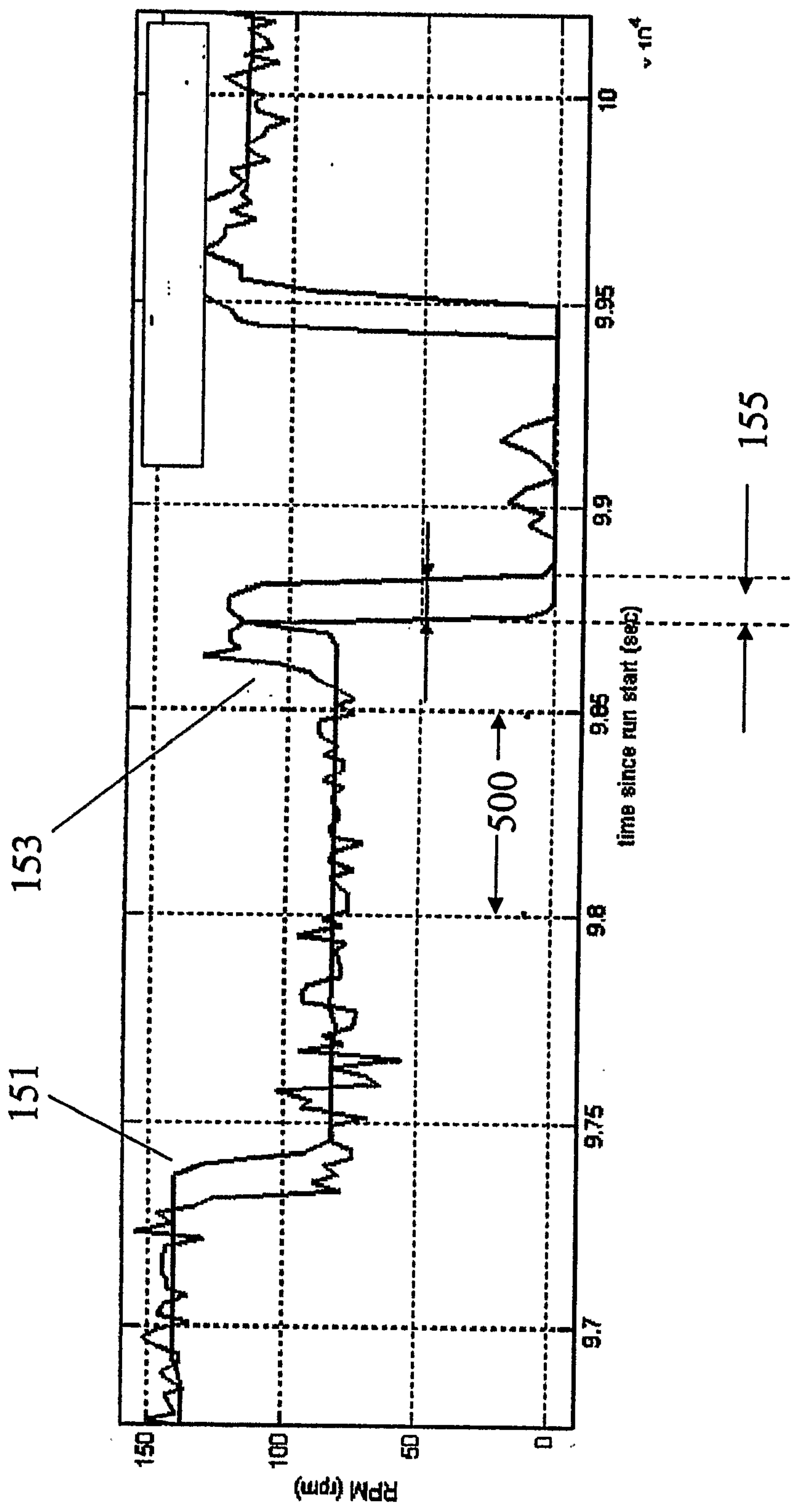
151
153
155
500
RPM (rpm)
150
100
50
0
9.7
9.75
9.8
9.85
9.9
9.95
10
x 10^4
time since run start (sec)

Figure 2a

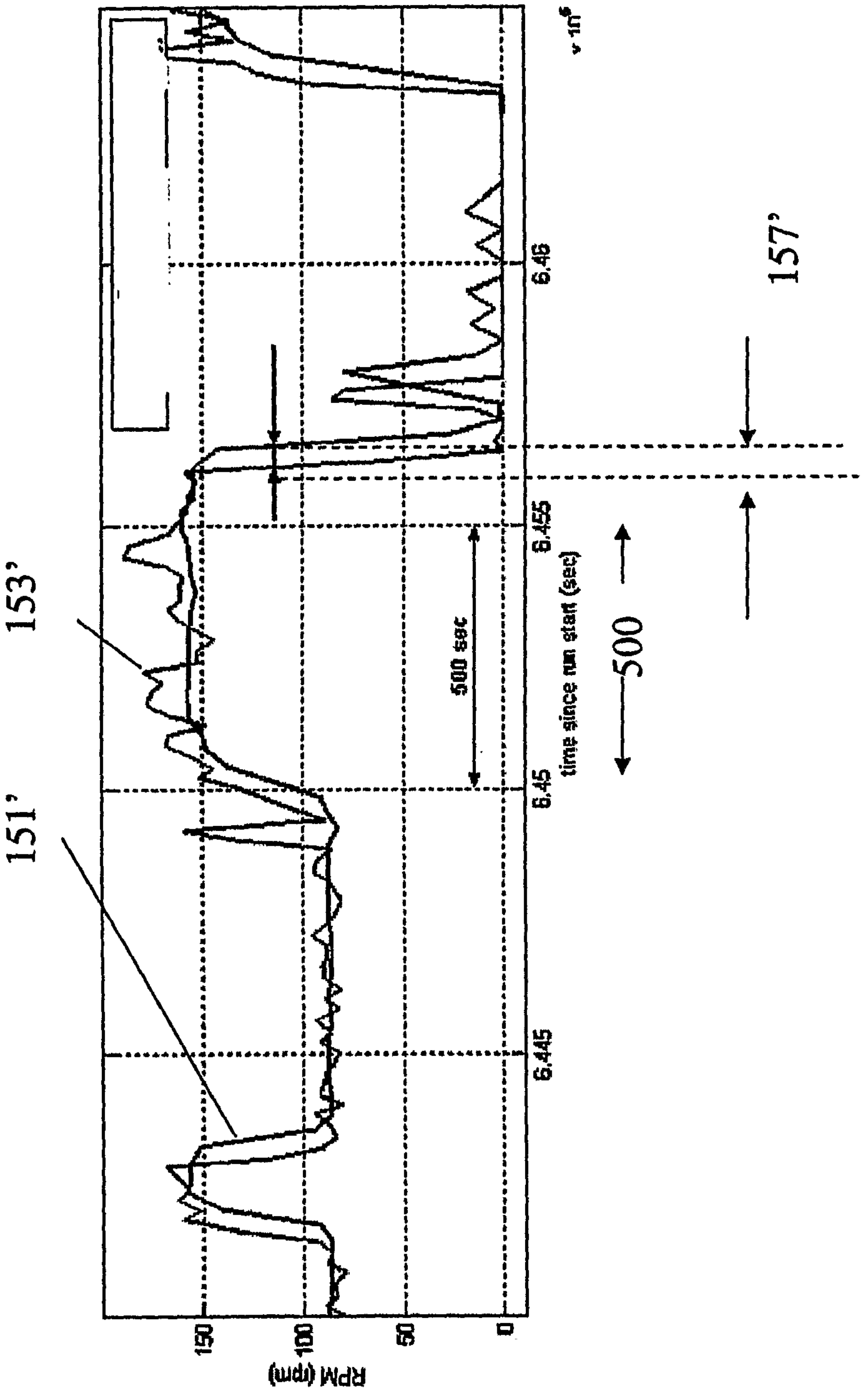
151'
153'
157'
500
500 sec
RPM (rpm)
150
100
50
0
6.445
6.45
6.455
6.46
x 10^6
time since run start (sec)

Figure 2b

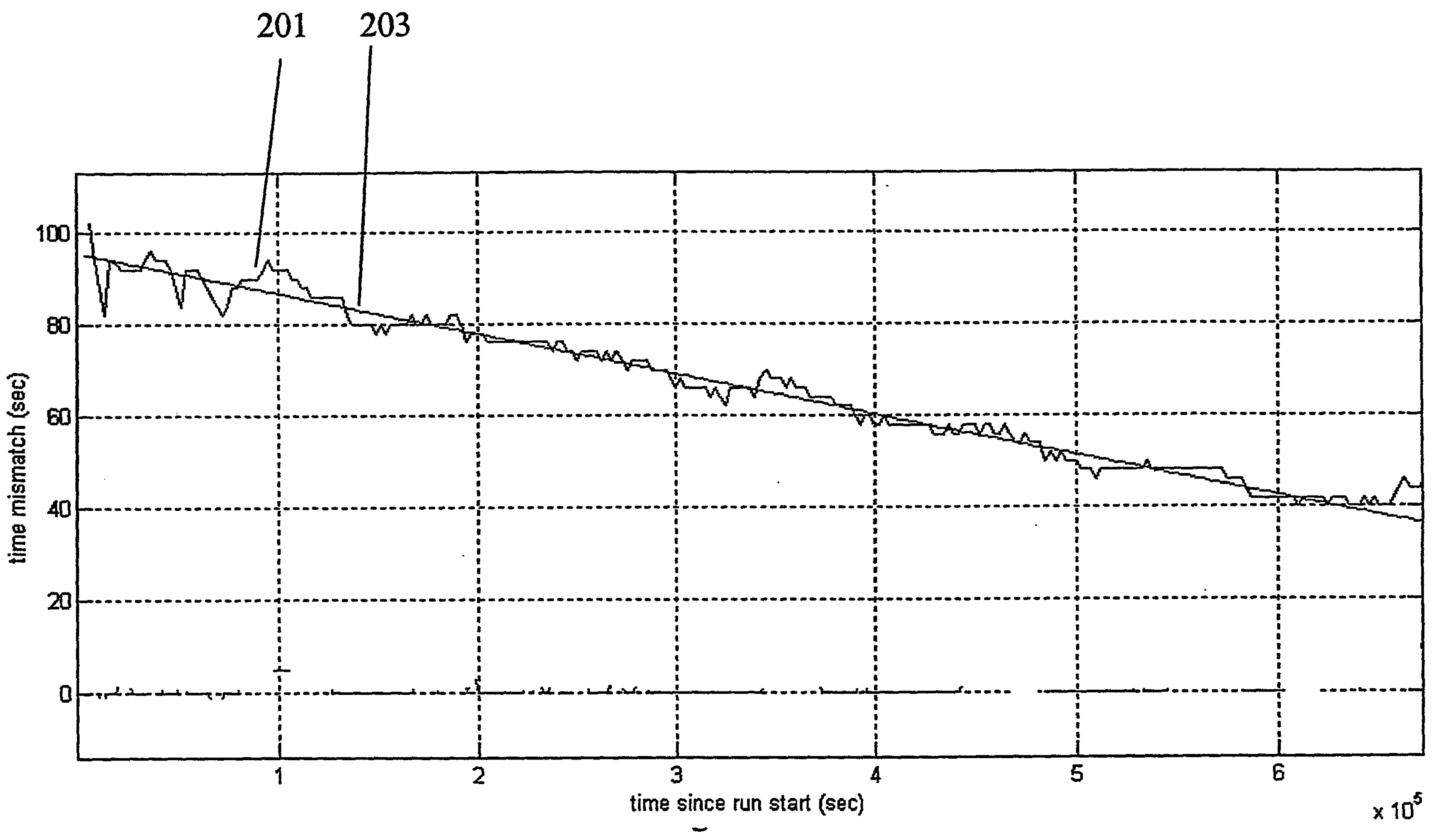
201
203
100
80
60
40
20
0
time mismatch (sec)
1
2
3
4
5
6
time since run start (sec)
x 10^5

Fig. 3a

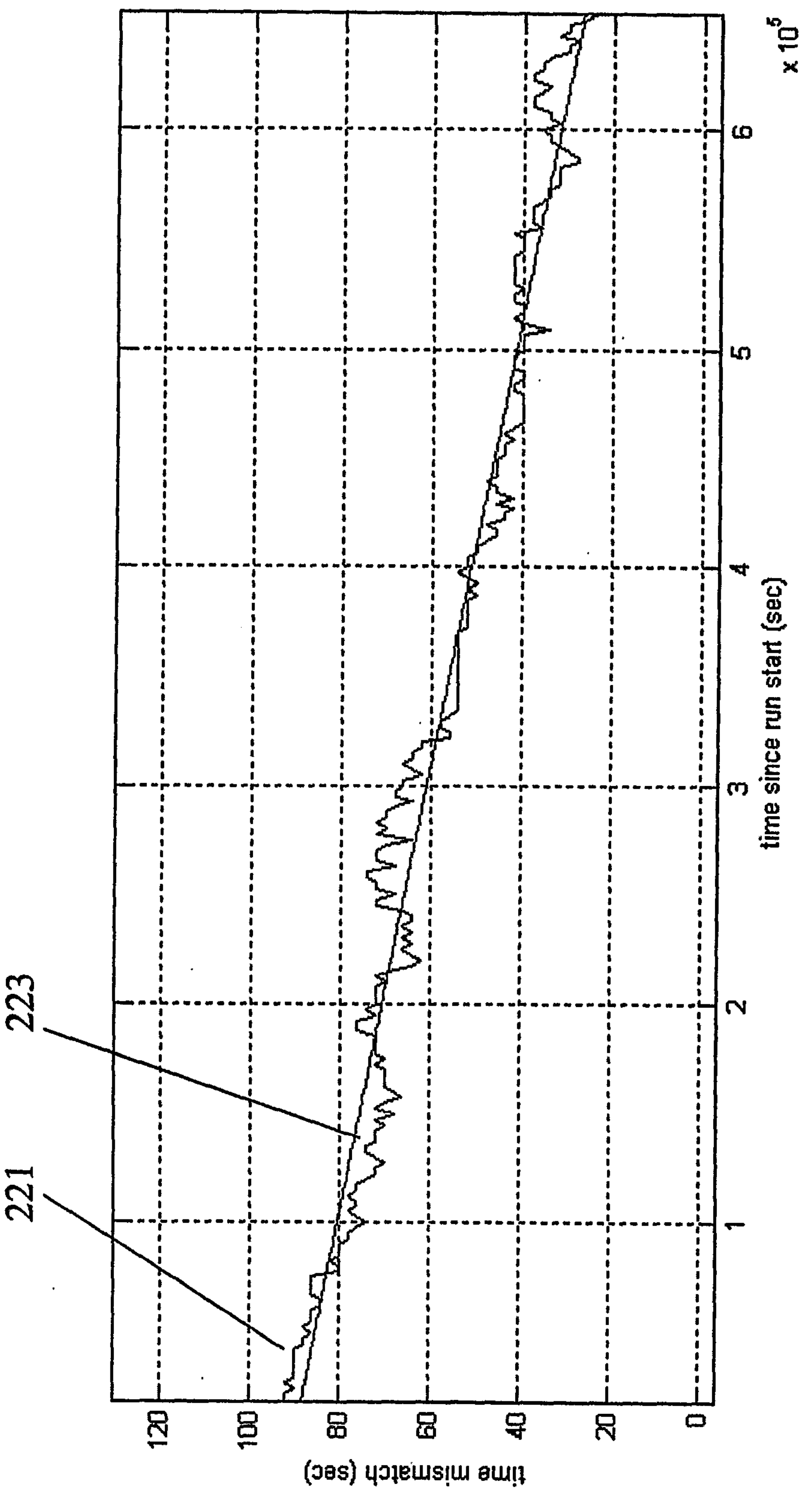
221
223
time mismatch (sec)
0
20
40
60
80
100
120
1
2
3
4
5
6
x 10^5
time since run start (sec)

Figure 3b

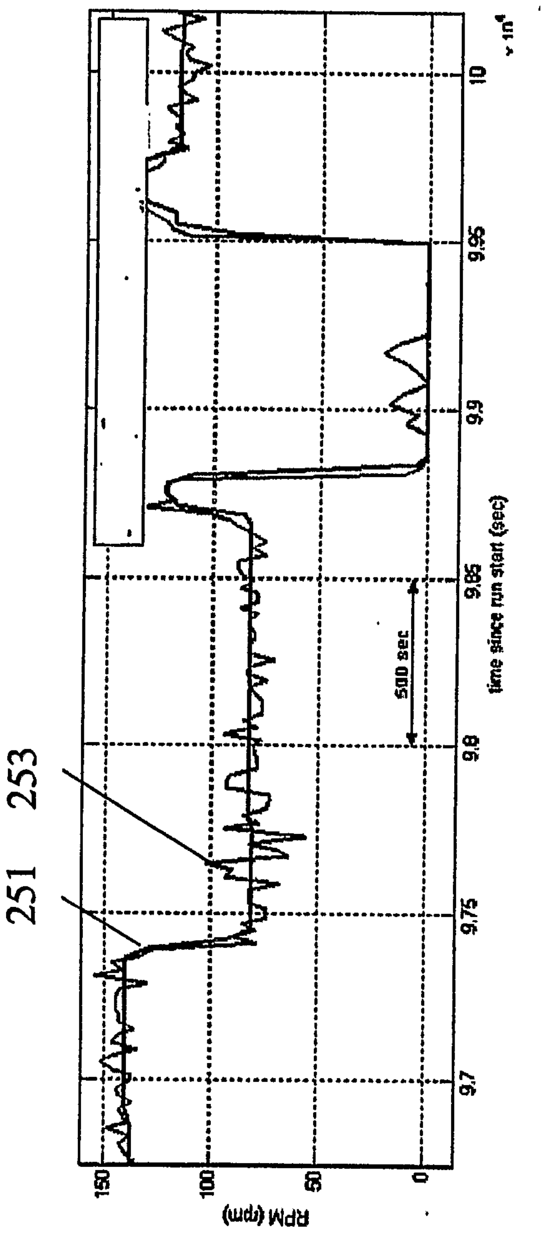
251
253
150
100
50
0
RPM (rpm)
9.7
9.75
9.8
9.85
9.9
9.95
10
x 10^4
500 sec
time since run start (sec)

Figure 4a

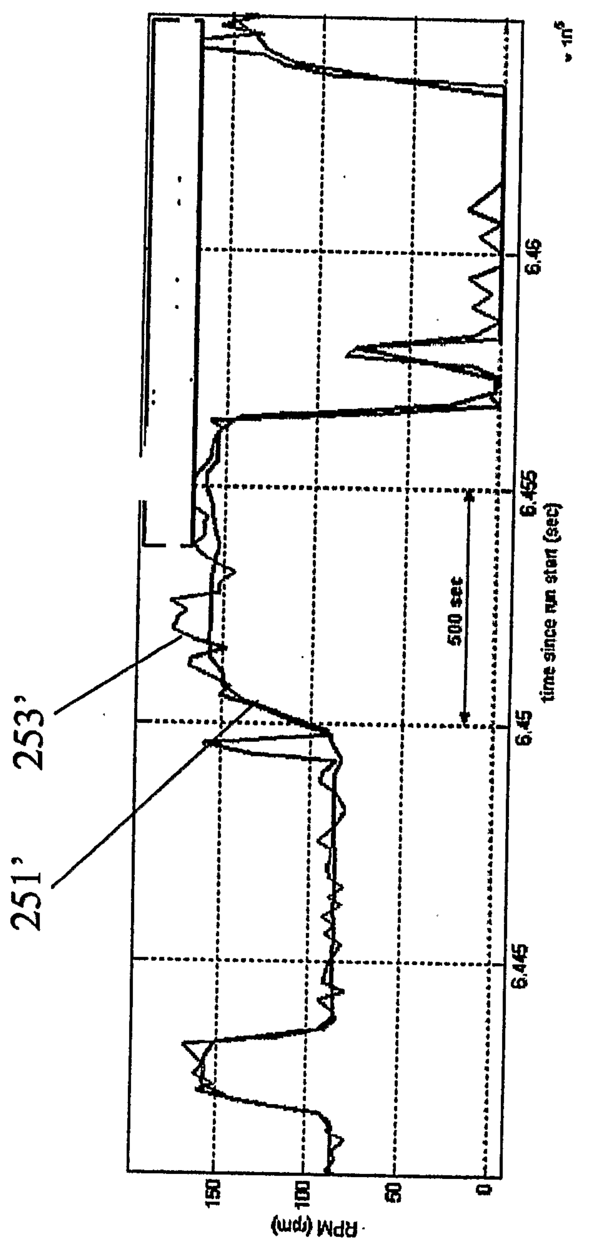
253'
251'
150
100
50
0
RPM (rpm)
6.445
6.45
6.455
6.46
$\times 10^5$
500 sec
time since run start (sec)

Figure 4b

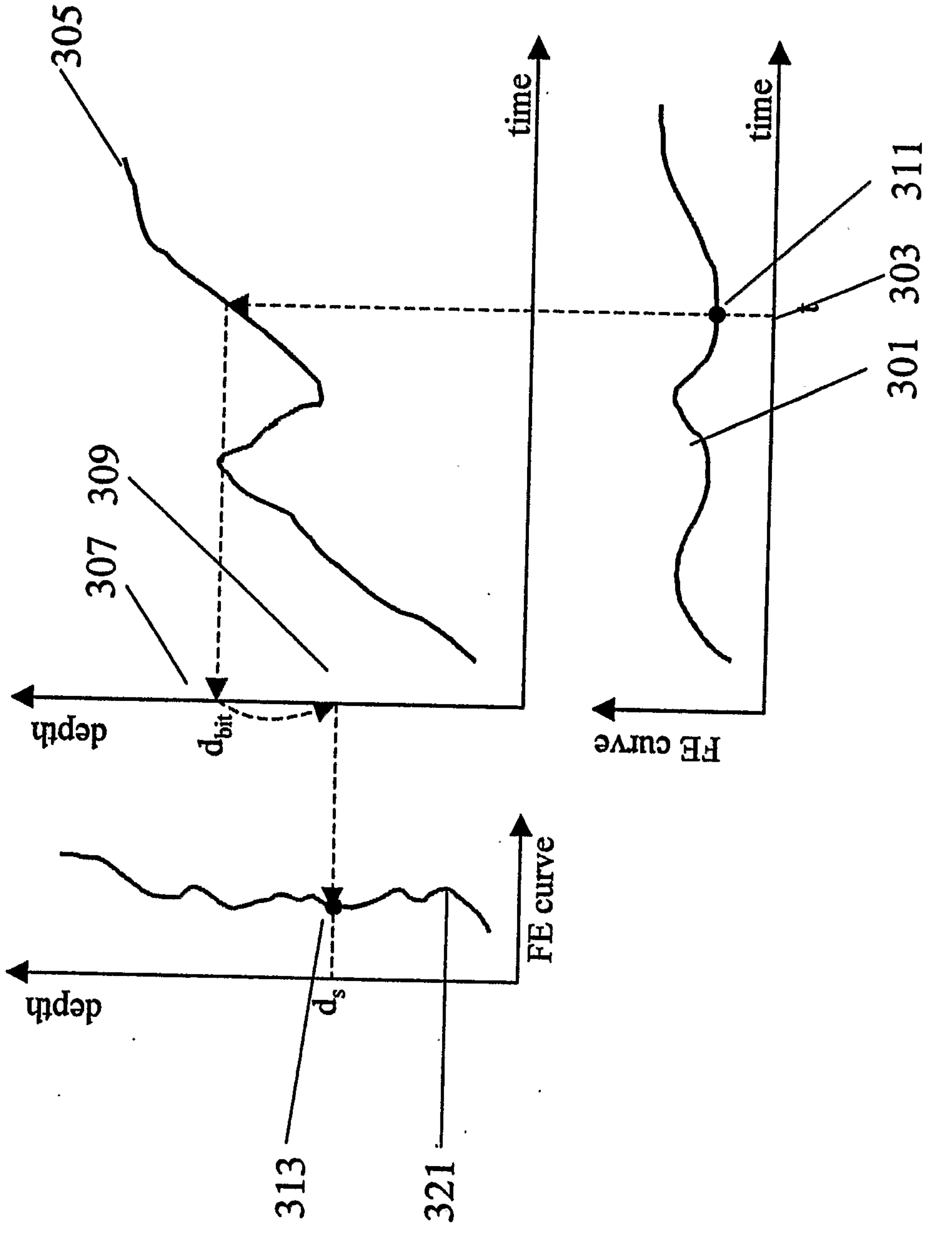
305
307
309
time
depth
d_bit
311
303
t
301
time
FE curve
depth
d_s
FE curve
313
321

Figure 5

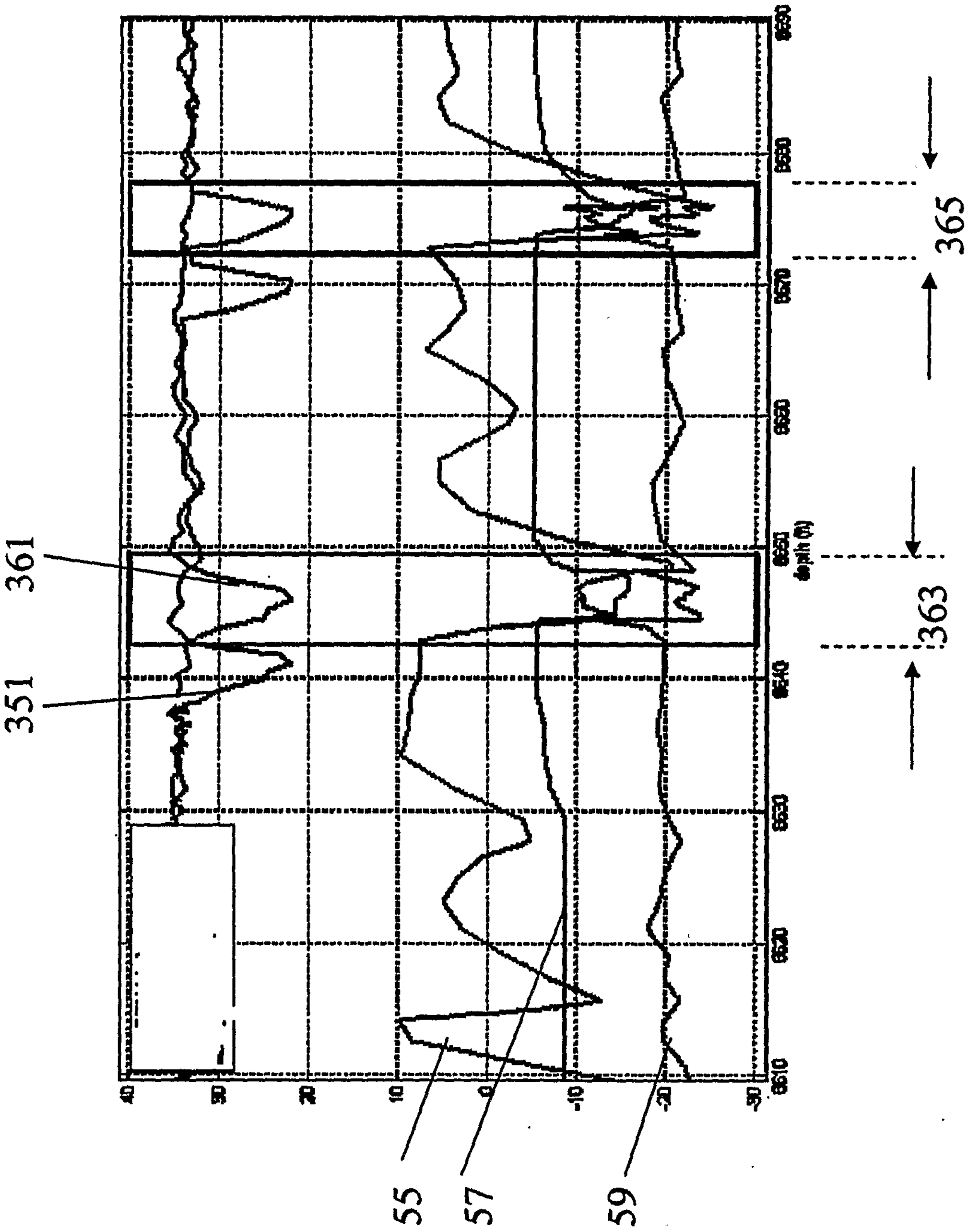
40
30
20
10
0
-10
-20
-30
8610
8620
8630
8640
8650
8660
8670
8680
8690
depth (ft)
351
361
355
357
359
363
365

Figure 6

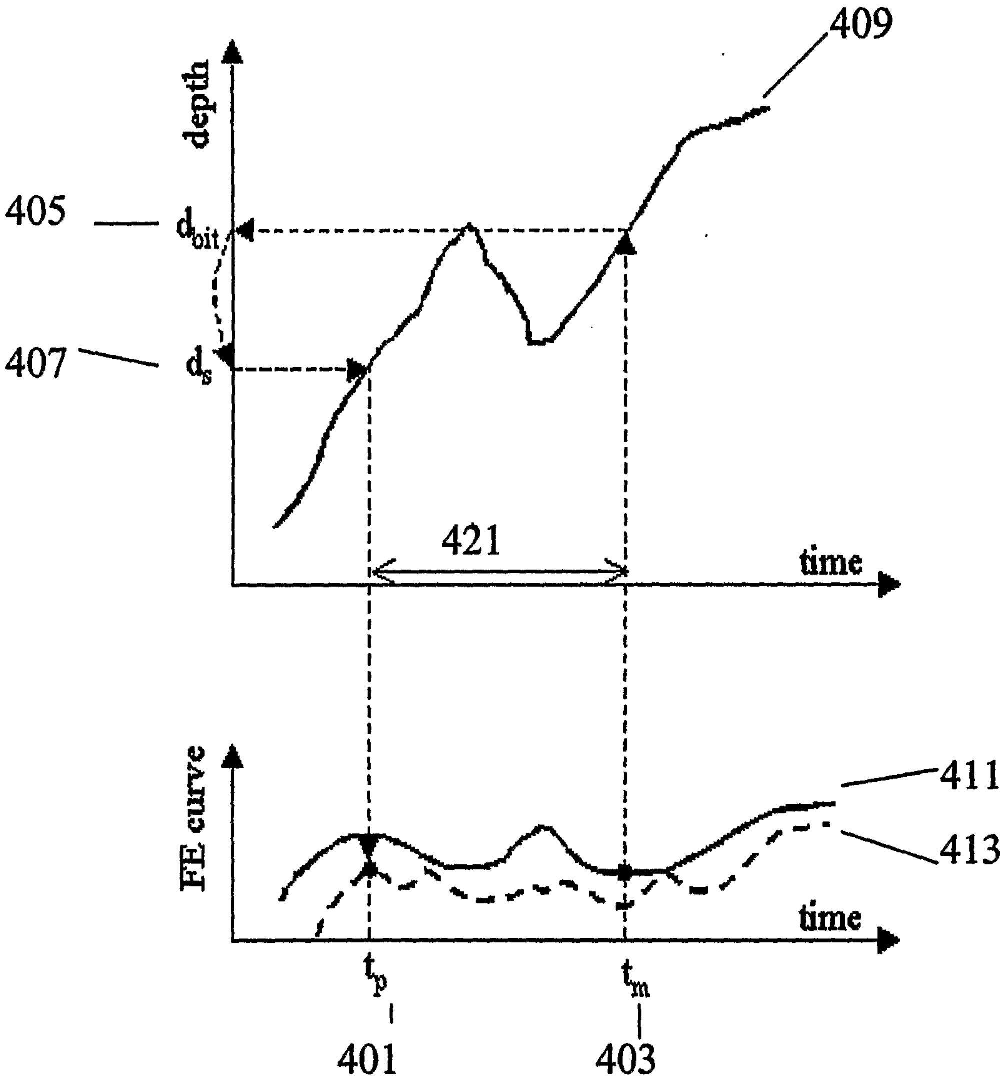
409
depth
405
d_{bit}
407
d_s
421
time
FE curve
411
413
time
t_p
t_m
401
403

Figure 7

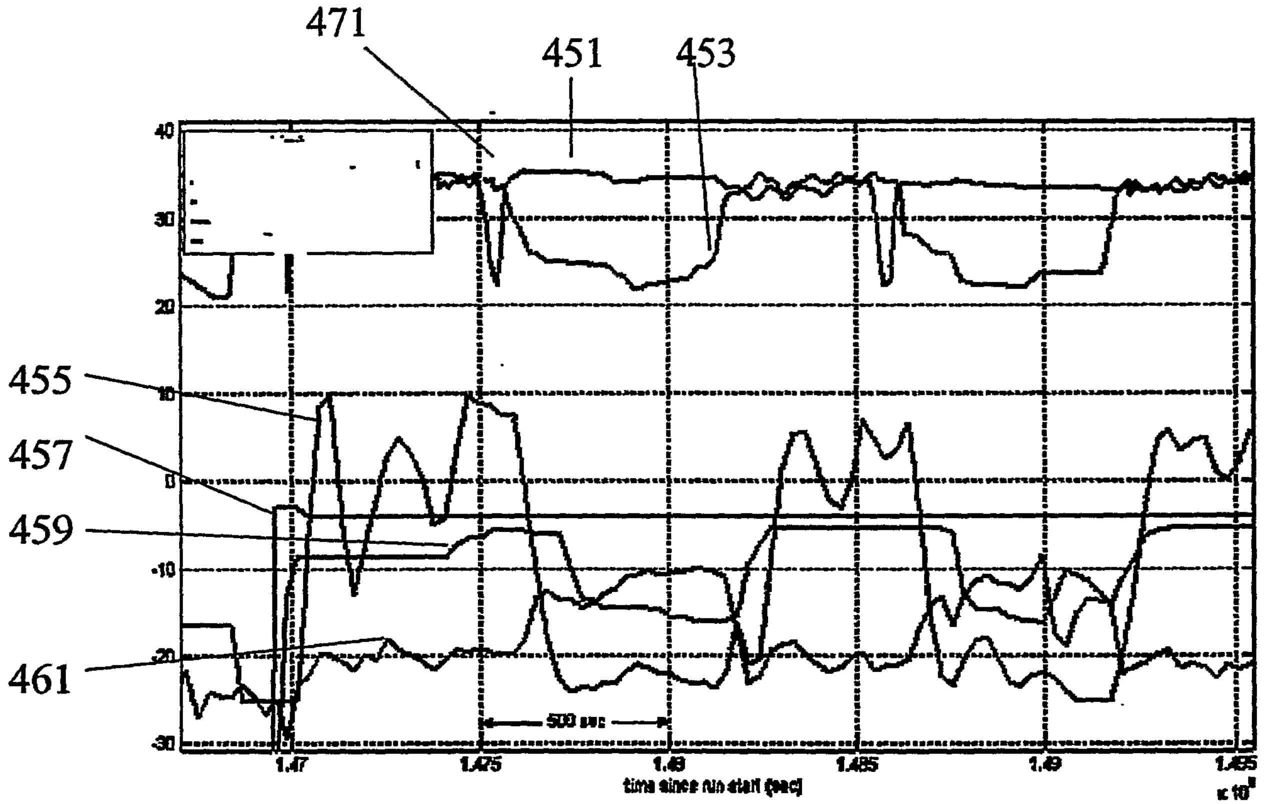
471
451
453
455
457
459
461
40
30
20
10
0
-10
-20
-30
1.47
1.475
1.48
1.485
1.49
1.495
500 sec
time since run start (sec)
x 10^5

Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/005457

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01V1/40

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01V

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/024305 A1 (IRELAND PETER J ET AL) 6 February 2003 (2003-02-06) paragraphs [0008] - [0011], [0032], [0034] - [0037], [0044], [0045] figures 1,5,6 -----	1-25
A	US 6 400 646 B1 (SHAH VIMAL V ET AL) 4 June 2002 (2002-06-04) column 3, line 64 - column 4, line 13 column 4, line 23 - line 32 column 6, line 42 - column 7, line 2 figure 3 -----	1-25
A	US 6 837 105 B1 (DIFOGGIO ROCCO ET AL) 4 January 2005 (2005-01-04) cited in the application column 3, line 26 - line 37 column 7, line 27 - line 45 -----	1-25

-/--

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

Date of the actual completion of the international search
9 June 2006

Date of mailing of the international search report
19/06/2006

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Authorized officer
Schneiderbauer, K

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/005457

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/117118 A1 (COLLINS ANTHONY L ET AL) 17 June 2004 (2004-06-17) paragraphs [0010], [0020] - [0023] -----	1-25

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2006/005457

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		EP 1238483 A2	11-09-2002
		NO 20022740 A	06-08-2002
		WO 0142614 A2	14-06-2001
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		US 2005122839 A1	09-06-2005
		WO 2005028811 A1	31-03-2005
US 2004117118 A1	17-06-2004	GB 2396214 A	16-06-2004
		MX PA03008378 A	24-06-2004