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Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

[Continued on next page]

(54) Title: ACTIVE CONTROL OF DRILL BIT WALKING

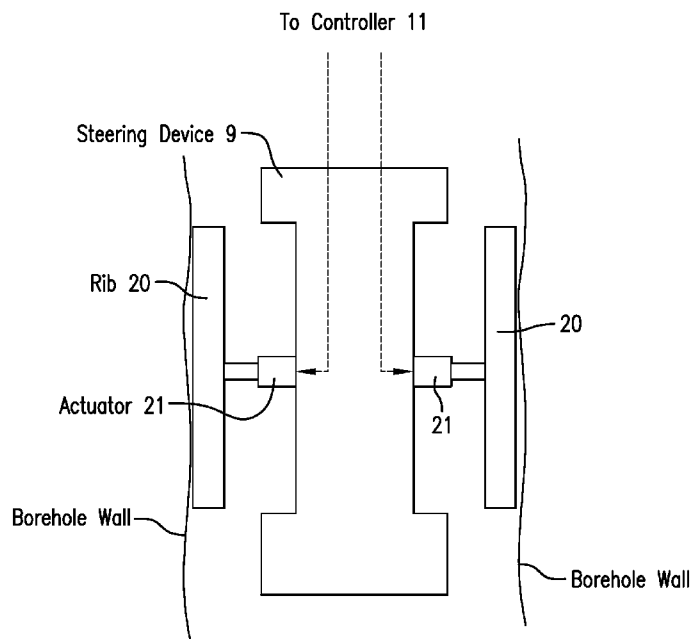


FIG. 2

(57) Abstract: An apparatus for drilling a borehole into an earth formation includes: a drill bit configured to be rotated to drill into the formation; a drill tubular coupled to the drill bit and configured to rotate the drill bit; a steering device coupled to the drill string and configured to impart a force on the drill string to control a direction of drilling; and a controller configured to communicate a control signal to the steering device. The control signal includes information for directing actuation of the steering device for steering the drill bit in an intended drilling direction. The controller is further configured to direct the steering device to provide a compensating force on the drill string that prevents or reduces an azimuthal deviation from the intended drilling direction due to drill bit walking.



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- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) — before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

Published:

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ACTIVE CONTROL OF DRILL BIT WALKING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Application No. 13/894117, filed on May 14, 2013, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Boreholes are drilled into the earth for various purposes such as hydrocarbon exploration and production, geothermal production, and carbon dioxide sequestration. A borehole is typically drilled by rotating a drill bit for cutting into formation rock, which is then evacuated from the borehole. Unfortunately, the interaction of the drill bit with the rock can cause the drill bit to move or walk away from an intended drilling direction. It would be well received in the drilling and geophysical exploration industries if apparatus and method could be developed to prevent drill bit walking.

BRIEF SUMMARY

[0003] Disclosed is an apparatus for drilling a borehole into an earth formation. The apparatus includes: a drill bit configured to be rotated to drill into the formation; a drill tubular coupled to the drill bit and configured to rotate the drill bit; a steering device coupled to the drill string and configured to impart a force on the drill string to control a direction of drilling; and a controller configured to communicate a control signal to the steering device, the control signal comprising information for directing actuation of the steering device for steering the drill bit in an intended drilling direction; wherein the controller is further configured to direct the steering device to provide a compensating force on the drill string that prevents or reduces an azimuthal deviation from the intended drilling direction due to drill bit walking.

[0004] Also disclosed is a method for drilling a borehole into an earth formation. The method includes: drilling into the formation with a drill bit being rotated by a drill tubular; and communicating a control signal from a controller to a steering device coupled to the drill tubular, the control signal includes information for directing actuation of the steering device for imparting a force on the drill string to control an intended direction of drilling; wherein the control signal includes instructions for the steering device to impart a compensating force on the drill tubular that prevents or reduces an azimuthal deviation from the intended drilling direction due to drill bit walking.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] FIG. 1 illustrates a cross-sectional view of an exemplary embodiment of a drill string having a drill bit disposed in a borehole penetrating the earth;

[0007] FIG. 2 depicts aspects of a steering device configured to control the drilling direction of the drill bit;

[0008] FIG. 3 depicts aspects of a drill bit having fixed cutters;

[0009] FIG. 4 depicts aspects of a drill bit having rolling cutters;

[0010] FIGS. 5A and 5B, collectively referred to as FIG. 5, depict aspects of testing a drill bit for a bit walk force; and

[0011] FIG. 6 is a flow chart of a method for drilling a borehole into an earth formation.

DETAILED DESCRIPTION

[0012] A detailed description of one or more embodiments of the disclosed apparatus and method presented herein by way of exemplification and not limitation with reference to the figures.

[0013] Disclosed are apparatus and method for drilling a borehole into an earth formation using a drill string that rotates a drill bit. The apparatus and method call for automatically applying a compensating force to the drill string that compensates for a bit walking force that forces the drill bit to drill or walk away from an intended drilling azimuth.

[0014] FIG. 1 illustrates a cross-sectional view of an exemplary embodiment of a drill tubular 5 disposed in a borehole 2 penetrating the earth 3, which may include an earth formation 4. The formation 4 represents any subsurface material of interest that may be drilled by the drill tubular 5. In the embodiment of FIG. 1, the drill tubular 5 is a drill string made of drill pipes 6 serially coupled together. A drill bit 7 is disposed at the distal end of the drill tubular 5. A drill rig 8 is configured to conduct drilling operations such as rotating the drill tubular 5 and thus the drill bit 7 in order to drill the borehole 2. In addition, the drill rig 8 is configured to pump drilling fluid through the drill string 6 in order to lubricate the drill bit 7 and flush cuttings from the borehole 2. A steering device 9 is coupled to the drill tubular 5 and is configured to steer the drilling of the borehole 2 in a desired or intended direction. The intended direction may include an inclination direction (i.e., up or down with

respect to the earth's surface) and/or an azimuthal direction (i.e., with respect a reference azimuth such as true or grid north). It can be appreciated that in one or more embodiments the steering device 9 is disposed close to the drill bit 7, within three feet for example, so that the force or portion of the force being applied to the drill tubular 5 by the steering device 9 is also being applied to the drill bit 7. The steering device 9 in one or more embodiments may be considered as part of the drill tubular 5. A controller 11 is configured to control the steering device 9 to steer the drilling of the borehole in the desired direction. The controller 11 may also act as an interface with telemetry to communicate data or commands between downhole components and a computer processing system 12 disposed at the surface of the earth 3. Non-limiting embodiments of the telemetry include pulsed-mud and wired drill pipe. System operation, control and/or data processing operations may be performed by the controller 11, the computer processing system 12, or a combination thereof.

[0015] In one or more embodiments, an inclination sensor 13 is disposed at the drill tubular 5 and coupled to the controller 11. The inclination sensor 13 is configured to sense inclination of the drill tubular 5 where the sensor 13 is disposed. In one or more embodiments, the inclination sensor 13 is configured to sense inclination using the direction of gravity as a reference. The term "inclination" relates to a vertical direction or angle such that the direction at zero degrees is horizontal, a positive direction or angle points to the surface of the earth 3, or a negative direction or angle points deeper into the earth 3. In contrast, the term "azimuthal" relates to a direction or angle with respect to a reference direction such as true north or grid north. In one or more embodiments, the controller 11 is configured to provide feedback control of drilling inclination using input from the inclination sensor 12 to control the steering device 9. The controller 11 may contain various control algorithms such as proportional (P) control, integral (I) control, proportional-integral-differential (PID) control, or some combination thereof. In one or more embodiments, an inclination setpoint for inclination feedback control may be transmitted to the controller 11 from the surface of the earth 3 by a surface interface such as the computer processing system 12. In one or more embodiments, a user such as a drill operator may manually input the inclination set point into the surface interface which then transmits the setpoint downhole to the controller 11.

[0016] Reference may now be had to FIG. 2 depicting aspects of one embodiment of the steering device 9 in a cross-sectional view. The steering device 9 includes a plurality of ribs 20 configured to extend from a body 21. The drill tubular 5 is free to rotate within the body 21. Each rib 20 is coupled to an actuator 22 configured to extend in order to extend the

corresponding rib. The actuator 22 applies a force to the corresponding rib 20 causing that rib 20 to extend until it contacts the borehole wall. With the rib 20 in contact with the borehole wall, a force is applied to the drill tubular 5 by the actuator 22 that is equal and opposite to the force applied to the rib 20. In general, the plurality of ribs 20 is disposed symmetrically (although they do not have to be) about the body 21 such that a combination of all forces applied to the drill tubular 5 by all the actuators 22 is a resultant force vector having a magnitude and direction that urges the drill tubular 5 and the drill bit 7 to drill the borehole 2 in an intended direction. The controller 11 is coupled to each actuator 22 for controlling extension of the ribs 20 and therefore controlling the force being applied to the drill tubular 5. By knowing the maximum force that each actuator 22 is capable of applying, the controller 11 can direct each actuator 22 to apply a certain percentage of the maximum force (e.g., 0-100% of maximum) in order to achieve a desired combined vector force applied to the drill tubular 5.

[0017] In one or more embodiments, the actuators 22 may be powered hydraulically by a hydraulic pump (not shown) with the controller 11 controlling the hydraulic pressure and, thus, the force being applied to each rib 21 with the combined vector force being applied to the drill tubular 5. In one or more embodiments, the controller 11 controls the hydraulic pressure by controlling the pump speed and/or position of a pump discharge valve (not shown).

[0018] Reference may now be had to FIG. 3 depicting aspects of a drill bit 30 having fixed cutters 31 in a bottom view. In one or more embodiments, the fixed cutters 31 are made of polycrystalline diamond (PCD). Directions are generally provided with reference to a top view, so the directions of motion when viewed from a bottom view are reversed. It can be appreciated that when the drill tubular rotates clockwise (in a top view) a force (i.e., side load) applied to the drill bit 30 to increase the inclination (i.e. in up direction) will cause the drill bit 30 to walk or move to the left due to the increased force on the drill bit 30 in the up direction. Walking to the left may be described as having a negative azimuthal angle. Similarly, a force applied to the drill bit to decrease inclination (i.e., in down direction) will cause the drill bit 30 to walk to the right. Walking to the right may be described as having a positive azimuthal angle. In one or more embodiments, the walking force is perpendicular to the inclination force so that the drilling direction is determined by the vector combination of the inclination force and the walking force applied to the drill bit with the walking force being a function of the inclination force.

[0019] Reference may now be had to FIG. 4 depicting aspects of a drill bit 40 having roller cutters 41 that are configured to rotate as they cut into formation rock. It can be appreciated that due to the roller action of the drill bit 40 the walking forces applied to the drill bit 40 will be opposite of the walking forces applied to the drill bit 30 due to the application of the same forces used to change the inclination of the drill bit. That is, an inclination force or side load that causes the drill bit 40 to increase inclination will cause the drill bit 40 to walk to the right. An inclination force to cause the drill bit 40 to decrease inclination will cause the drill bit 40 to walk to the left.

[0020] Reference may now be had to FIG. 5 depicting aspects of testing a drill bit of interest to determine a drill bit walking force (i.e., azimuthal force) resulting from an applied inclination force. In the embodiment illustrated in FIG. 5A, a test stand 50 is configured to rotate the drill bit of interest in a rock sample. From the inclination displacement of the drill bit resulting from a known inclination force, the walking angle α can be measured, generally using a laser measurement device, strain gauges (not shown), or other precision measurement devices. From the walking angle, the walking force that would cause the drill bit 7 to walk at that angle can be calculated. Hence, for the specific drill bit 7 being tested, the walking force is correlated to a percentage value of the inclination force. By knowing the percentage value for a specific type of drill bit, the controller 11 can direct the steering device 9 to apply an opposing force equal to the percentage value multiplied times the known inclination force to prevent that specific type of drill bit from walking when the inclination force is being applied. For example, if one specific type of drill bit has a tendency to walk left and a percentage value of 20% and an inclination force (i.e., side load) of 2500 pound-force is being applied to that specific type of drill bit to change the drilling inclination, then the controller 11 can direct the steering device 9 to apply a compensating or counter force of 500 pound-force to the drill tubular and, thus, to the drill bit to prevent the drill bit from walking from an intended drilling direction. Without the compensating force, the walking angle would be about 11.3°. It can be appreciated that the determined percentage value may be dependent on the rotary speed being used to drill the borehole and, thus, percentage values may be determined for a plurality of rotary speeds of interest.

[0021] In one or more embodiments, the walking force is perpendicular to or has a vector component perpendicular to the inclination force vector. Accordingly, the compensating force is generally applied perpendicular to the inclination force vector and in a direction opposite of the walking force. Any walking force vector component aligned with

the inclination force vector can be compensated for by the controller 11 using feedback from the inclination sensor 13.

[0022] It can be appreciated that for each specific type of drill bit that may be used several different magnitudes of inclination forces may be applied to that drill bit and corresponding walking forces or walking angles measured. The test data can be organized in a lookup table or a mathematical curve can be fit to the data enabling the controller 11 to determine and apply the appropriate compensating force when a known inclination force is or is going to be applied to the drill tubular 5 or drill bit 7.

[0023] FIG. 6 is a flow chart for a method 60 for drilling a borehole into an earth formation. Block 61 calls for drilling into the formation with a drill bit being rotated by a drill tubular. Block 62 calls receiving drill bit walking data using a controller for the specific type of drill bit being used. The drill bit walking data includes (a) a direction that the drill bit walks when a side force is applied to the drill bit during rotation of the drill bit and (b) a percentage value which when multiplied times an inclination force applied to the drill bit results in a drill bit walking force that has a vector component perpendicular to the inclination force. Block 63 calls for receiving an inclination angle using the controller. Block 64 calls for communicating a control signal from the controller to a steering device configured for steering the direction of drilling. The control signal includes information for directing the steering device to apply an inclination force to drill at the inclination angle and for applying a compensating force to the drill tubular that opposes a walking force induced by the inclination force.

[0024] The above techniques provide several advantages. One advantage is that the borehole can be drilled in an intended azimuthal direction by automatically compensating for drill bit walking. The automatic aspects do not require operator intervention and, thus, the compensating force can be applied continuously or at a high rate as needed such as when an inclination force is being applied. This can result in a more accurately drilled borehole than if an operator had to take manual action to correct for drill bit walking after the time it takes to detect the drill bit walking.

[0025] It can be appreciated that the drill bit 7 can be a hybrid drill bit having both fixed cutters 31 and roller cutters 41. The test stand 50 can be used to determine the directional tendency of the hybrid drill bit and the associated percentage value of the inclination force that the hybrid bit walking force is.

[0026] It can be appreciated that on certain occasions the maximum force capability of the steering device 9 may be exceeded such as when the user calls for applying the

maximum capable force in the inclination direction. On these occasions, the controller 11 will reduce the force being applied in the inclination direction and apply the appropriate walk compensation force so that drilling in the intended azimuthal direction can be maintained. In one or more embodiments in these situations, the maximum force capability will be applied in the direction of the vector sum of the inclination force and the walk compensation force (i.e., azimuth force in FIG. 5).

[0027] In one or more embodiments, a user may transmit to the controller 11, via the processing system 12, a new percentage of the inclination force that is to be applied as the walk compensation force. A borehole survey tool (not shown) may be disposed at the drill tubular 7 generally several feet away from the drill bit and steering device. If the survey tool, which can measure the azimuth of the already drilled borehole, detects drill bit walking that is not being compensated for (such as due to drill bit wear), the user can adjust the percentage value to correct the walking.

[0028] In support of the teachings herein, various analysis components may be used, including a digital and/or an analog system. For example, the controller 11, the computer processing system 12, or the inclination sensor 13 may include digital and/or analog systems. The system may have components such as a processor, storage media, memory, input, output, communications link (wired, wireless, pulsed mud, optical or other), user interfaces, software programs, signal processors (digital or analog) and other such components (such as resistors, capacitors, inductors and others) to provide for operation and analyses of the apparatus and methods disclosed herein in any of several manners well-appreciated in the art. It is considered that these teachings may be, but need not be, implemented in conjunction with a set of computer executable instructions stored on a non-transitory computer readable medium, including memory (ROMs, RAMs), optical (CD-ROMs), or magnetic (disks, hard drives), or any other type that when executed causes a computer to implement the method of the present invention. These instructions may provide for equipment operation, control, data collection and analysis and other functions deemed relevant by a system designer, owner, user or other such personnel, in addition to the functions described in this disclosure.

[0029] Elements of the embodiments have been introduced with either the articles “a” or “an.” The articles are intended to mean that there are one or more of the elements. The terms “including” and “having” are intended to be inclusive such that there may be additional elements other than the elements listed. The conjunction “or” when used with a list of at least two terms is intended to mean any term or combination of terms.

[0030] While one or more embodiments have been shown and described, modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitation.

[0031] It will be recognized that the various components or technologies may provide certain necessary or beneficial functionality or features. Accordingly, these functions and features as may be needed in support of the appended claims and variations thereof, are recognized as being inherently included as a part of the teachings herein and a part of the invention disclosed.

[0032] While the invention has been described with reference to exemplary embodiments, it will be understood that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS:

1. An apparatus for drilling a borehole into an earth formation, the apparatus comprising:
 - a drill bit configured to be rotated to drill into the formation;
 - a drill tubular coupled to the drill bit and configured to rotate the drill bit;
 - a steering device coupled to the drill string and configured to impart a force on the drill string to control a direction of drilling; and
 - a controller configured to communicate a control signal to the steering device, the control signal comprising information for directing actuation of the steering device for steering the drill bit in an intended drilling direction;wherein the controller is further configured to direct the steering device to provide a compensating force on the drill string that prevents or reduces an azimuthal deviation from the intended drilling direction due to drill bit walking.
2. The apparatus according to claim 1, wherein the controller is further configured to receive drill bit walking data comprising a direction of deviation for the drill bit being used.
3. The apparatus according to claim 2, wherein the drill bit has fixed cutters and the direction of deviation is to the left with clockwise rotation in a frame of reference above the drill bit.
4. The apparatus according to claim 2, wherein the drill bit has cutters configured to rotate and the direction of deviation is to the right with clockwise rotation in a frame of reference above the drill bit.
5. The apparatus according to claim 2, wherein the steering device comprises a plurality of elements configured to extend and contact a borehole wall to impart a selected magnitude and direction of force on the drill string.
6. The apparatus according to claim 5, wherein a direction of the compensating force is opposite to the direction of the azimuthal deviation.
7. The apparatus according to claim 1, wherein the controller is further configured to receive an inclination direction and to provide inclination control inputs to the steering device to automatically maintain drilling in the inclination direction, the inclination control inputs having an amount of force to be applied to the drill string in the inclination direction.
8. The apparatus according to claim 7, wherein the controller is further configured to calculate the compensating force using the inclination control inputs.

9. The apparatus according to claim 8, wherein the drill bit walking factor comprises a percentage of the amount of force applied in the inclination direction that is to be applied by the steering device as a compensating force to prevent or reduce the azimuthal deviation.

10. The apparatus according to claim 1, wherein the drill string comprises a bottomhole assembly and the controller is disposed in the bottomhole assembly.

11. The apparatus according to claim 1, wherein the controller contains drill bit walking data for a plurality of types of drill bits.

12. The apparatus according to claim 1, wherein the controller comprises a lookup table configured to provide the compensating force using at least one of a type of the drill bit used and a force applied the drill string to maintain drilling at a selected inclination as input.

13. A method for drilling a borehole into an earth formation, the method comprising:

drilling into the formation with a drill bit being rotated by a drill tubular; and

communicating a control signal from a controller to a steering device coupled to the drill tubular, the control signal comprising information for directing actuation of the steering device for imparting a force on the drill string to control an intended direction of drilling;

wherein the control signal comprises instructions for the steering device to impart a compensating force on the drill tubular that prevents or reduces an azimuthal deviation from the intended drilling direction due to drill bit walking.

14. The method according to claim 13, further comprising looking up in a lookup table the compensating force to be applied by the steering device to the drill tubular, the lookup table correlating the compensating force to at least one of a type of the drill bit used and an inclination force applied the drill string to maintain drilling at a selected inclination.

15. The method according to claim 13, further comprising receiving drill bit walking data for the type of drill bit being used.

16. The method according to 15, wherein the drill bit walking data comprises:
a direction that the drill bit walks when a side force is applied to the drill bit during rotation of the drill bit; and

a percentage value which when multiplied times an inclination force applied to the drill bit results is a drill bit walking force that is perpendicular to the inclination force.

17. The method according to claim 16, further comprising:

receiving an inclination direction for drilling using the controller;

using the controller to automatically control the inclination direction during drilling by having the steering device impart an inclination force on the drill tubular in a direction that causes the drill bit to drill in the inclination direction; and

imparting a compensating force on the drill string having a direction opposite of the walking force and a magnitude that is the percentage value multiplied by the imparted inclination force.

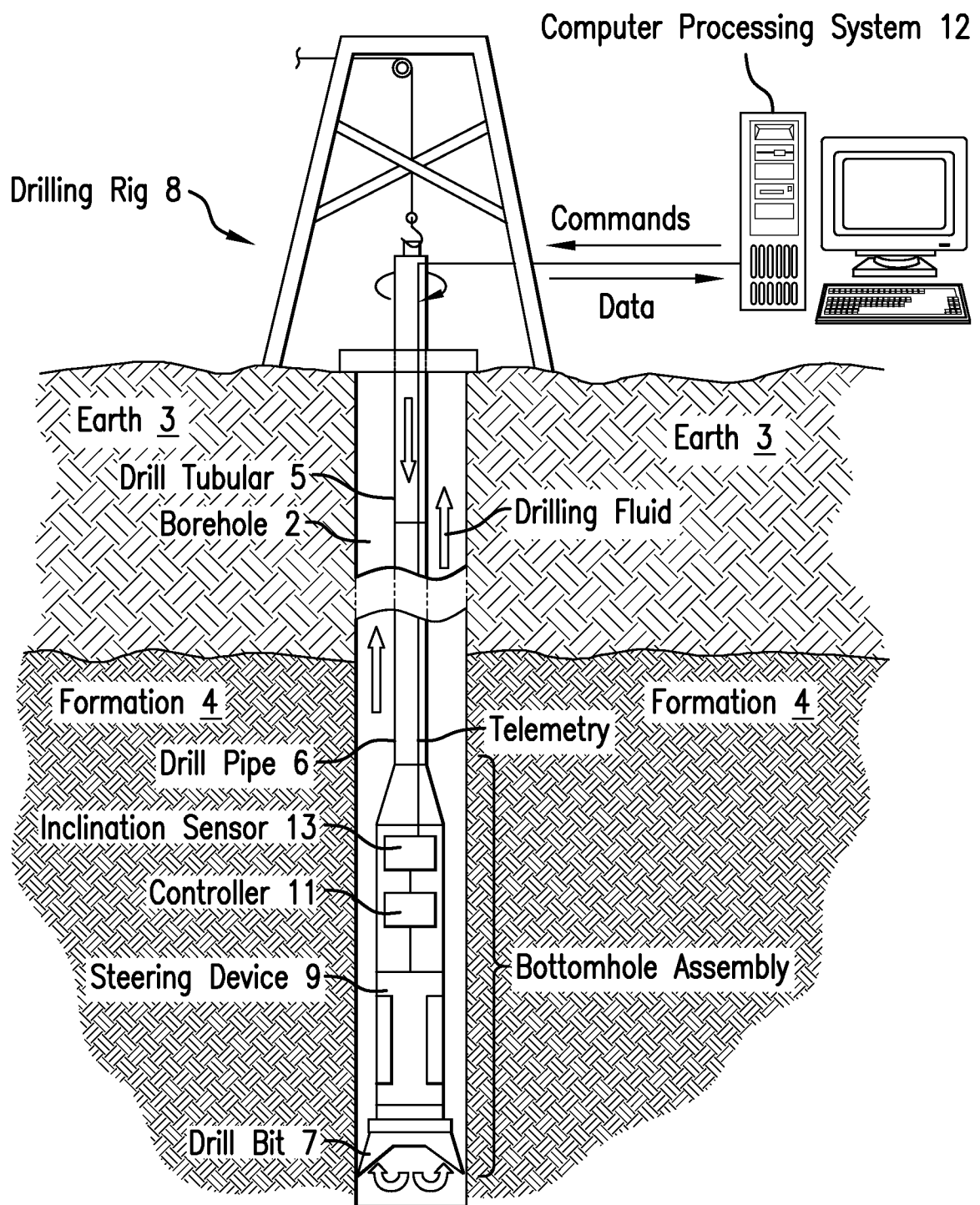


FIG. 1

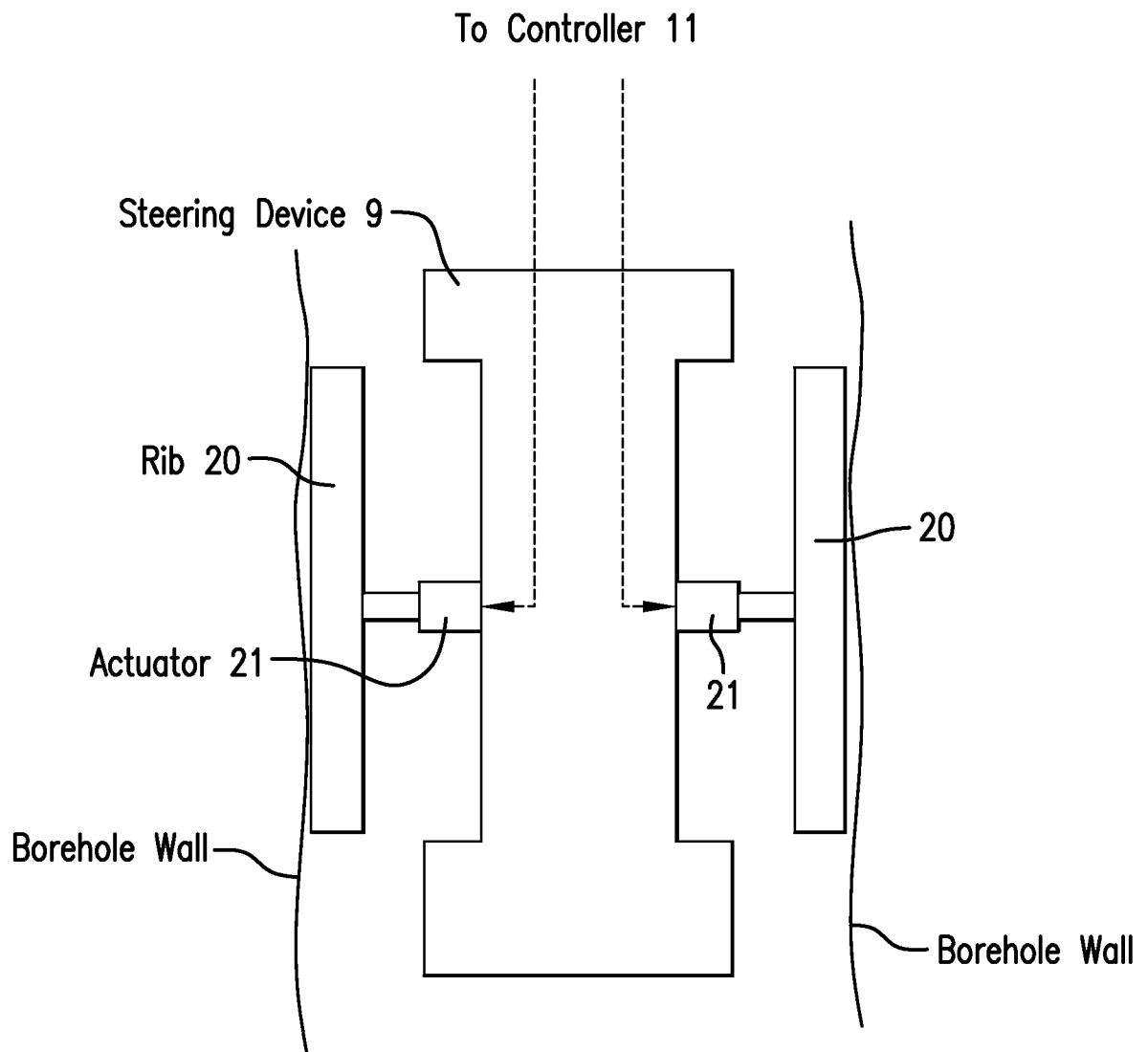


FIG.2

Drill Bit 7, 30

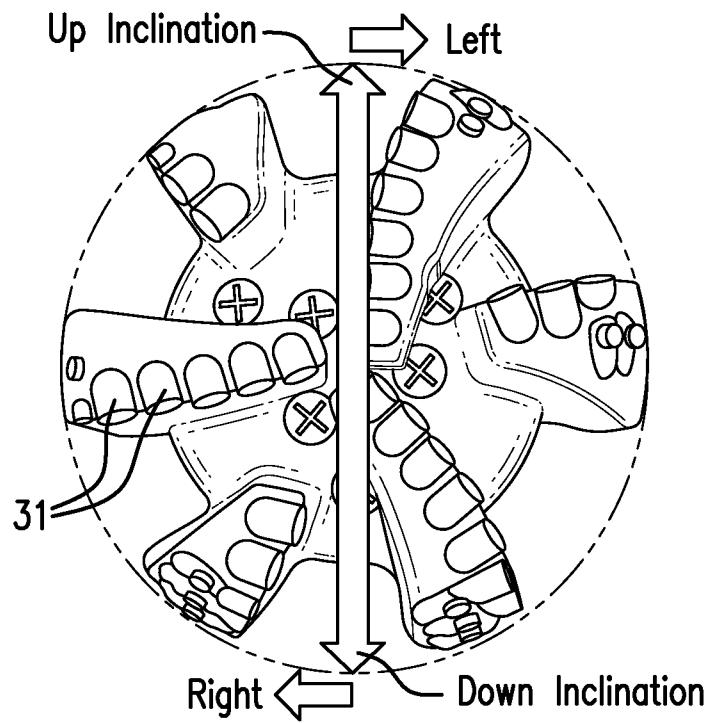


FIG. 3

Drill Bit 7, 40

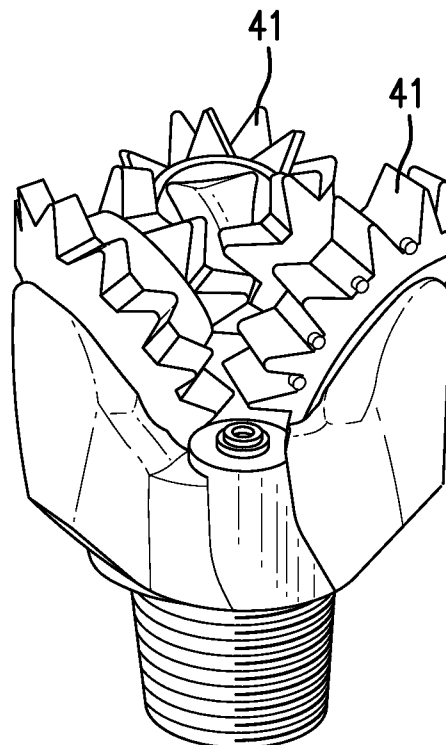


FIG. 4

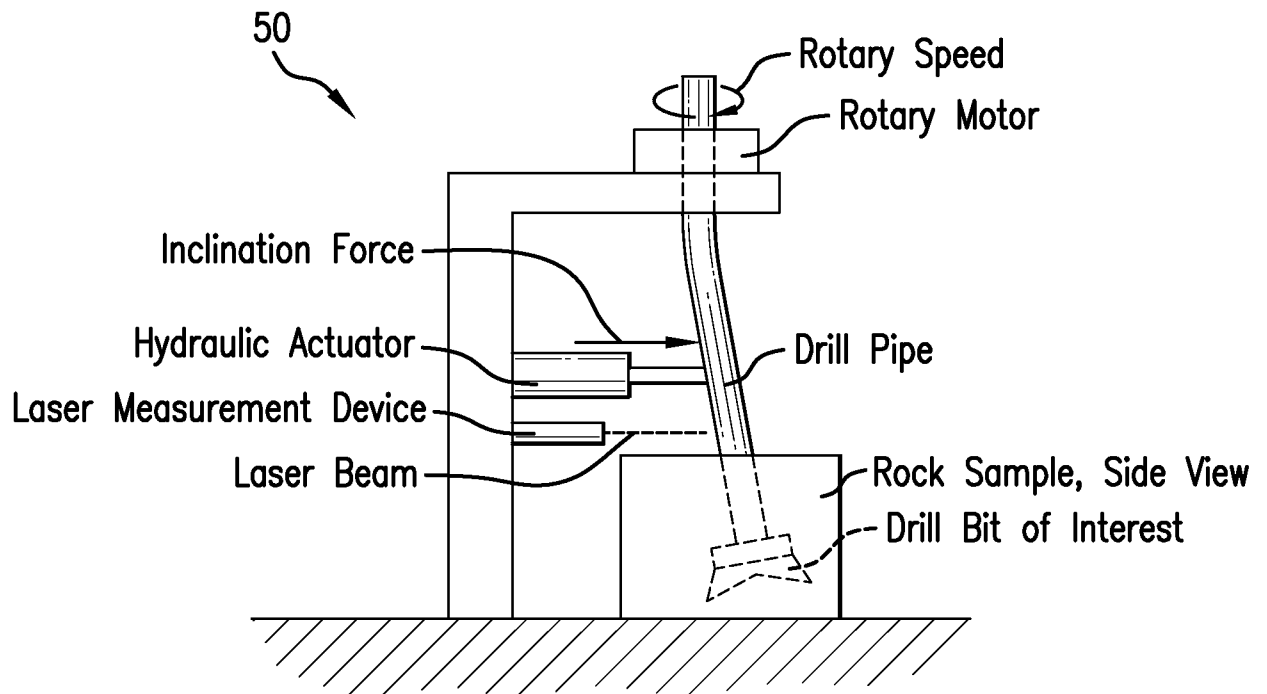


FIG. 5A

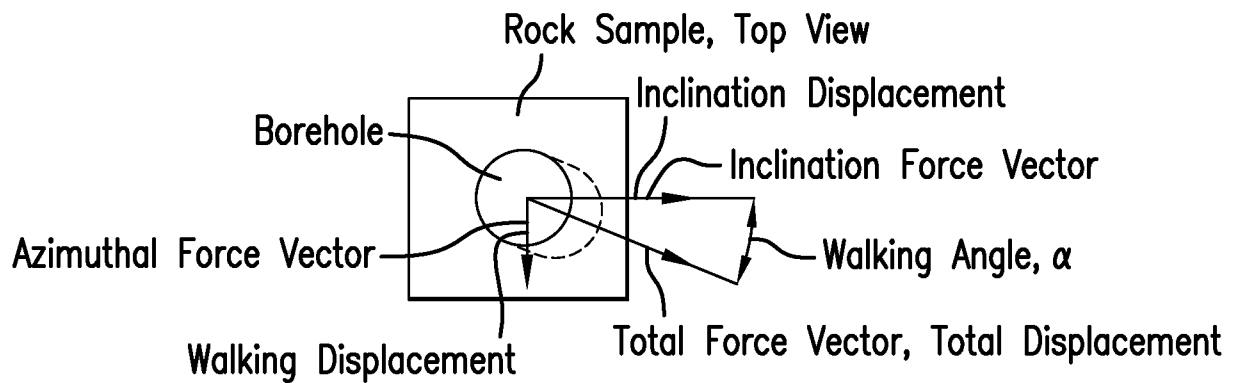


FIG. 5B

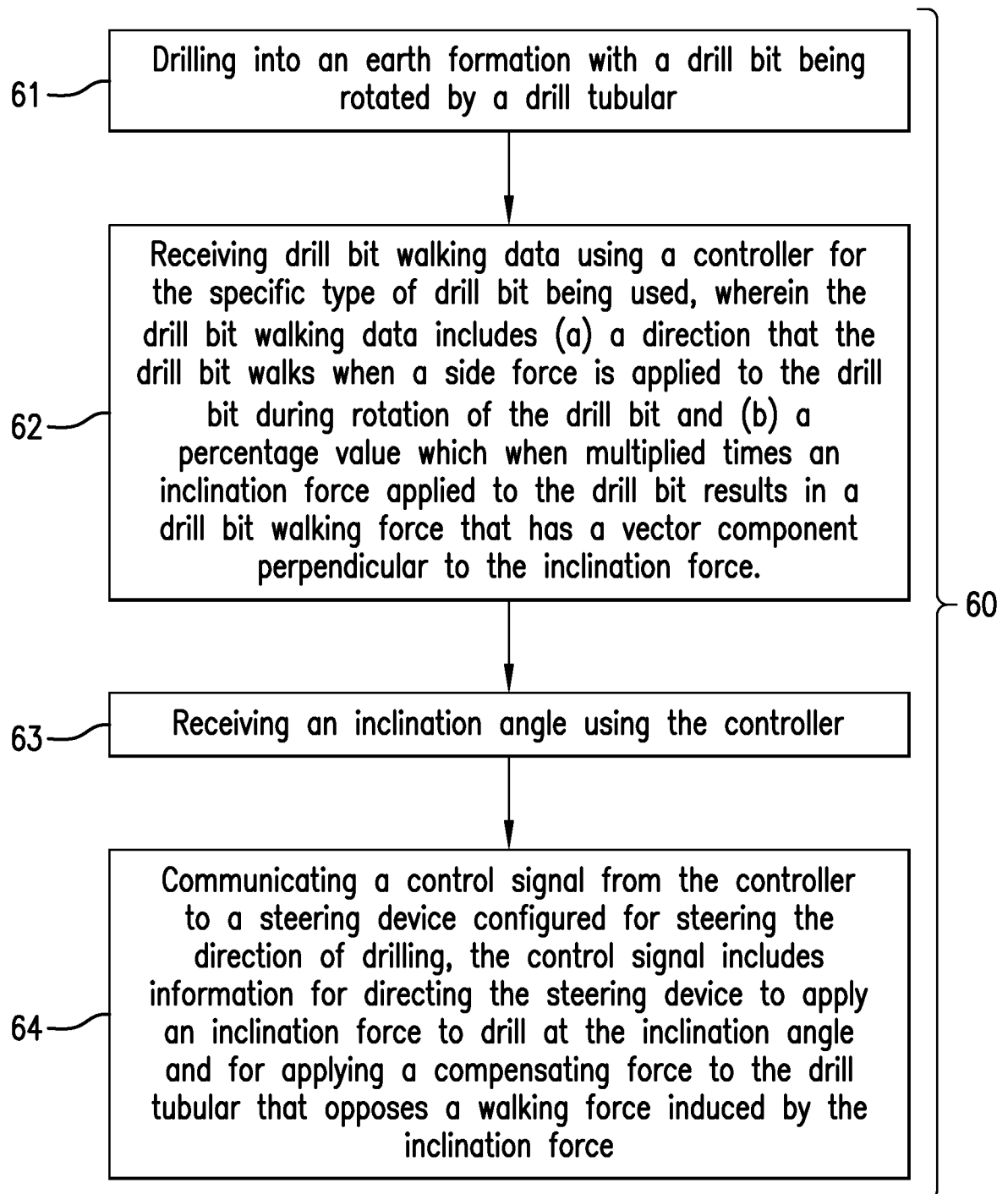


FIG.6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/037697**A. CLASSIFICATION OF SUBJECT MATTER****E21B 44/00(2006.01)i, E21B 7/04(2006.01)i**

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)

E21B 44/00; E21B 25/16; G06G 7/48; E21B 10/00; E21B 7/04; G01V 1/40; B21K 5/02

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: drill bit, drill tubular, steering device, controller, drill bit walking, inclination, and compensating force**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005-0150692 A1 (BALLANTYNE et al.) 14 July 2005 See abstract, paragraphs [0018]-[0020],[0027],[0036], and figures 1-3.	1-17
A	US 2007-0192074 A1 (CHEN, SHILIN) 16 August 2007 See abstract, paragraphs [0088]-[0089],[0137]-[0141], and figures 1A,4A-4C.	1-17
A	US 2008-0135292 A1 (SIHLER et al.) 12 June 2008 See abstract, paragraphs [0055]-[0057], and figures 1,6A-6B.	1-17
A	US 5608162 A (HO, HWA-SHAN) 04 March 1997 See abstract, column 5, line 51 - column 6, line 48, and figures 1-2.	1-17
A	US 2007-0240904 A1 (STAUFFER et al.) 18 October 2007 See abstract, claim 1, and figures 1-2.	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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"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

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Date of the actual completion of the international search

10 October 2014 (10.10.2014)

Date of mailing of the international search report

10 October 2014 (10.10.2014)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/037697

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005-0150692 A1	14/07/2005	GB 0609363 D0	21/06/2006
		GB 2423545 A	30/08/2006
		GB 2423545 B	28/03/2007
		US 7306056 B2	11/12/2007
		WO 2005-047644 A1	26/05/2005
US 2007-0192074 A1	16/08/2007	AU 2008-338627 A1	25/06/2009
		CA 2624106 A1	15/02/2007
		CA 2624106 C	09/07/2013
		CA 2625009 A1	15/02/2007
		CA 2625012 A1	15/02/2007
		CA 2684276 A1	30/10/2008
		CA 2704718 A1	20/11/2010
		CA 2706343 A1	25/06/2009
		EP 1929117 A1	11/06/2008
		EP 1931854 A1	18/06/2008
		EP 1931858 A1	18/06/2008
		EP 2149104 A1	03/02/2010
		EP 2240881 A1	20/10/2010
		EP 2258918 A2	08/12/2010
		EP 2264275 A2	22/12/2010
		EP 2281996 A2	09/02/2011
		GB 2443125 A	23/04/2008
		GB 2443126 A	23/04/2008
		GB 2443127 A	23/04/2008
		GB 2482850 A	15/02/2012
		GB 2482851 A	15/02/2012
		GB 2483022 A	22/02/2012
		MX 2009011178 A	11/12/2009
		US 2007-0029111 A1	08/02/2007
		US 2007-0029113 A1	08/02/2007
		US 2007-0032958 A1	08/02/2007
		US 2009-0090556 A1	09/04/2009
		US 2009-0229888 A1	17/09/2009
		US 2010-0300758 A1	02/12/2010
		US 2011-0015911 A1	20/01/2011
		US 2011-0077928 A1	31/03/2011
		US 7729895 B2	01/06/2010
		US 7778777 B2	17/08/2010
		US 7827014 B2	02/11/2010
		US 7860693 B2	28/12/2010
		US 7860696 B2	28/12/2010
		US 8145465 B2	27/03/2012
		US 8296115 B2	23/10/2012
		US 8352221 B2	08/01/2013
		WO 2007-019471 A1	15/02/2007
		WO 2007-019472 A1	15/02/2007
		WO 2007-019483 A1	15/02/2007
		WO 2008-130997 A1	30/10/2008

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/037697

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		WO 2009-079371 A1	25/06/2009
US 2008-0135292 A1	12/06/2008	CA 2613815 A1	07/06/2008
		CA 2613815 C	05/04/2011
		GB 0723863 D0	16/01/2008
		GB 2444642 A	11/06/2008
		GB 2444642 B	13/01/2010
		RU 2007145369 A	20/06/2009
		RU 2363844 C1	10/08/2009
		US 7610970 B2	03/11/2009
US 5608162 A	04/03/1997	EP 0728050 A1	28/08/1996
		EP 0728050 B1	26/09/2001
		US 5456141 A	10/10/1995
		WO 95-13152 A1	18/05/1995
US 2007-0240904 A1	18/10/2007	CA 2648192 A1	25/10/2007
		CN 101460701 A	17/06/2009
		EP 2007969 A1	31/12/2008
		RU 2008144801 A	20/05/2010
		US 7866413 B2	11/01/2011
		WO 2007-120786 A1	25/10/2007
		WO 2007-120786 B1	21/12/2007