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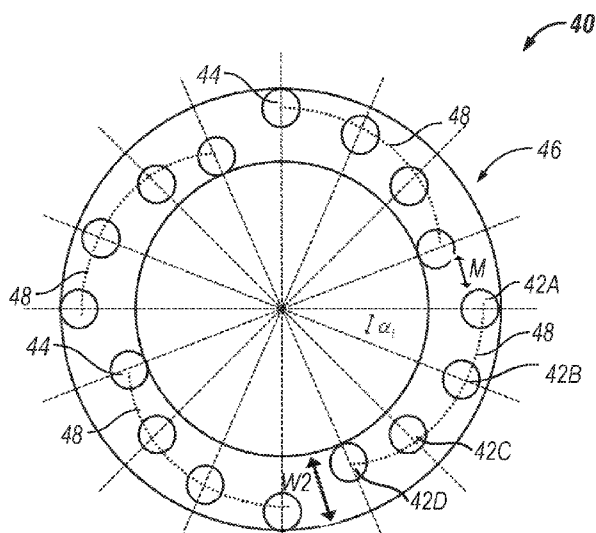


FIG. 4

(57) Abstract: A method for designing a drill bit includes assigning a score to cutting element arrangements that differ based on a design parameter, comparing the scores for different arrangements, and selecting the arrangement having the preferred or optimal score. The parameter may be, for example, the number of cutting elements in an array of cutting elements on a roller cone, the number of spiral sets in an array of a cutting elements, or the pitch between adjacent cutting elements in an array.

Determination of Spiral Sets

Cross-Reference to Related Applications

[0001] This application claims priority to U.S. Provisional Application No. 62/221,614, filed on September 21, 2015, which is incorporated by reference.

Background of Invention

Field of the Invention

[0002] The invention relates generally to drill bits for drilling boreholes in subsurface formations. More particularly, the invention relates to methods for designing drill bits, methods for evaluating cutting structures for drill bits, and methods for optimizing a spiral cutting arrangement for a drill bit. The invention also provides a novel method that can be used to calculate scores for spiral cutting arrangements proposed for drill bits.

Background Art

[0003] Figure 1 shows one example of a conventional drilling system used in the oil and gas industry for drilling wells in earth formations. The drilling system includes a drilling rig 10 used to turn a drill string 12 which extends downward into a well bore 14. Connected to the end of the drill string 12 is a drill bit 20. The drill bit 20 is designed to break up and gouge earth formations 16 when rotated on the formations 16 under an applied force. Formation 16 broken up by the drill bit 20 during drilling is removed from the well bore 14 by drilling fluid typically pumped through the drill string 12 and drill bit 10 and up the annulus between the drill string 12 and the well bore 14.

[0004] One example of a conventional drill bit is shown in Figure 2. This type of drill bit is typically referred to as a roller cone drill bit. The drill bit 20 includes a bit body 22 having a threaded section 24 at its upper end for securing to the drill string (12 in Figure 1) and a plurality of legs 25 extending downwardly at

its lower end. A frustro-conical rolling cone cutter (hereafter referred to as roller cone 26) is rotatably mounted on each leg 25 by a bearing shaft pin which extends downwardly and inwardly from each leg 25. Each of the roller cones 26 has a cutting structure comprising a plurality of cutting elements 28 arranged on the conical surface of the cones 26. The cutting elements 28 project from the cone body and act to break up earth formations at the bottom of the borehole when the bit 20 is rotated under an applied axial load. The cutting elements 28 may comprise teeth formed on the conical surface of the cone 26 (typically referred to as milled steel teeth) or inserts press-fitted into holes in the conical surface of the cone 26 (such as tungsten carbide inserts or polycrystalline diamond compacts).

[0005] Many prior art roller cone drill bits have been found to provide poor drilling performance due to problems such as “tracking” and “slipping.” Tracking occurs when cutting elements on a drill bit fall into previous impressions formed in the formation by cutting elements at a preceding moment in time during revolution of the drill bit. Slipping is related to tracking and occurs when cutting elements strike a portion of previous impressions and slides into the previous impressions.

[0006] In the case of roller cone drill bits, the cones of the bit typically do not exhibit true rolling during drilling due to action on the bottom of the borehole (hereafter referred to as “the bottomhole”), such as slipping. Because cutting elements do not cut effectively when they fall or slide into previous impressions made by other cutting elements, tracking and slipping should be avoided. In particular, tracking is inefficient since there is no fresh rock cut, and thus a waste of energy. Ideally every hit on a bottomhole cuts fresh rock. Additionally, slipping should also be avoided because it can result in uneven wear on the cutting elements which can result in premature failure. It has been found that tracking and slipping often occur due to a less than optimum spacing of cutting elements on the bit. In many cases, by making proper adjustments to the arrangement of cutting elements on a bit, problems such as tracking and slipping can be significantly reduced. This is especially true for cutting elements on a

drive row of a cone on a roller cone drill bit because the drive row is the row that generally governs the rotation speed of the cones.

[0007] Tracking and slipping may be partially addressed by arranging cutting elements into arrays, where inserts are positioned in three, four, or more different radial locations relative to the bit axis to produce a spiral or staggered arrangement. For an array, successive hits in the same general area of the bottomhole may be by inserts in different radial locations, enhancing bottomhole coverage and reducing the likelihood of an insert hitting exactly the same depression as the previous insert.

[0008] Currently, cutting arrangements, such as the arrangement of cutting elements on rows and arrays of a roller cone drill bit are designed either by gut feel, in reaction to field performance, such as the addition of odd pitches to alleviate tracking and slipping, or by trial and error in conjunction with other programs used to predict drilling performance. Use of staggered and spiraled arrays introduce additional design variables, which further complicates the design process and cutter-formation interactions. The problem in these design approaches is that the resulting arrangements are often arrived at somewhat arbitrarily, which can be time consuming in the evolution of the bit design and may or may not lead to drill bits producing desired drilling characteristics.

[0009] Therefore, methods for predicting drilling characteristics prior to the manufacturing of drill bits are desired to reduce costs associated with designing bits and to enhance the development of longer lasting bits and/or bits which more aggressively drill through earth formations. Methods are also desired to minimize or eliminate the design and manufacturing of ineffective drill bits which exhibit significant tracking or slipping problems during drilling. Methods are also desired to reduce the time required for designing effective drill bits. Additionally, drill bit designs that exhibit reduced tracking and slipping over prior art bit designs are also desired. Furthermore, designs with optimized spiral and staggered array arrangements are desired.

Summary of Invention

[0010] The invention generally relates to drill bits for drilling boreholes in earth formations. In one aspect, the invention provides methods for evaluating cutting arrangements for drill bits, methods for designing drill bits, and methods for optimizing a cutting arrangement for a drill bit. In another aspect, the invention provides new cutting arrangements for roller cone drill bits.

[0011] A method for evaluating a cutting arrangement for a drill bit includes selecting a cutting element arrangement for the drill bit including at least one array, calculating a first score for a first number of spiral sets within the array, calculating a second score for a second number of spiral sets within the array, comparing the first score to the second score; and selecting a number of spiral sets for the design based on the comparison, according to an embodiment of the invention.

[0012] In another embodiment of the invention, a method for designing a drill bit including an array having an optimized number of spiral sets, the method includes (a) selecting an arrangement of cutting elements for the drill bit, the arrangement comprising the array having a first number of spiral sets, (b) calculating a score for the arrangement, (c) adjusting the number of spiral sets, (d) repeating (b) through (c) until a desired score satisfying a selected criterion is obtained, and (e) designing the drill bit using the number of spiral sets having the desired score.

[0013] In another embodiment of the invention, a drill bit includes a roller cone including an array of a number of spiral sets, wherein the number of spiral sets is selected based on a desired performance score.

[0014] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

Brief Description of Drawings

[0015] Figure 1 shows a schematic diagram of one example of a system for drilling well bores in subterranean earth formations.

- [0016] Figure 2 shows a perspective view of a conventional roller cone drill bit.
- [0017] Figure 3A shows a partial cross sectional view of one leg of a roller cone drill bit with a roller cone mounted thereon.
- [0018] Figure 3B shows a rotated profile view of a spiral array cutting element arrangement.
- [0019] Figure 4 shows a schematic layout illustrating a spiral cutting element arrangement for a row on a roller cone of a drill bit.
- [0020] Figure 5 shows a schematic layout illustrating a bottomhole hit pattern made by a cutting element arrangement for a row of a roller cone of a drill bit during a number of revolutions of the bit.
- [0021] Figure 6 shows a schematic layout illustrating a preferred bottomhole hit pattern in comparison to the bottomhole hit pattern shown in Figure 5.
- [0022] Figure 7 shows a flow chart of a method in accordance with one embodiment of the invention that may be used to evaluate a quality of a spiral cutting arrangement for a drill bit.
- [0023] Figure 8 shows a flow chart of a method in accordance with one embodiment of the invention that may be used to evaluate a quality of a cutting arrangement for a drill bit.
- [0024] Figure 9A shows a flow chart of a method in accordance with one embodiment of the invention that may be used to select an optimal number of inserts for a spiral array cutting element arrangement of a roller cone of a drill bit.
- [0025] Figure 9B shows a flow chart of a method in accordance with one embodiment of the invention that may be used to select an optimal number of spiral sets for a spiral cutting element arrangement in an array of a roller cone of a drill bit.

[0026] Figure 10 shows one example of a plurality of score curves, each generated for a different spiral cutting element arrangement for an array of a roller cone drill bit.

[0027] Figure 11 shows a flow chart of a method in accordance with one embodiment of the invention that may be used to select optimal pitches, or angular spacings, between adjacent cutting elements in a spiral array arrangement of a roller cone of a drill bit.

[0028] Figure 12 shows one example of a pitch pattern for a row of a roller cone drill bit in accordance with an aspect of the present invention.

Detailed Description

[0029] The present invention relates to drill bits for drilling bore holes through earth formations. More particularly, the present invention provides a method for scoring a drill bit, a method for evaluating a spiral cutting arrangement for a drill bit, a method for designing a drill bit including a spiral array, and a method for selecting the optimal number of spiral sets in an array within a cutting arrangement for a drill bit. In another aspect, the invention provides an improved spiral cutting arrangement for a roller cone drill bit.

[0030] A flow chart showing one example of a method for scoring a drill bit in accordance with the present invention is shown in Figure 7. This method may also be adapted and used to evaluate a cutting arrangement for a drill bit or to optimize a cutting arrangement on a drill bit. The method includes selecting a cutting arrangement for a drill bit including at least one array of cutting elements 101 and determining at least one characteristic representative of drilling for the array of cutters on the drill bit 103. The method also includes selecting a criterion for evaluating the at least one characteristic 105, and calculating a score for the arrangement based on the at least one characteristic and the criterion 107.

[0031] In one or more embodiments, the method may additionally include adjusting at least one parameter of the cutting arrangement, repeating the determining of the at least one characteristic, but this time for the adjusted

arrangement, and calculating a score for the adjusted arrangement. Cutting arrangement parameters may include, for example, the total number of inserts in an array, the number of spiral sets in an array, and the pitch (axial spacing) between each individual insert. These additional steps can be repeated a selected number of times to obtain a plurality of scores corresponding to a plurality of different arrangements. A preferred arrangement for the drill bit can then be selected from the plurality of different arrangements based on a comparison of the scores for the different arrangements. Preferably, the arrangement having the most favorable score or a combination of a favorable score and more favorable additional characteristics (i.e., more favorable arrangement characteristics, more favorable drilling characteristics, etc.) is selected as the arrangement for the drill bit. More favorable arrangement characteristics may include things such as a more preferable number of spiral sets in an array. More favorable drilling characteristics may include a higher rate of penetration, a more stable dynamic response during drilling, etc.

[0032] Examples related to this aspect of the invention are further developed below. In the examples below, the selected characteristic representative of drilling is the bottomhole pattern produced by the selected cutting arrangement. The selected criterion for evaluating the cutting element arrangement is a preferred bottomhole pattern. Those skilled in the art will appreciate that in view of the above description and the examples below, other characteristics and criterion may be selected and used for other embodiments of the invention. For example, the selected criterion may be a preferred value for a drilling parameter, such as a preferred rate of penetration, weight on bit, axial force response, lateral vibration response, or other characteristic representative of drilling that can be adjusted or altered by altering a parameter of a spiral cutting arrangement. Other parameters may include, for example, the radial width of the array, the spacing between spiral sets, the spacing within spiral sets, the spacing between radial locations of a spiral array, etc.

[0033] For one or more embodiments of the invention, methods, such as the methods disclosed in U.S. Patent No. 6,516,293 and U.S. Application No.

09/689,299, which are assigned to the assignee of the present invention and incorporated herein by reference, may be used in determining the characteristic representative of drilling for the drill bit, or a drilling tool assembly including the drill bit, having the selected cutting arrangement. In addition, for one or more embodiments of the invention, methods such as those disclosed in U.S. Patent No. 7,234,549 and U.S. Patent No. 7,292,967, which are assigned to the assignee of the present invention and incorporated herein by reference, may be used in calculating a score for a cutting arrangement.

[0034] The examples developed in detail below are described with reference to a roller cone drill bit, similar to the one shown in Figure 2. However, those skilled in the art will appreciate that in view of this disclosure, similar methods may be developed for fixed cutter bits, which do not depart from the spirit of the invention.

[0035] Referring to Figure 2, the roller cone drill bit 20 includes a bit body 22 having a plurality of legs 25 that extend from one end. Rotatably mounted on each leg is a roller cone 26 having a plurality of cutting elements 28 disposed thereon for cutting through earth formations as the cone 26 is rotated along a bottomhole of a well bore.

[0036] A partial cross section view of one leg of a roller cone drill bit is shown in Figure 3A. The leg 32 extends downward from the main portion of the bit body 22 and includes a bearing shaft pin 34 which extends downward and inwardly with respect to the bit body 22. The roller cone 36 is rotatably mounted on the bearing shaft pin 34. Roller cone 36 includes a nose 37 and a heel 35. The cutting elements 38 disposed on the conical surface of the cone 36 may be arranged in rows or arrays 38A-C that are axially spaced apart with respect to the cone axis 39. Typically each of the rows or arrays of cutting elements 38 on one cone are axially offset from rows or arrays of cutting elements arranged on the other cones (not shown) to provide an intermeshing of cutting elements between the cones. Intermeshing cutting element arrangements are desired to permit high insert protrusion to achieve competitive rates of penetration while

preserving the longevity of the bit. Though three rows/arrays 38A-C are illustrated in Figure 3A, cutting arrangements may include any number of rows and arrays of cutting elements. For example, a single array may span the entire cone from nose 37 to heel 35.

[0037] A row of cutting elements includes a number of elements each having the same radial location, but located at different circumferential positions relative to one another. A spiral array of cutting elements includes elements located at a number of different radial locations within the radial width of the array, and at different circumferential positions relative to one another. An array may include fewer radial locations than the number of cutting elements in the array, in which case the cutting elements are arranged into spiral sets, or the array may include a different radial location for each cutting element in the array (i.e., one spiral set). The radial locations in a spiral set generally result in overlapping cutting element profiles, when viewed in a rotated projection.

[0038] Figure 3B illustrates a rotated profile view of the array of cutting elements 38B. Each cutting element 38 of array 38B is disposed at a different radial location, which is the distance from the bit axis 11, measured along a line perpendicular to the bit axis to the point at which the cutter axis 90 intersects the tip of the cutting element. For purposes of illustration, cutting elements in array 38B are labelled 38B-1 through 38B-14, with the understanding that 38B-2 through 38B-10 have been omitted for clarity. Cutting elements 38B-1 through 38B-14 are disposed on a generally frustoconical-shaped region or band 48c which encircles the cone 36, and is located between rows 38A and 38C (shown in Figure 3A). In this embodiment, cutting element 38B-1 is located in the radial location within array 38B that is closest to the nose 37 of the cone, while 38B-14 is positioned in the radial location closest to the heel 35 of the cone. This array 38B of cutting elements, where a series of adjacent elements are positioned progressively further (or closer) to the bit axis, is generally described herein as a spiral arrangement or spiral array.

[0039] The cutter element axis 90 of each of the cutter elements 38B-1 through 38B-14 is spaced a uniform distance D from the element axis of the immediately adjacent cutter elements across the width W of the array 38B. In another embodiment, the distance between adjacent cutting elements, or adjacent radial locations, is not uniform across the width W of the array. The overlapping and relatively close positioning, in rotated profile, of the cutter elements 38 in array 38B prevent ridges from forming on the bottomhole surface.

[0040] For one or more embodiments of the invention, spiral and staggered cutter arrangements, such as those disclosed in U.S. Patent No. 7,370,711 and U.S. Patent No. 7,686,104, which are assigned to the assignee of the present invention and incorporated herein by reference, may be used in association with the instant invention.

[0041] In general, cutting element arrangements for drill bits can be generally defined by the location of each cutting element in the arrangement. The location of each cutting element may be expressed with respect to a bit coordinate system or a cone coordinate system, depending on the type of drill bit being considered. In some cases, such as for drill bits having cutting elements generally arranged in rows and arrays, the cutting element arrangements may be even more simply defined by the “pitch” (or spacing) between cutting elements in a row on the face of a roller cone or bit body and the radial location of the row on the cone or bit (as described above).

[0042] Those skilled in the art will appreciate that, for clarity, simplified examples are presented herein and described below. In these examples, the cutting elements are described as generally arranged in one or more spiral sets. It should be understood that the invention is not limited to these simplified arrangements. Rather, other embodiments of the invention may be adapted and used for other arrangements, such as staggered arrays, or any array-based arrangement including a number of different radial locations within a radial width of a cone, or an array encompassing the entire cone.

[0043] Referring to Figure 4, one example of a cutting element arrangement 40 proposed for an array 46 of a roller cone of a roller cone drill bit is shown. The arrangement includes sixteen cutting elements 44. In this case, cutting elements 44 are spaced apart and arranged in four spiral sets 48 about the conical surface of the roller cone. The amount of spacing between each pair of adjacent cutting elements 44 is defined in terms of a pitch angle, α_i . This type of spacing arrangement for a row of cutting elements on a roller cone of a roller cone drill bit is often referred to as a “spacing pattern” or a “pitch pattern” for a row.

[0044] Each spiral set 48 includes four radial locations 42A-D, spread out evenly over the width W of array 46. Array 46 has a median radial location M and a width W2, which, among other bit design factors, may affect how many inserts may be included in the array. Median radial location M may be, in an embodiment, half of the distance between the innermost radial location in the array 46 and the outermost radial location in the array 46. While four spiral sets 48 of four cutting elements 44 are shown, other cutting arrangements for an array having the same dimensions as array 46 may include a different number of spiral sets or a different number of total inserts in the array. For example, two spiral sets of eight cutting elements, or one spiral set of sixteen. Another possible arrangement may include three spiral sets of five each. Yet another arrangement may include three spiral sets where two sets each include five cutting elements and one set includes six elements. In general, the number of spiral sets in an array can vary from a single set to the total number of inserts in the entire array divided over three or more radial locations.

[0045] One example of a pattern of impressions made on a hole bottom by cutting elements in a array on a roller cone of a roller cone drill bit (such as array 46 in Figure 4) is shown in Figure 5. In this example, each impression made by a cutting element that contacted the bottomhole during the rotation of the bit is referred to as a “hit.” Although the actual impression made by a cutting element on a roller cone drill bit is more of an area of scrape and impact often resulting in the formation of a crater, in the example shown and discussed below, each

impression will be simply represented by a hit centered on a point located on the line shown in Figure 5. The location of each hit on the bottomhole will be referred to as a “bottomhole hit location.” The collection of hits made on the bottomhole during a selected number of revolutions of the bit will be referred to as a “bottomhole hit pattern.”

[0046] The bottomhole hit pattern 52 shown in Figure 5 includes a number of hits 54 made on the bottomhole 56 by all or a subset of the cutting elements in one array on a roller cone of a roller cone drill bit (not shown) during a selected number of revolutions of the bit on the bottomhole 56. Most of the hits 54 in this example occurred in close proximity to other hits made which resulted in a bottomhole hit pattern 52 with wide gaps 58 of uncut formation separating clustered hits on the bottomhole 56.

[0047] The bottomhole hit pattern shown in Figure 5 is typically considered undesirable because the hits occur in close proximity to previous hits with wide gaps of uncut formation remaining. This type of pattern typically signifies a high likelihood of tracking and slipping during drilling. This bottomhole hit pattern may also indicate a poor use of hits when the crater sizes corresponding to each hit are larger than the distances between the hits.

[0048] To minimize a potential for tracking and slipping and/or to improve a cutting efficiency of a cutting arrangement, an arrangement may be desired that results in a more even distribution of hits on the bottomhole during a selected number of revolutions of the drill bit. For example, a bottomhole hit pattern 62 as shown in Figure 6 may be considered more preferable than the bottomhole hit pattern shown in Figure 5 because this bottomhole hit pattern 62 includes a plurality of hits 64 that are substantially evenly spaced about the section of the bottomhole 66 cut by the cutting arrangement.

[0049] Referring to Figure 8, in accordance with the aspect of the invention show in Figure 7, in one or more embodiments, a method for evaluating a cutting arrangement for a drill bit includes: selecting a design for a drill bit having a cutting arrangement including a spiral array 201; selecting a number of spiral

sets for the array 203, determining a bottomhole hit pattern for the array including the selected number of spiral sets 205; and calculating a score for the arrangement 207. For example, the score may be calculated by comparing the bottomhole hit pattern (such as that shown in Figure 5) to a desired bottomhole hit pattern (such as that shown in Figure 6). In this embodiment, determining the characteristic representative of drilling (103 in Figure 7) can be carried out by numerically calculating (generating) a bottomhole hit pattern, and the criterion selected for evaluating this characteristic (105 in Figure 7) is the percentage of bottomhole coverage. As such, the score for the arrangement is calculated based on a comparison of the bottomhole hit pattern (such as that shown in Figure 5) to a preferred hit pattern (such as that shown in Figure 6). In an embodiment, a bottomhole hit pattern similar to the preferred bottomhole hit pattern indicates increased bottomhole coverage as compared to a bottomhole hit pattern that is less similar to the preferred hit pattern.

[0050] In one embodiment, the bottomhole pattern may be determined based on the hits for each individual cutting element in the array. In another embodiment, a single radial location is selected so that one insert from each spiral set is modeled as a representation of the entire spiral set.

[0051] The score calculated in Figure 8 may be used to determine the preferred total number of cutting elements in an array (Figure 9A), and/or the number of spiral sets in a cutting element array of a bit design (Figure 9B). These examples are simplified examples specifically configured for selecting the number of cutting elements and the number of spiral sets of cutting elements to be used in a particular array portion of a cutting arrangement on a roller cone of a roller cone drill bit. Referring to Figure 9A, a score may be calculated for each of a range of a total number of cutting elements in an array over a range of cone to bit rotation ratios 301. Each of scores calculated for each number of cutting elements may be compared 303. Then, the number of cutting elements having the score closest to a desired score may be selected for a bit design 305. While it may seem logical that an maximum possible number of cutting elements in an array would increase bottom hole coverage and drilling efficiency, the inventors

have noted that – in some embodiments – if loads are sufficiently balanced across cutting elements, a number of cutting elements less than the maximum possible for the dimensions of an array may lead to higher bit ROP, as the balanced loads are concentrated on fewer cutting elements, resulting in an overall more aggressive cutting structure.

[0052] Once the total number of cutting elements has been determined via the method in Figure 9A – or selected via some other method, the cutting elements may be arranged into an optimal number of spiral sets. Referring to Figure 9B scores may be calculated over a range of cone to bit rotation ratios (or cone to bit speed ratios) for a range of spiral set numbers 307. The scores for different numbers of spiral sets may be compared at a target cone to bit rotation ratio 303. An optimal, or preferred, number of spiral sets may then be selected based on the comparison of the different scores for each potential number of spiral sets in the array 305. It is to be understood that each of the methods illustrated in Figures 9A and 9B may be used either independently or together for a particular bit design.

[0053] Figure 10 illustrates a plot of cutter pattern scores over a range of cone to bit rotation ratios, according to an embodiment of the invention. Scores are plotted for arrays including N-1 spiral sets 403, N spiral sets 401, and N+1 spiral sets 405. The target cone to bit rotation ratio 407, along as the minimum ratio 409 and maximum ratio 411 are also indicated. One of ordinary skill in the art will understand the range of cone to bit rotation ratios illustrated in Figure 10 to be only illustrative; target ratio 407, minimum ratio 409, and maximum ratio 411 may have different values from those illustrated, and will depend on the particulars of the bit design. Several approaches may be used to select a number of spiral sets for an array based on a pattern score. The set number having the highest score at the target cone to bit rotation ratio may be selected. In this case, N+1 spiral sets 405 has the highest score 413 at the target cone to bit rotation ratio 407, while N spiral sets 401 and N-1 spiral sets have the lowest score 415. The number of spiral sets may also be selected based on the maximum score over the range of cone to bit rotation ratios from the minimum ratio 409 to the

maximum ratio 411. This may be determined by identifying the score curve having the maximum area under the curve – in this case, N spiral sets 401. In addition, the number of spiral sets may be selected based on the shape or trend of the curve. For example, while N+1 spiral sets 405 has a higher score at the target cone to bit rotation ratio 407, the score falls off steeply in both directions toward minimum ratio 409 and maximum ratio 411, while N spiral sets 401 generally increase in the direction of minimum ratio 409 and maximum ratio 411. In cases where the cone to bit rotation ratio may be expected to vary within minimum ratio 409 and maximum ratio 411, spiral set N may be selected due to the increased scores within the ratio range. However, if the variance is expected to be tighter around the target cone to bit speed ratio for a particular design or application, then N+1 spiral sets may be selected.

[0054] Once the total number of cutting elements and the number of spiral sets have been determined via the methods in Figures 9A – 9B – or selected via some other method, the pitch pattern of the cutting elements may be adjusted to further improve the performance score of a design. Referring to Figure 11, a score may be calculated over a range of cone to bit rotation ratios for a pitch pattern having an equal pitch between cutting elements 501. An example of such an equal pitch is shown in Figure 4, according to an embodiment. A score is calculated for a pitch pattern having non-uniform spacing 503. An example of a pitch pattern including non-uniform, or unequal pitch spacing is shown in Figure 12, according to an embodiment of the invention. The scores for the different pitch patterns may be compared 505. An optimal, or preferred, pitch pattern may then be selected based on the comparison of the different scores for each potential pitch pattern for the array 507. It is to be understood that each of the methods illustrated in Figures 9A, Figure 9B, and Figure 11 may be used either independently or together for a particular bit design. Referring to Figure 12, one example of a cutting element arrangement 80 proposed for an array 86 of a roller cone of a roller cone drill bit is shown. The arrangement includes sixteen cutting elements 88. In this case, cutting elements 88 are spaced apart and arranged in four spiral sets 84 about the conical surface of the roller cone. According to an

embodiment of the invention, cutting element arrangement 80 includes two different pitch angles, α_1 and α_2 . In this case, α_1 is less than α_2 . In an embodiment, the larger α_2 angles are oriented on one half of the cutting element arrangement, while the smaller α_1 angles are oriented on the opposing half of the arrangement. Introducing such incongruence into a pitch pattern may help improve a performance score by reducing tracking over a target range of cone to bit rotation ratio. Additional details of optimizing pitch in a cutting element arrangement based on a performance score are further described in U.S. Patent No. 7,234,549, incorporated by reference.

[0055] Certain bit designs may incorporate more than one array on a single cone, and across all of the multiple cones. In such cases, each row may be analyzed separately in order to select the preferred number of spiral sets. In another embodiment, the entire cone or bit may be analyzed as a whole in order to determine the appropriate number of spiral sets for each array in the design.

[0056] The calculations in this example may be performed by a computer program, such as a C-program or a program developed using Microsoft® Excel®. Alternatively, these steps may be carried out manually and/or experimentally as determined by a system or bit designer.

[0057] Advantageously embodiments in accordance with this aspect of the invention provide a roller cone drill bit having a cutting arrangement that breaks up the pattern laid down by a previous revolution of the bit. By selecting an appropriate number of spiral sets, the probability of tracking for a given array may be reduced, and the bottomhole coverage of the array and of the bit may be increased. The desired degree of tracking and bottomhole coverage may be selected to optimize ROP for a given bit design, drilling conditions, rock formations, etc.

[0058] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the

scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

Claims

What is claimed is:

- 1) A method for evaluating a design for a drill bit, comprising:
selecting an arrangement of cutting elements on the drill bit including a first array
of a plurality of cutting elements;
calculating a first score for a first number of spiral sets within the first array;
calculating a second score for a second number of spiral sets within the first
array;
comparing the first score to the second score; and
selecting a number of spiral sets for the design based on the comparison.
- 2) The method of claim 1, wherein each spiral set includes a plurality of cutting
elements.
- 3) The method of claim 1, wherein the first array is located on a first rolling cone.
- 4) The method of claim 3, further comprising:
selecting a second arrangement of cutting elements including a second array of
cutting elements;
calculating a third score for a third number of spiral sets within the second array;
calculating a fourth score for a fourth number of spiral sets within the second
array;
comparing the third score to the fourth score; and
selecting a second number of spiral sets for the design based on the comparison.
- 5) The method of claim 4, wherein the second array is located on a second rolling
cone.
- 6) The method of claim 4, wherein the second array is located on the first rolling
cone.

- 7) The method of claim 1, wherein the score is selected from the group consisting of: representative of rate of penetration, weight on bit, axial force response, and lateral vibration response.
- 8) The method of claim 1, wherein each of the first score and the second score is calculated over a range of cone to bit rotation ratios, and wherein the comparison of the first score and second score comprises comparing values over the range of cone to bit rotation ratios.
- 9) A drill bit designed according to the method in claim 1.
- 10) A method for creating a drill bit design including an array of cutting elements having an optimized number of spiral sets, the method comprising:
 - (a) selecting an arrangement of cutting elements for the drill bit, the arrangement comprising the array having a first number of spiral sets;
 - (b) calculating a score for the arrangement;
 - (c) adjusting the number of spiral sets;
 - (d) repeating (b) through (c) until a the score satisfies a performance criterion; and
 - (e) designing the drill bit using the number of spiral sets having the score satisfying the performance criterion.
- 11) The method of claim 10, wherein the performance criterion is selected from the group consisting of: representative of rate of penetration, weight on bit, axial force response, and lateral vibration response.
- 12) The method of claim 10, wherein the array is located on a rolling cone.
- 13) The method of claim 10, wherein the score is calculated over a range of cone to bit rotation ratios.
- 14) The method of claim 13, wherein the performance criterion includes a minimum score over the range of cone to bit rotation ratios.
- 15) A drill bit designed according to the method in claim 10.

- 16) A drill bit, comprising: a roller cone including an array of cutting elements, wherein the cutting elements are arranged into a plurality of spiral sets.
- 17) The drill bit of claim 16, wherein the number of spiral sets is selected based on a desired performance score.
- 18) The drill bit of claim 17, wherein the performance score is selected from the group consisting of: representative of rate of penetration, weight on bit, axial force response, and lateral vibration response.
- 19) The drill bit of claim 16, further comprising a second array having a second number of spiral sets.
- 20) The drill bit of claim 16, wherein the second array is located on a second roller cone.

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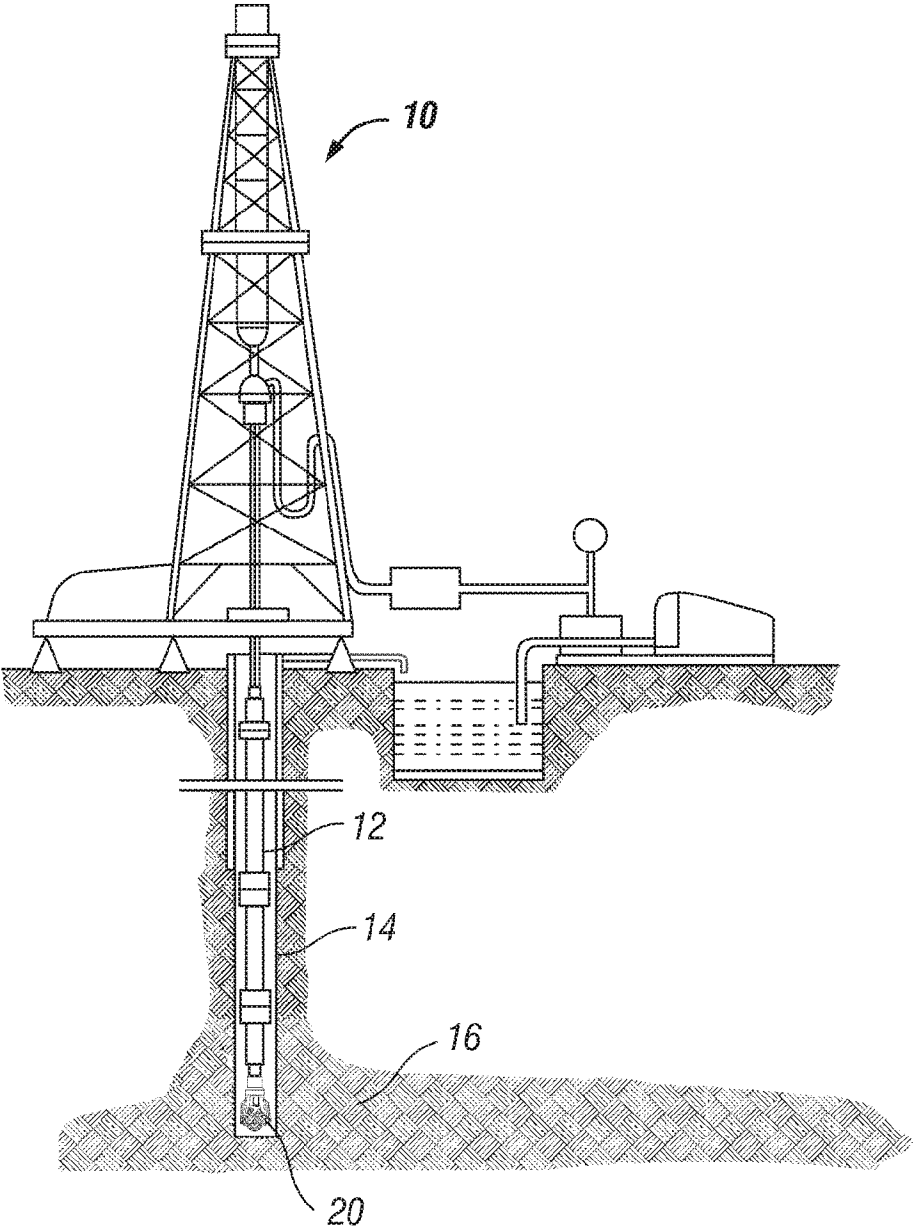


FIG. 1
(Prior Art)

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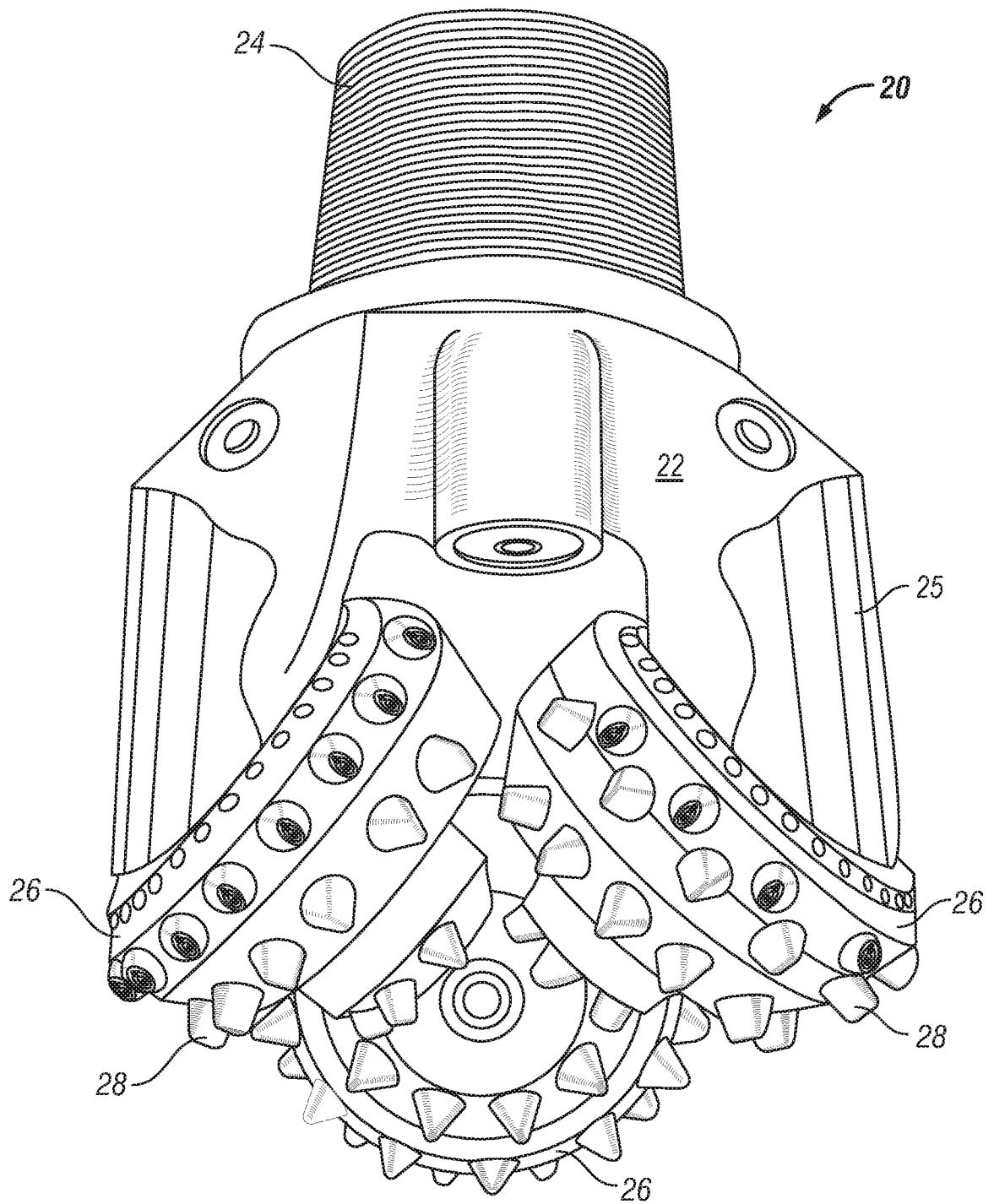


FIG. 2
(Prior Art)

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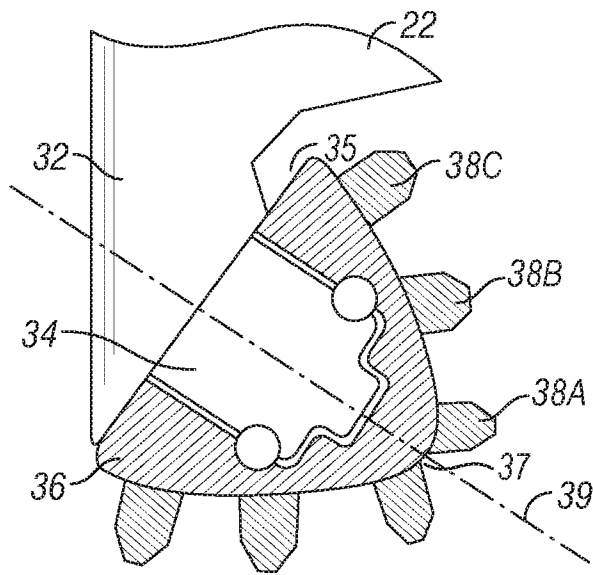


FIG. 3A

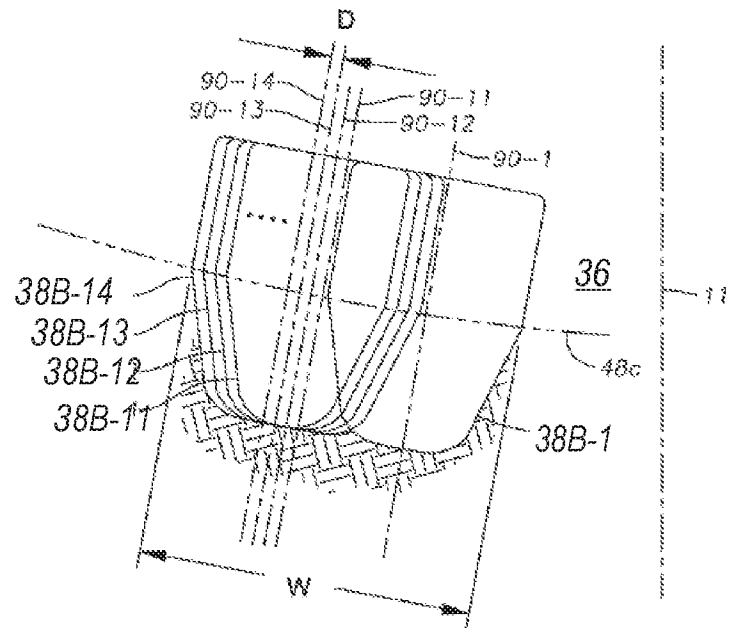


FIG. 3B

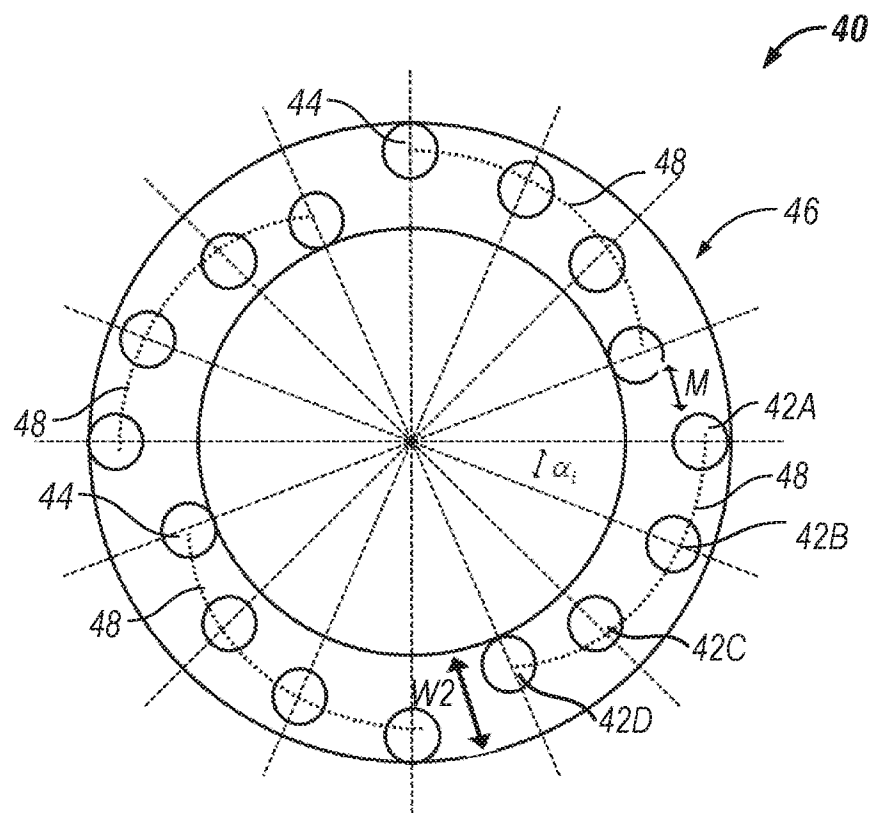
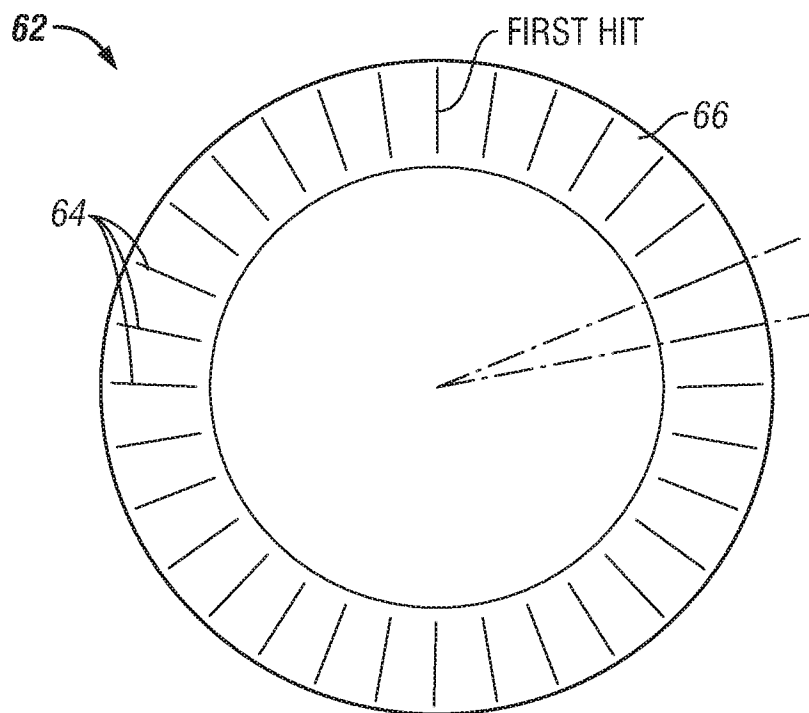
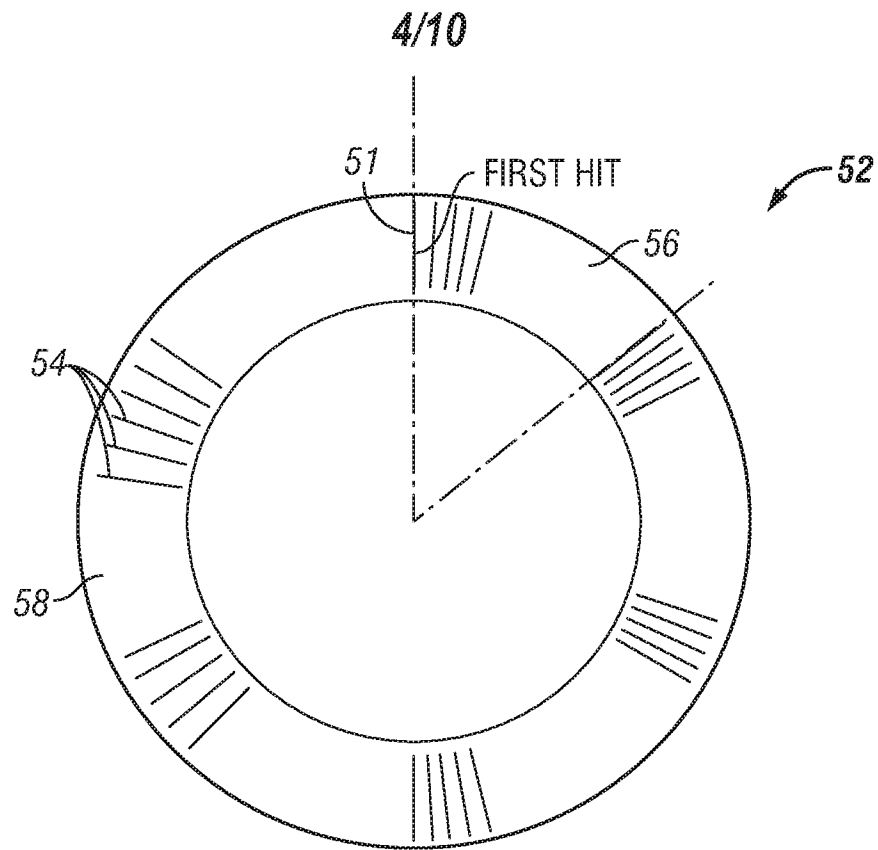


FIG. 4



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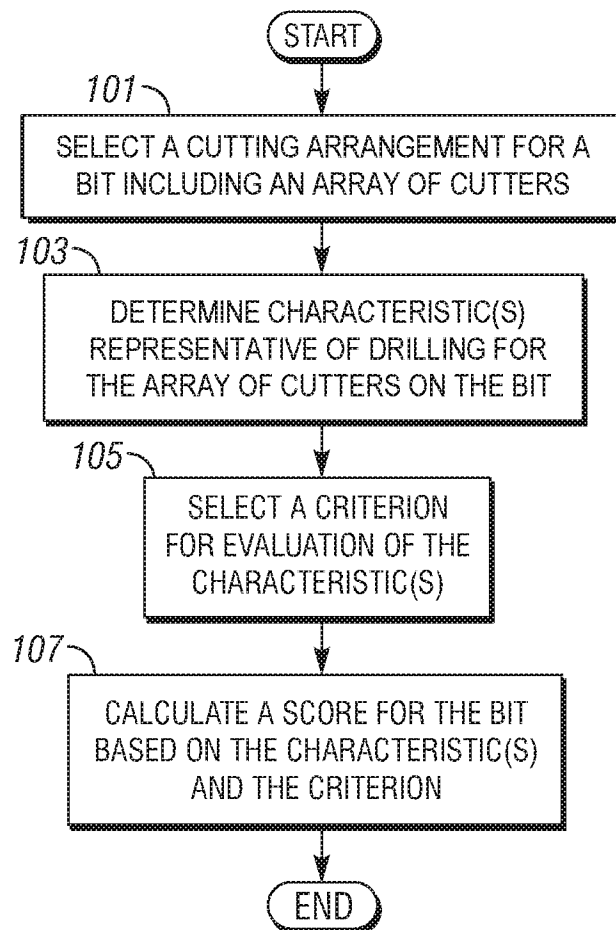


FIG. 7

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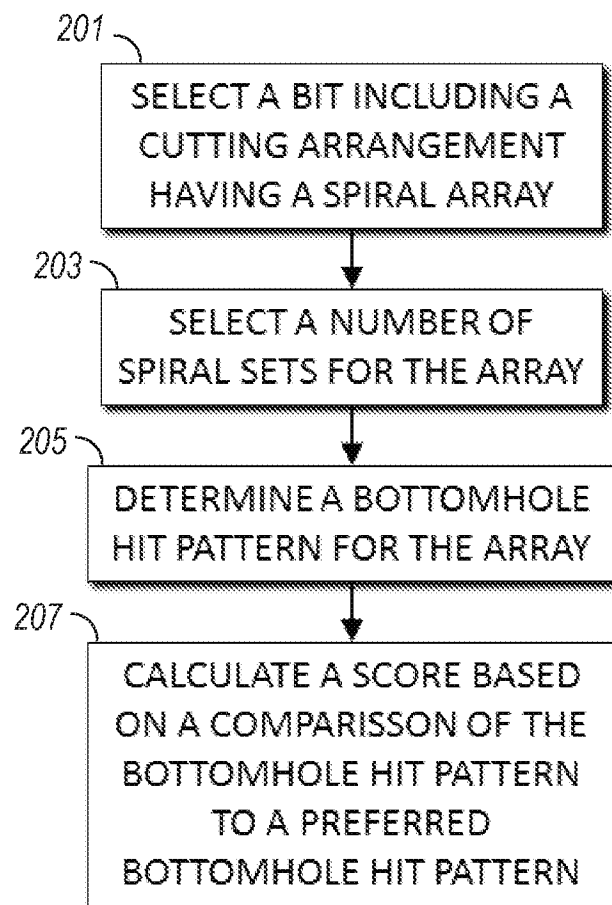


FIG. 8

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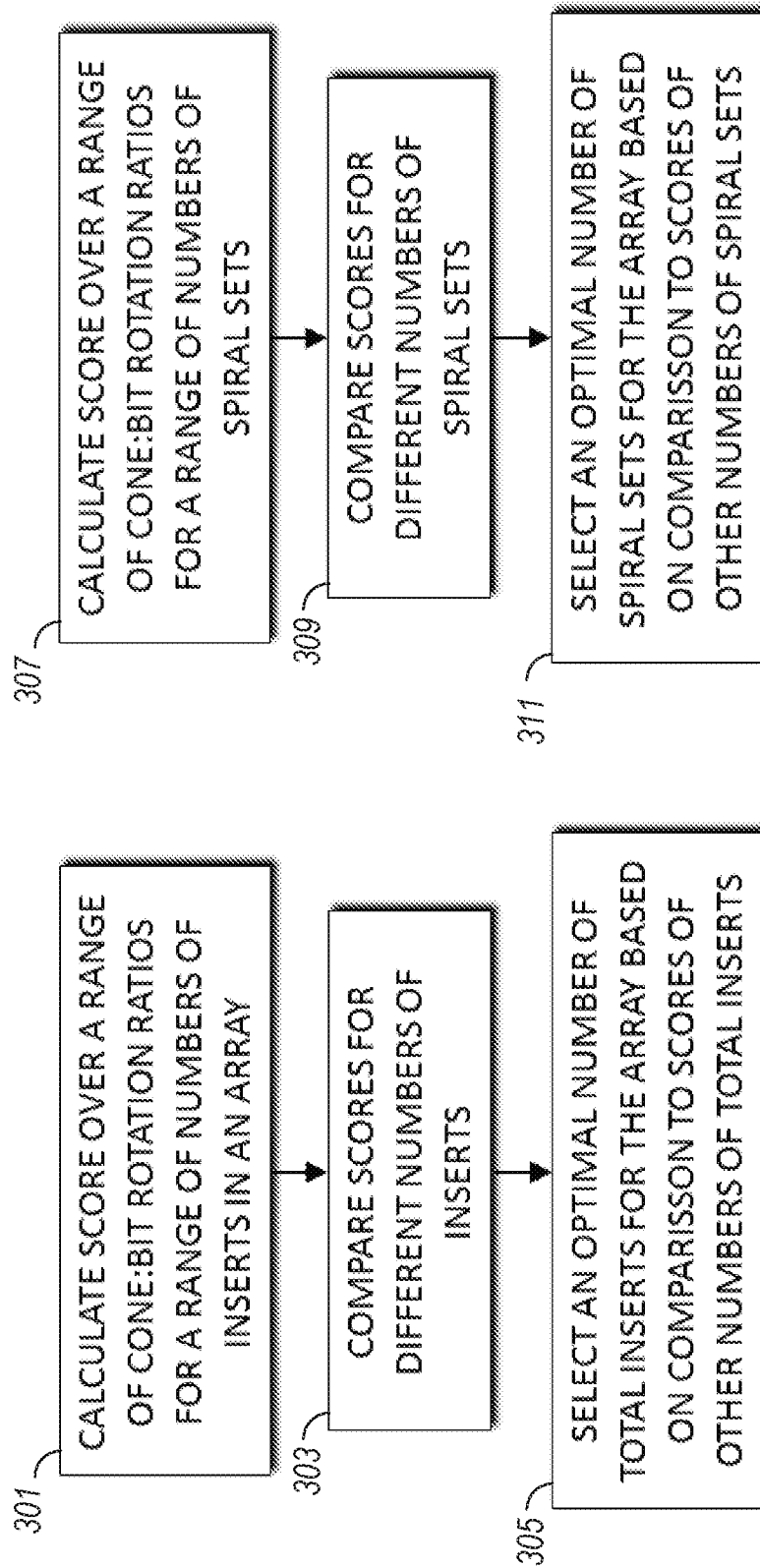


FIG. 9A

FIG. 9B

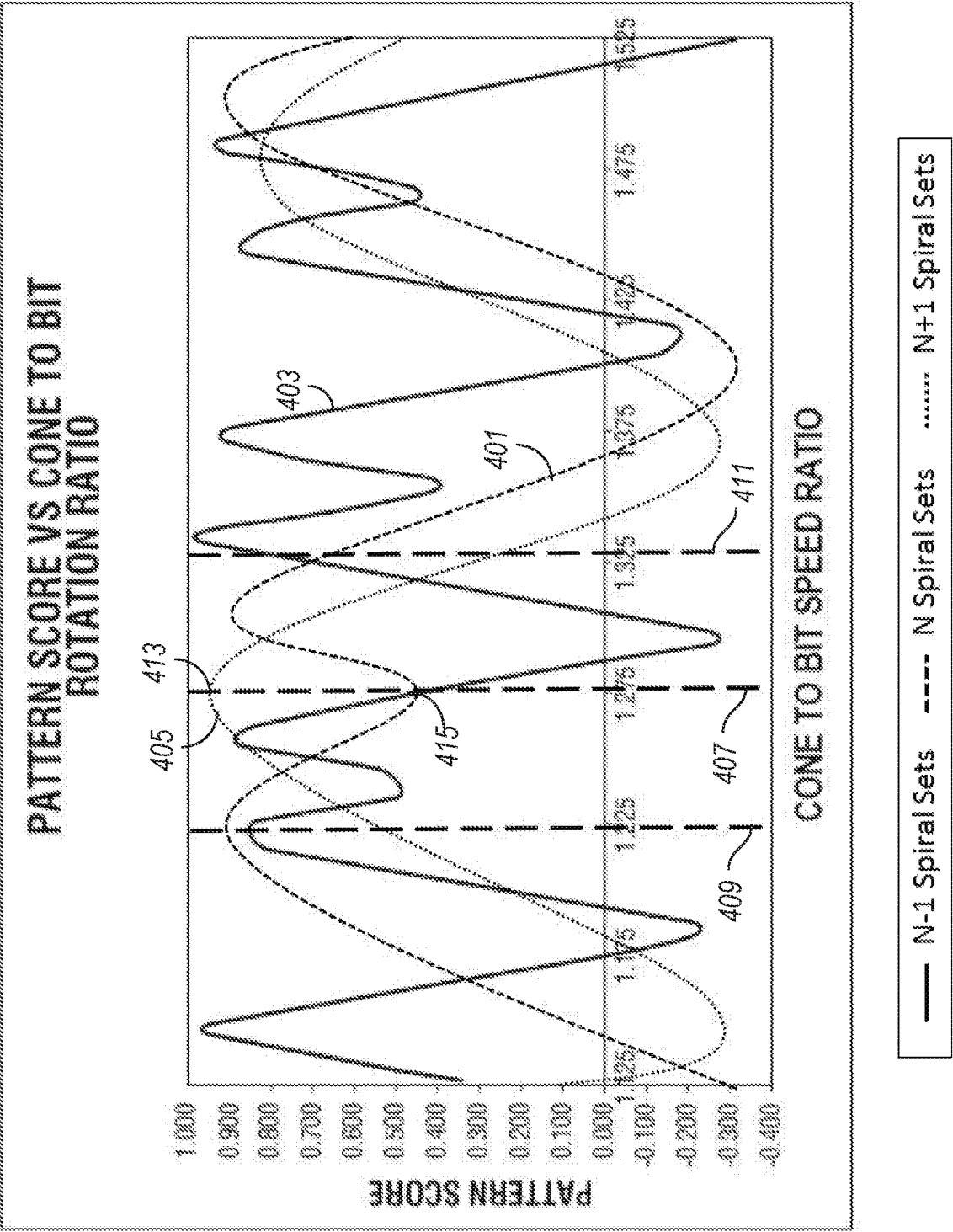


FIG. 10

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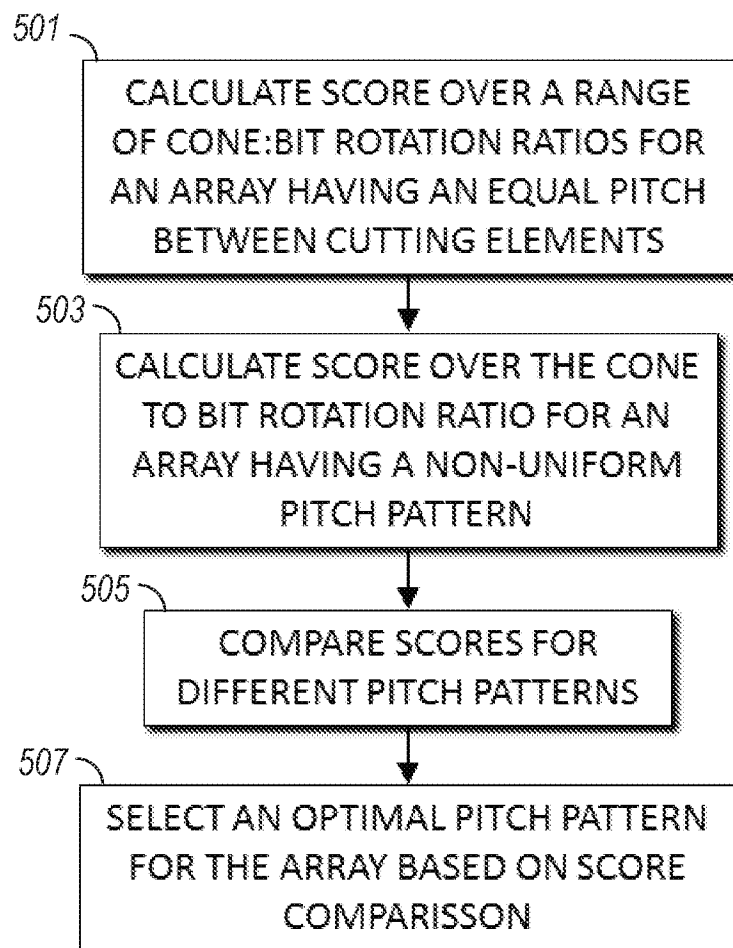


FIG. 11

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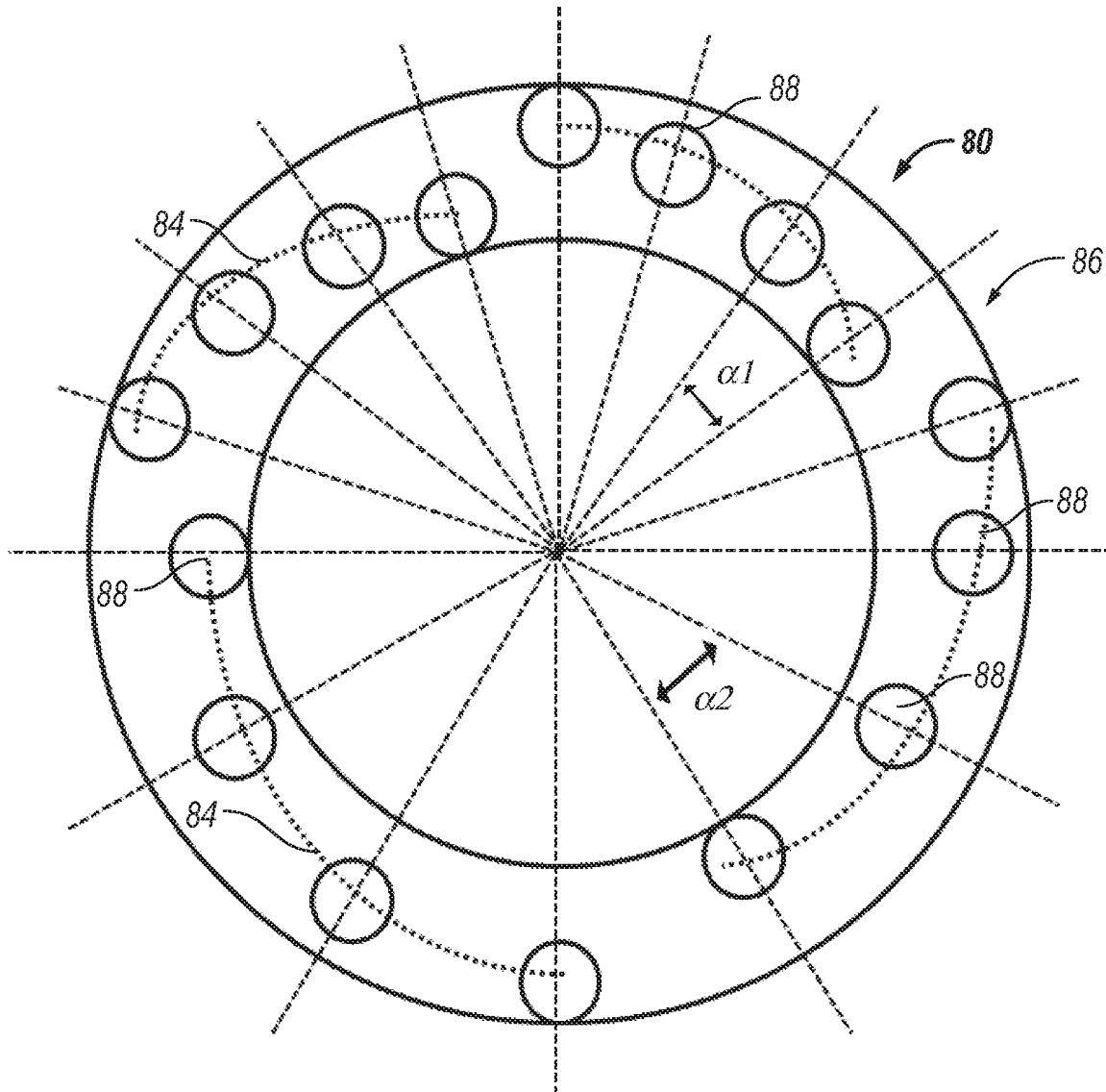


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/052899**A. CLASSIFICATION OF SUBJECT MATTER****E21B 10/08(2006.01)i, E21B 10/16(2006.01)i, E21B 10/50(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 10/08; E21B 10/14; G06G 7/48; G06F 17/50; E21B 10/16; G06G 7/64; E21B 10/50

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, cutting element, spiral set, arrangement, score, array, design, evaluating

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2004-0243367 A1 (MCDONOUGH et al.) 02 December 2004 See paragraphs [0013]-[0042], [0087]-[0102]; and figures 7-12.	1-20
Y	US 2009-0055135 A1 (TANG et al.) 26 February 2009 See paragraphs [0182]-[0187]; and figure 13.	1-20
A	US 2009-0271161 A1 (RICKS, GREGORY L.) 29 October 2009 See paragraphs [0016]-[0031]; and figure 2.	1-20
A	US 2011-0315452 A1 (BUSKE et al.) 29 December 2011 See paragraphs [0055]-[0064]; and figure 4.	1-20
A	WO 2011-017642 A2 (BAKER HUGHES INCORPORATED et al.) 10 February 2011 See page 15, line 31 - page 17, line 12; and figure 3.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

27 December 2016 (27.12.2016)

Date of mailing of the international search report

28 December 2016 (28.12.2016)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/052899

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