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(54) **DOWNHOLE CUTTING TOOLS HAVING HYBRID CUTTING STRUCTURES**

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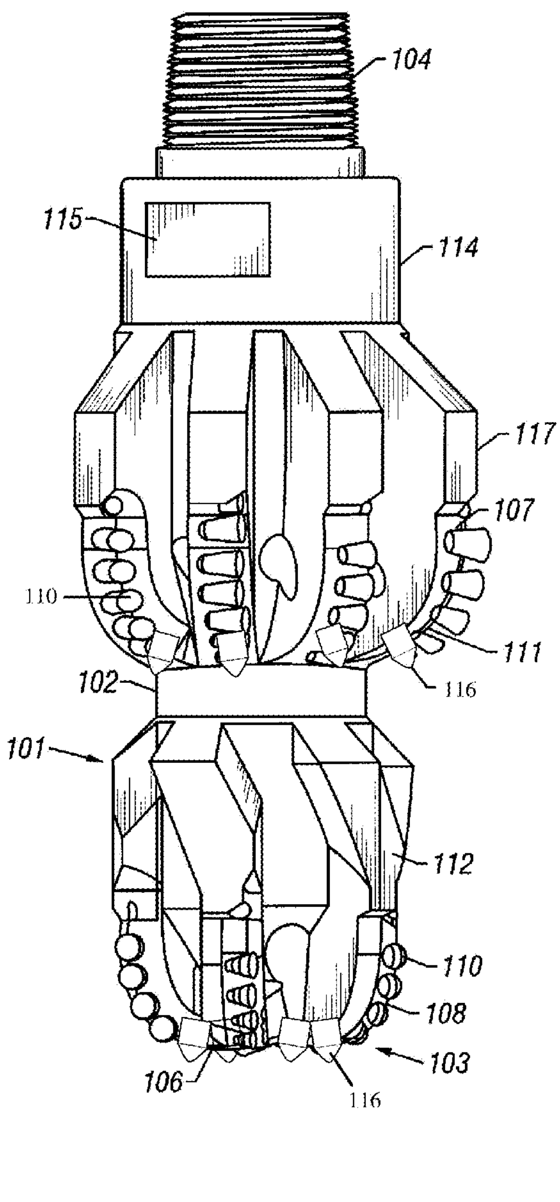
USPC **175/335**; 175/336; 175/334

(57) **ABSTRACT**

A drill bit is disclosed, wherein the drill bit has a bit body with a longitudinal axis extending there through and a bit face. A plurality of blades extends from the bit body, wherein the plurality of blades has a blade profile including a nose. A plurality of cutting elements are disposed on the plurality of blades, including a plurality of non-planar cutting elements and a plurality of rotatable cutting elements, wherein the plurality of non-planar cutting elements are disposed in a non-planar cutting element region on at least one of the blades between the longitudinal axis and the nose



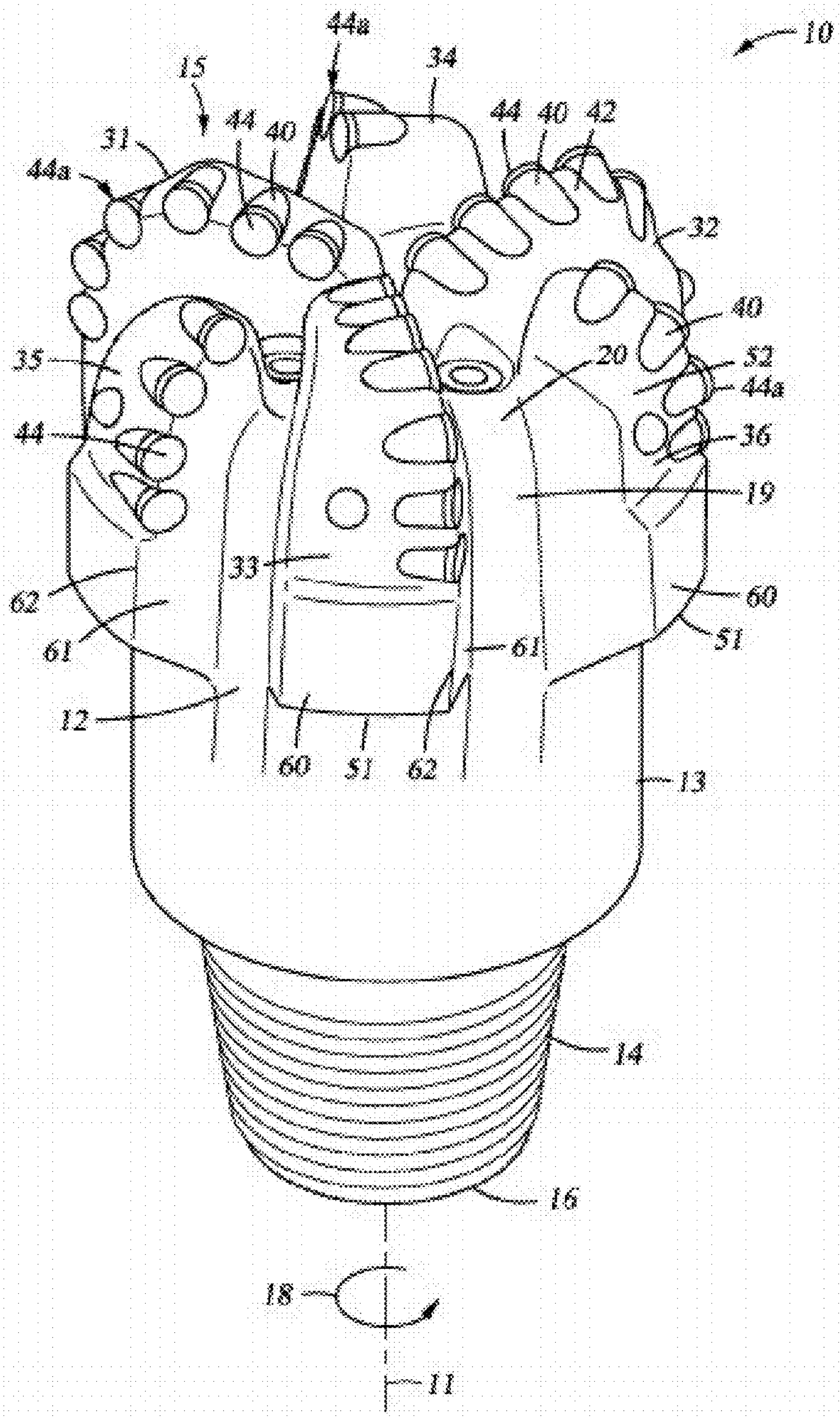


Fig. 1
(PRIOR ART)

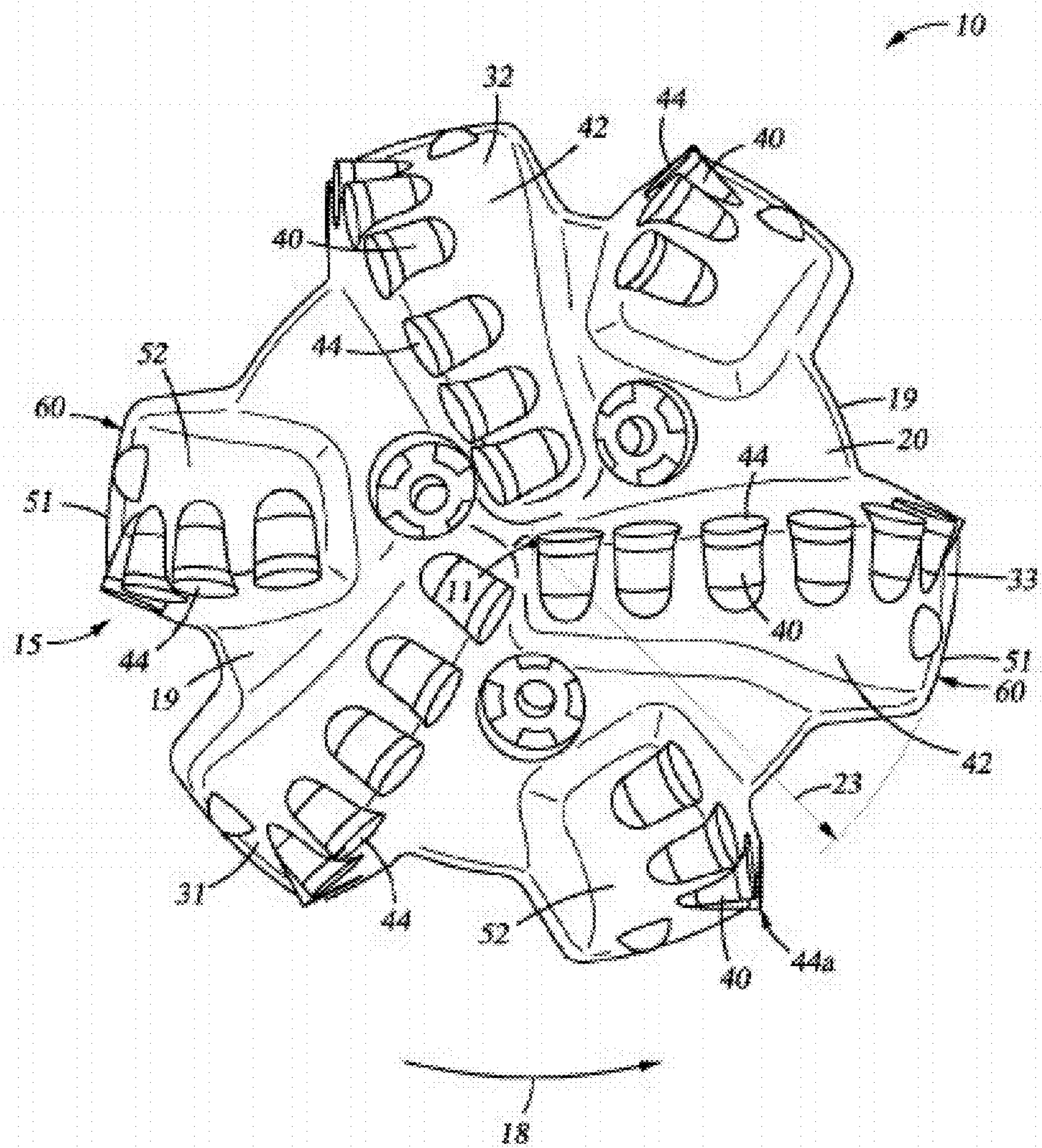


Fig. 2
(PRIOR ART)

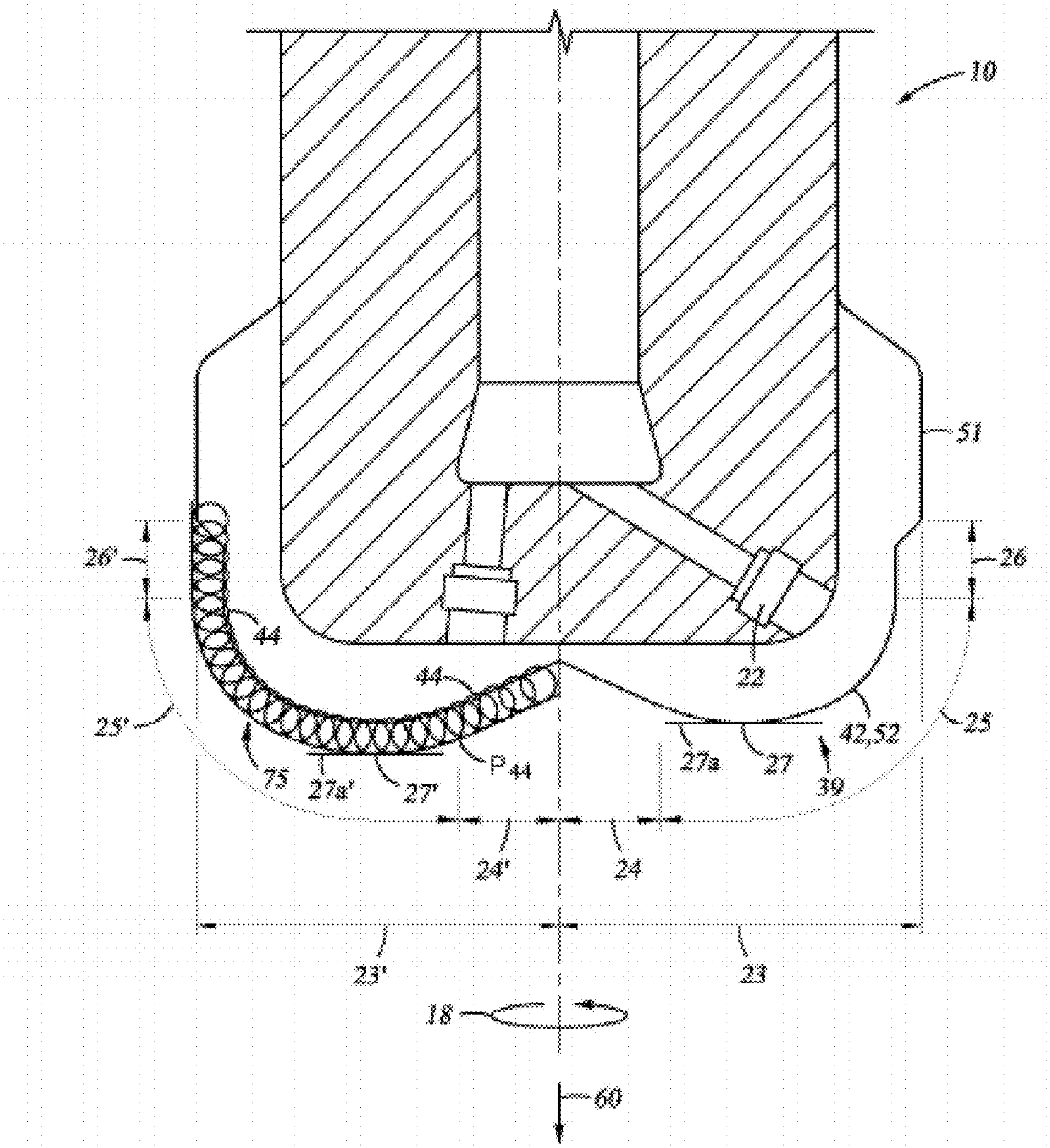


Fig. 3
(PRIOR ART)

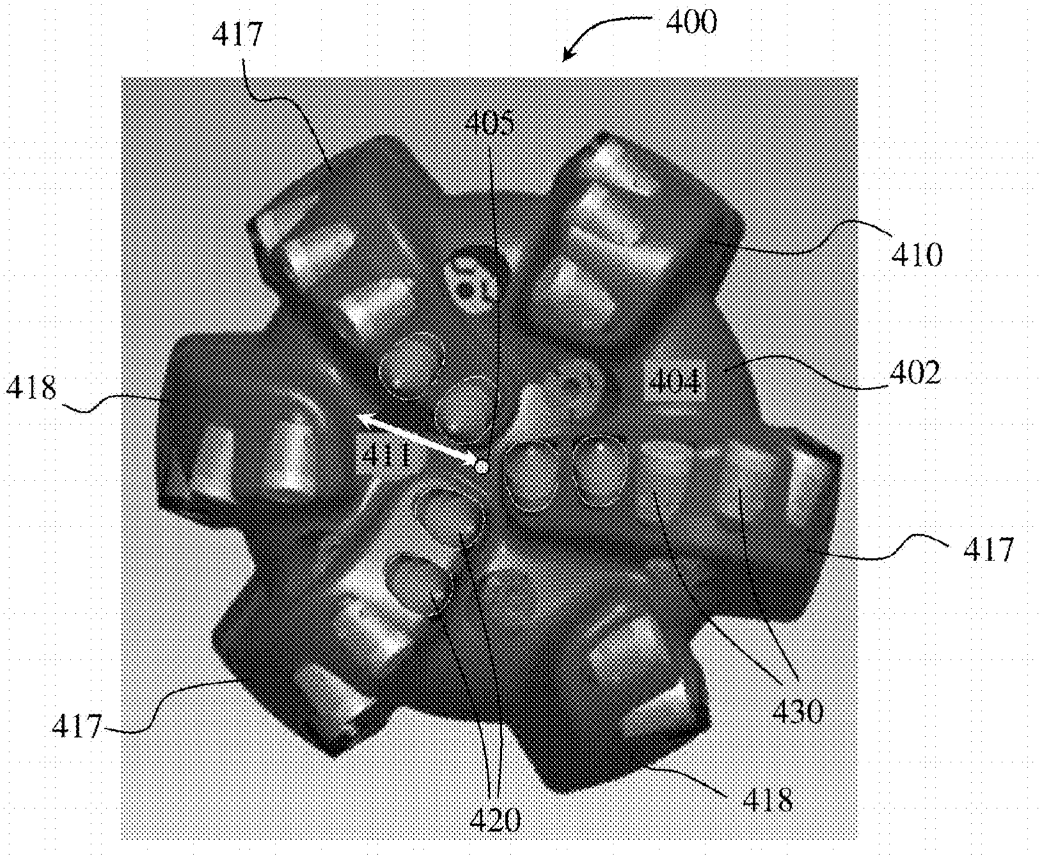


FIG. 4

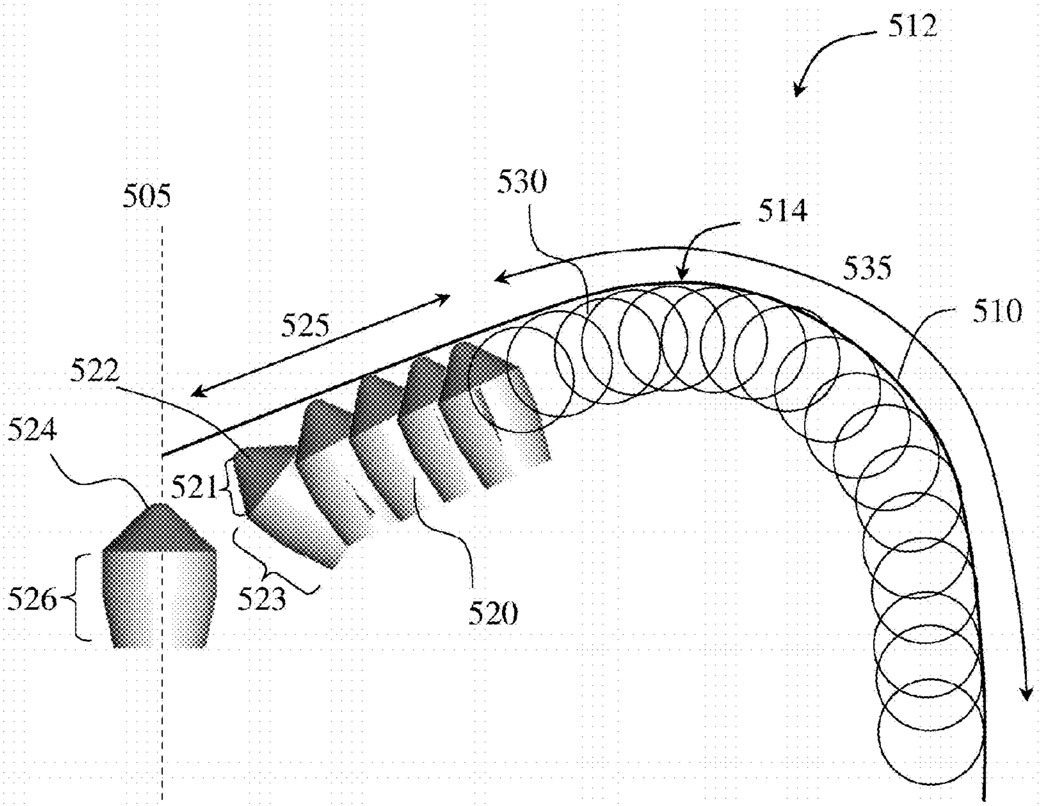


FIG. 5

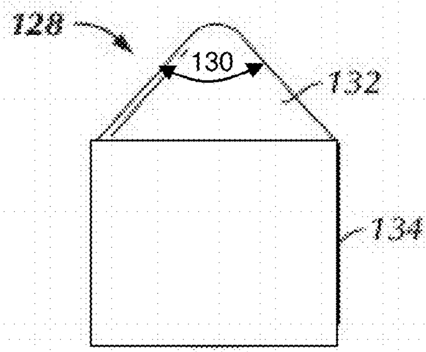


FIG. 6

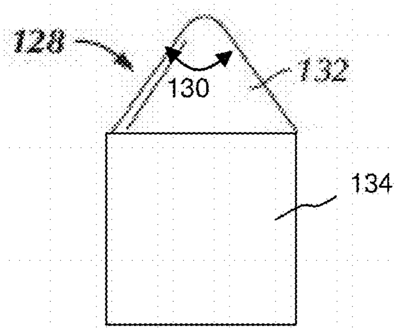


FIG. 7

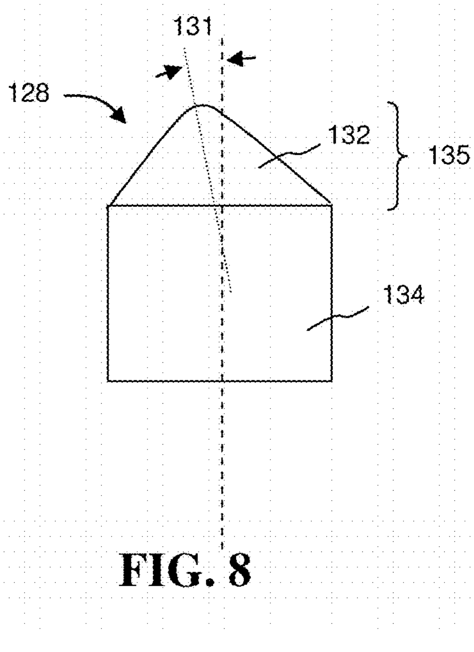


FIG. 8

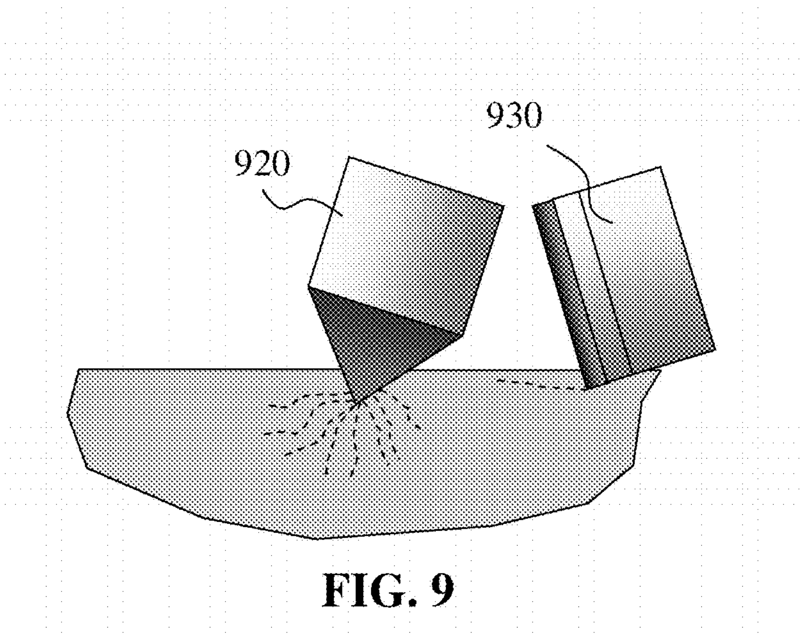


FIG. 9

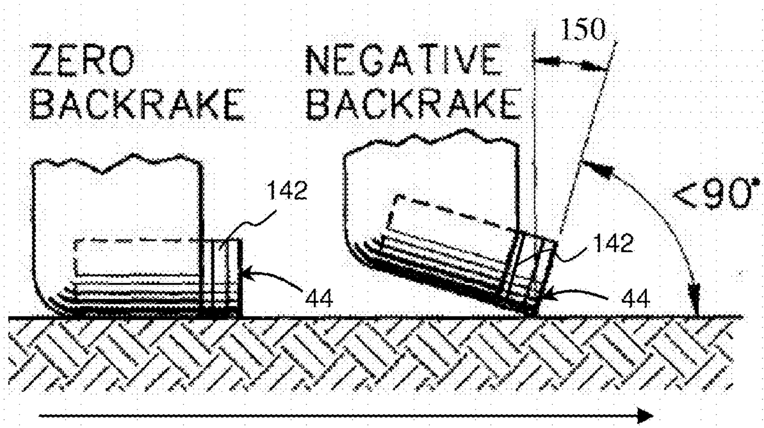


FIG. 10

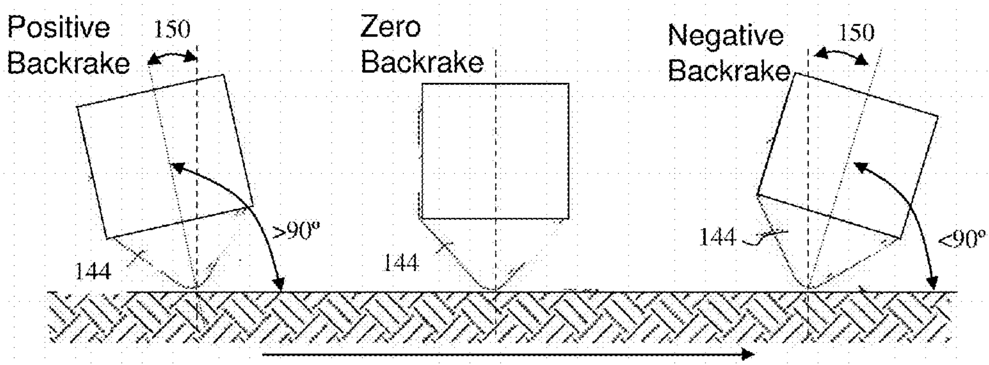

Positive
Backrake
150
>90°
144
Zero
Backrake
144
Negative
Backrake
150
144
<90°

FIG. 11

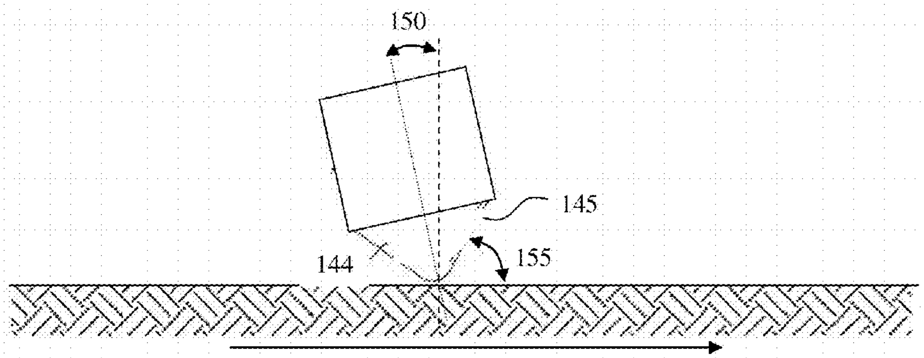

150
145
144
155

FIG. 12

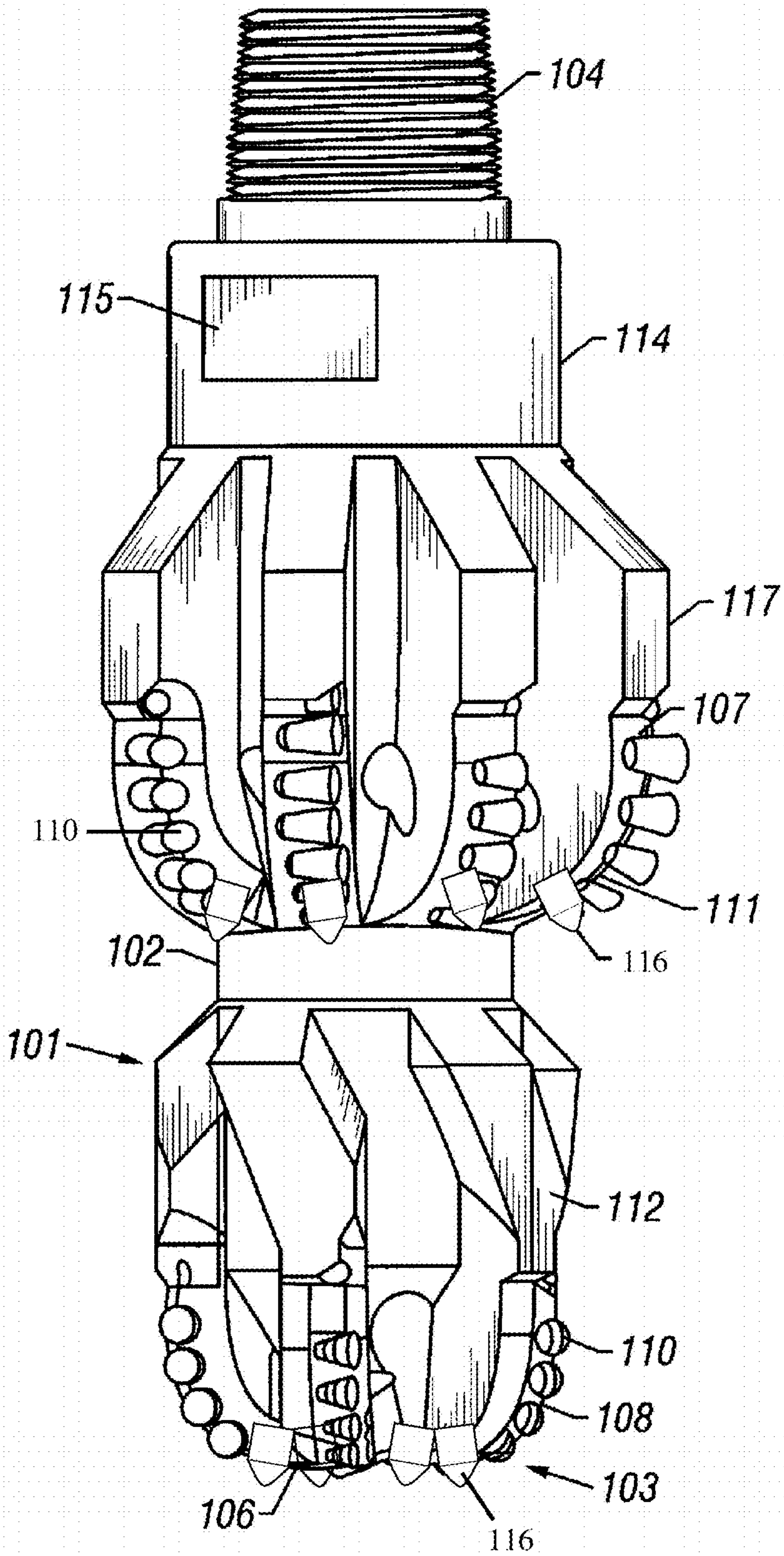


FIG. 13

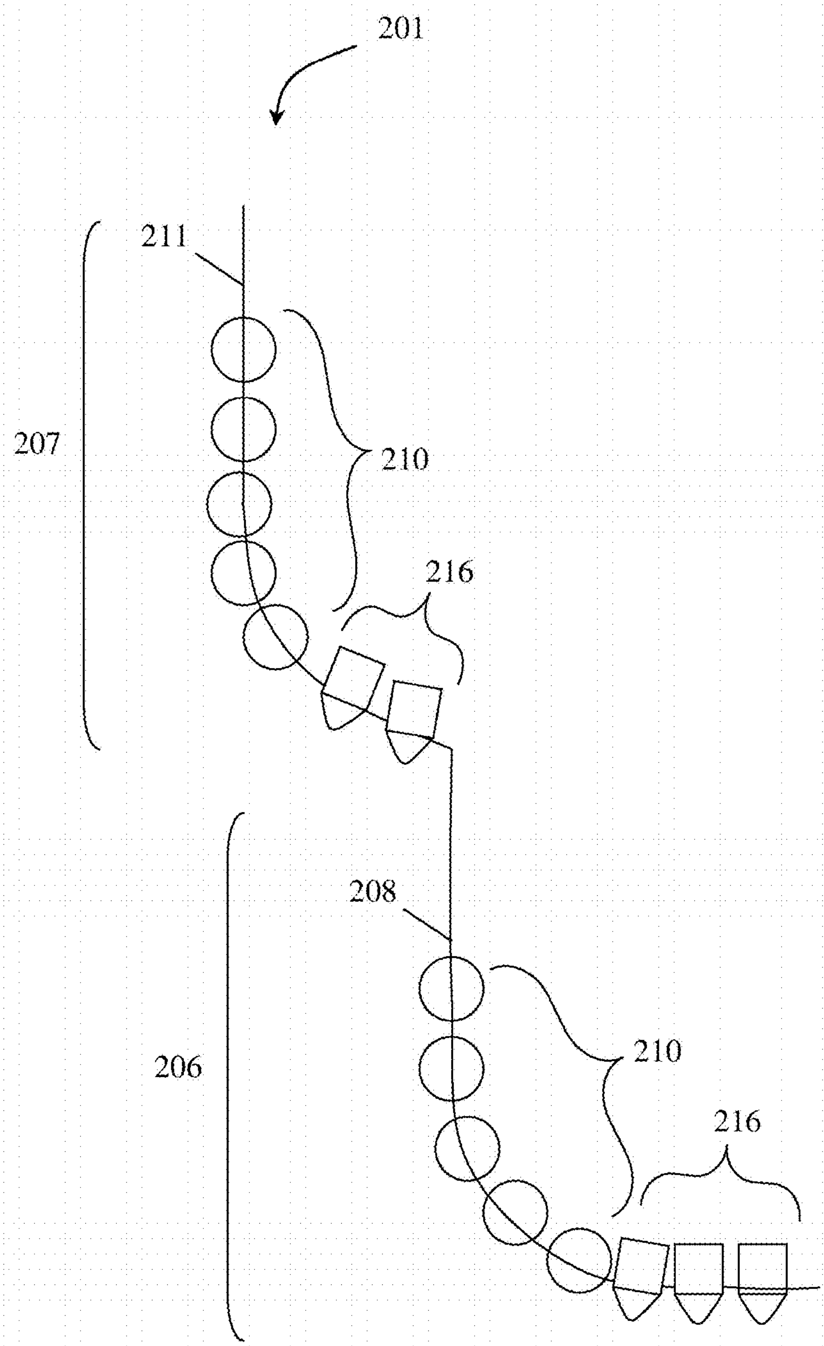


FIG. 14

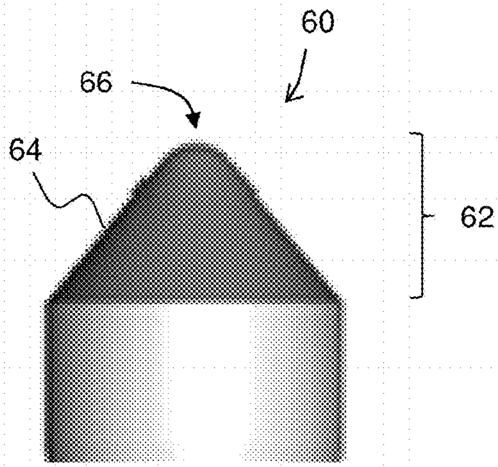


FIG. 15A

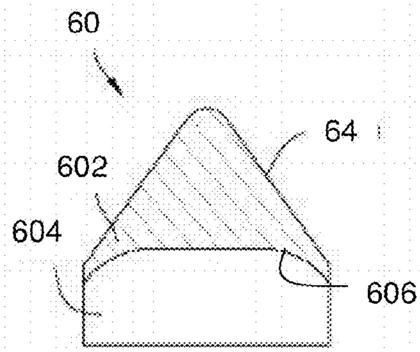


FIG. 15B

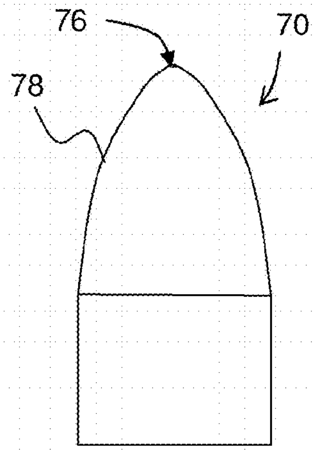


FIG. 16A

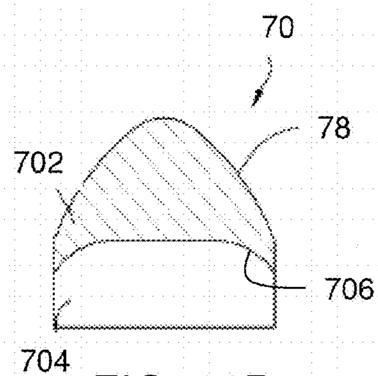


FIG. 16B

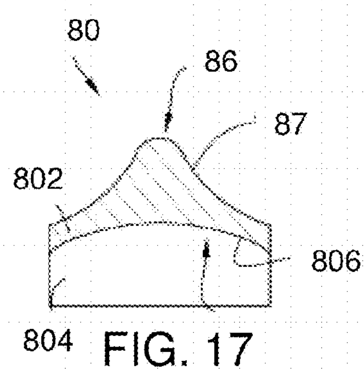


FIG. 17

DOWNHOLE CUTTING TOOLS HAVING HYBRID CUTTING STRUCTURES

BACKGROUND

[0001] In drilling a borehole in the earth, such as for the recovery of hydrocarbons or for other applications, it is conventional practice to connect a drill bit on the lower end of an assembly of drill pipe sections that are connected end-to-end so as to form a "drill string." The bit is rotated by rotating the drill string at the surface or by actuation of downhole motors or turbines, or by both methods. With weight applied to the drill string, the rotating bit engages the earthen formation causing the bit to cut through the formation material by either abrasion, fracturing, or shearing action, or through a combination of all cutting methods, thereby forming a borehole along a predetermined path toward a target zone.

[0002] Many different types of drill bits have been developed and found useful in drilling such boreholes. Two predominate types of drill bits are roller cone bits and fixed cutter (or rotary drag) bits. Most fixed cutter bit designs include a plurality of blades angularly spaced about the bit face. The blades project radially outward from the bit body and form flow channels therebetween. In addition, cutting elements are typically grouped and mounted on several blades in radially extending rows. The configuration or layout of the cutting elements on the blades may vary widely, depending on a number of factors such as the formation to be drilled.

[0003] The cutting elements disposed on the blades of a fixed cutter bit are typically formed of extremely hard materials. In a typical fixed cutter bit, each cutting element comprises an elongate and generally cylindrical tungsten carbide substrate that is received and secured in a pocked formed in the surface of one of the blades. The cutting elements typically includes a hard cutting layer of polycrystalline diamond (PCD) or other superabrasive materials such as thermally stable diamond or polycrystalline cubic boron nitride. For convenience, as used herein, reference to "PDC bit" or "PDC cutters" refers to a fixed cutter bit or cutting element employing a hard cutting layer of polycrystalline diamond or other superabrasive materials.

[0004] Referring to FIGS. **1** and **2**, a conventional fixed cutter or drag bit **10** adapted for drilling through formations of rock to form a borehole is shown. Bit **10** generally includes a bit body **12**, a shank **13**, and a threaded connection or pin **14** for connecting the bit **10** to a drill string (not shown) that is employed to rotate the bit in order to drill the borehole. Bit face **20** supports a bladed cutting structure **15** and is formed on the end of the bit **10** that is opposite pin end **16**. Bit **10** further includes a central axis **11** about which bit **10** rotates in the cutting direction represented by arrow **18**.

[0005] Cutting structure **15** is provided on face **20** of bit **10**. Cutting structure **15** includes a plurality of angularly spaced-apart primary blades **31**, **32**, **33**, and secondary blades **34**, **35**, **36**, each of which extends from bit face **20**. Primary blades **31**, **32**, **33** and secondary blades **34**, **35**, **36** extend generally radially along bit face **20** and then axially along a portion of the periphery of bit **10**. However, secondary blades **34**, **35**, **36** extend radially along bit face **20** from a position that is distal bit axis **11** toward the periphery of bit **10**. Thus, as used herein, "secondary blade" may be used to refer to a blade that begins at some distance from the bit axis and extends generally radially along the bit face to the periphery of the bit. Primary blades **31**, **32**, **33** and secondary blades **34**, **35**, **36** are separated by drilling fluid flow courses **19**.

[0006] Referring still to FIGS. **1** and **2**, each primary blade **31**, **32**, **33** includes blade tops **42** for mounting a plurality of cutting elements, and each secondary blade **34**, **35**, **36** includes blade tops **52** for mounting a plurality of cutting elements. In particular, cutting elements **40**, each having a cutting face **44**, are mounted in pockets formed in blade tops **42**, **52** of each primary blade **31**, **32**, **33** and each secondary blade **34**, **35**, **36**, respectively. Cutting elements **40** are arranged adjacent one another in a radially extending row proximal the leading edge of each primary blade **31**, **32**, **33** and each secondary blade **34**, **35**, **36**. Each cutting face **44** has an outermost cutting tip **44***a* furthest from blade tops **42**, **52** to which cutting element **40** is mounted.

[0007] Referring now to FIG. **3**, a profile of bit **10** is shown as it would appear with all blades (e.g., primary blades **31**, **32**, **33** and secondary blades **34**, **35**, **36**) and cutting faces **44** of all cutting elements **40** rotated into a single rotated profile. In rotated profile view, blade tops **42**, **52** of all blades **31**-**36** of bit **10** form and define a combined or composite blade profile **39** that extends radially from bit axis **11** to outer radius **23** of bit **10**. Thus, as used herein, the phrase "composite blade profile" refers to the profile, extending from the bit axis to the outer radius of the bit, formed by the blade tops of all the blades of a bit rotated into a single rotated profile (i.e., in rotated profile view).

[0008] Conventional composite blade profile **39** (most clearly shown in the right half of bit **10** in FIG. **3**) may generally be divided into three regions labeled cone region **24**, shoulder region **25**, and gage region **26**. Cone region **24** comprises the radially innermost region of bit **10** and composite blade profile **39** extending generally from bit axis **11** to shoulder region **25**. As shown in FIG. **3**, in most conventional fixed cutter bits, cone region **24** is generally concave. Adjacent cone region **24** is shoulder (or the upturned curve) region **25**. In most conventional fixed cutter bits, shoulder region **25** is generally convex. Moving radially outward, adjacent shoulder region **25** is the gage region **26** which extends parallel to bit axis **11** at the outer radial periphery of composite blade profile **39**. Thus, composite blade profile **39** of conventional bit **10** includes one concave region—cone region **24**, and one convex region—shoulder region **25**.

[0009] The axially lowermost point of convex shoulder region **25** and composite blade profile **39** defines a blade profile nose **27**. At blade profile nose **27**, the slope of a tangent line **27***a* to convex shoulder region **25** and composite blade profile **39** is zero. Thus, as used herein, the term "blade profile nose" refers to the point along a convex region of a composite blade profile of a bit in rotated profile view at which the slope of a tangent to the composite blade profile is zero. For most conventional fixed cutter bits (e.g., bit **10**), the composite blade profile includes only one convex shoulder region (e.g., convex shoulder region **25**), and only one blade profile nose (e.g., nose **27**). As shown in FIGS. **1**-**3**, cutting elements **40** are arranged in rows along blades **31**-**36** and are positioned along the bit face **20** in the regions previously described as cone region **24**, shoulder region **25** and gage region **26** of composite blade profile **39**. In particular, cutting elements **40** are mounted on blades **31**-**36** in predetermined radially-spaced positions relative to the central axis **11** of the bit **10**.

[0010] Without regard to the type of bit, the cost of drilling a borehole is proportional to the length of time it takes to drill the borehole to the desired depth and location. The drilling time, in turn, is greatly affected by the number of times the drill bit must be changed in order to reach the targeted formation. This is the case because each time the bit is changed, the entire drill string, which may be miles long, must be retrieved from the borehole section by section. Once the drill string has been retrieved and the new bit installed, the bit must be lowered to the bottom of the borehole on the drill string, which again must be constructed section by section. This process, known as a "trip" of the drill string, requires considerable time, effort, and expense. Accordingly, it is always desirable to employ drill bits that will drill faster and longer and that are usable over a wider range of differing formation hardnesses.

SUMMARY

[0011] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0012] In one aspect, embodiments disclosed herein relate to a drill bit having a bit body with a longitudinal axis extending there through and a bit face. A plurality of blades extends from the bit body, wherein the plurality of blades has a blade profile including a nose. A plurality of cutting elements are disposed on the plurality of blades, including a plurality of non-planar cutting elements and a plurality of rotatable cutting elements, wherein the plurality of non-planar cutting elements are disposed in a non-planar cutting element region on at least one of the blades between the longitudinal axis and the nose

[0013] In another aspect, embodiments disclosed herein relate to a downhole cutting tool having a tool body with a longitudinal axis extending there through and a cutting end. A plurality of blades extends azimuthally from the tool body, and a plurality of cutting elements is disposed on the plurality of blades. The plurality of cutting elements include at least one rotatable cutting element and at least one non-planar cutting element, wherein the at least one non-planar cutting element is in a non-planar cutting element region of the blades closest to the cutting end.

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

BRIEF DESCRIPTION OF DRAWINGS

[0015] FIG. **1** shows a prior art drill bit.

[0016] FIG. **2** shows a top view of a prior art drill bit.

[0017] FIG. **3** shows a cross-sectional view of a prior art drill bit.

[0018] FIG. **4** shows a top view of a drill bit according to embodiments of the present disclosure.

[0019] FIG. **5** shows a cutting profile according to embodiments of the present disclosure.

[0020] FIG. **6** shows a conical cutting element according to embodiments of the present disclosure.

[0021] FIG. **7** shows a conical cutting element according to embodiments of the present disclosure.

[0022] FIG. **8** shows a conical cutting element according to embodiments of the present disclosure.

[0023] FIG. **9** shows cutting elements according to one embodiment of the present disclosure.

[0024] FIG. **10** shows rotatable cutting elements according to embodiments of the present disclosure.

[0025] FIG. **11** shows conical cutting elements according to embodiments of the present disclosure.

[0026] FIG. **12** shows a conical cutting element according to embodiments of the present disclosure.

[0027] FIG. **13** shows a side view of a bi-center bit according to embodiments of the present disclosure.

[0028] FIG. **14** shows a cutting profile of a bi-center bit according to embodiments of the present disclosure.

[0029] FIG. **15**A-**15**B show a side view and cross-sectional view of a conical cutting element.

[0030] FIG. **16**A-**16**B show a side view and a cross-sectional view of a pointed cutting element having a convex side surface.

[0031] FIG. **17** shows a cross-sectional view of a pointed cutting element having a concave side surface

DETAILED DESCRIPTION

[0032] In one aspect, embodiments disclosed herein relate to drill bits or other downhole cutting tools containing multiple types of cutting structures. In particular, embodiments disclosed herein relate to cutting tools containing two or more types of cutting elements, each type having a different mode of cutting action against a formation. Other embodiments disclosed herein relate to drill bits containing fixed cutting elements having a non-planar cutting end and rotatable cutting elements, including the placement of such cutting elements on a bit and variations on the cutting elements that may be used to optimize drilling.

[0033] As used herein, "non-planar cutting elements" refers to cutting elements having a non-planar cutting end and may also be referred to as shaped cutting elements. The shape of the non-planar cutting end may include any geometric shape in which the portion of the cutting element that engages with the formation is not planar. Generally, a conventional cutter engages at the circumferential edge of the cylindrical compact and as the cutter cuts or digs into the formation, a portion of the planar cutting face engages with the formation. Such cutters may also generally include a beveled or chamfered edge; however a substantial majority of the surface area of the cutting face is planar. However, such shapes are not within the scope of the "non-planar cutting elements" as that term is defined herein. Rather, a non-planar cutting element possesses a height extension above the transition from the cylindrical side surface and the cutting end, and a substantial majority of the cutting end is non-planar. Such shapes may include generally pointed cutting elements and domed cutting elements. Generally pointed cutting elements may have generally pointed cutting end, i.e., having terminating in an apex, with a conical, convex, or concave side surfaces, shown in FIGS. **15**-**17**. For ease in distinguishing between the two types of cutting elements, the term "cutting elements" will generically refer to any type of cutting element, while "cutter" will refer those cutting elements with a planar cutting face, as described above in reference to FIGS. **1** and **2**, and "non-planar cutting element" will refer to those cutting elements having a non-planar cutting end.

[0034] As used herein, the term "conical cutting elements" refers to cutting elements having a generally conical cutting end **62** (including either right cones or oblique cones), i.e., a conical side wall **64** that terminates in a rounded apex **66**, as shown in FIGS. **15**A-**15**B. Unlike geometric cones that terminate at a sharp point apex, the conical cutting elements of the present disclosure possess an apex having curvature between the side surfaces and the apex. Further, in one or more embodiments, a bullet cutting element **70** may be used. The term “bullet cutting element” refers to cutting element having, instead of a generally conical side surface, a generally convex side surface **78** terminated in a rounded apex **76**, as shown in FIGS. **16**A-**16**B. In one or more embodiments, the apex **76** has a substantially smaller radius of curvature than the convex side surface **78**. However, it is also intended that the non-planar cutting elements of the present disclosure may also include other shapes, including, for example, a concave side surface terminating in a rounded apex, shown in FIG. **17**. In each of such embodiments, the non-planar cutting elements may have a smooth transition between the side surface and the rounded apex (i.e., the side surface or side wall tangentially joins the curvature of the apex), but in some embodiments, a non-smooth transition may be present (i.e., the tangent of the side surface intersects the tangent of the apex at a non-180 degree angle, such as for example ranging from about 120 to less than 180 degrees). Further, in one or more embodiments, the non-planar cutting elements may include any shape having an cutting end extending above a grip or base region, where the cutting end extends a height that is at least 0.25 times the diameter of the cutting element, or at least 0.3, 0.4, 0.5 or 0.6 times the diameter in one or more other embodiments.

[0035] For example, variations of conical cutting elements that may be in any of the embodiments disclosed herein are shown in FIGS. **6-8**. As shown, conical cutting elements **128** may have a diamond layer **132** on a substrate **134** (such as a cemented tungsten carbide substrate), where the diamond layer **132** forms a conical diamond working surface. However, conical cutting elements may be made of other materials, as it is their shape and not material that defines conical cutting elements. Specifically, the conical geometry may comprise a side wall that tangentially joins the curvature of the apex. Conical cutting elements **128** may be formed in a process similar to that used in forming diamond enhanced inserts (used in roller cone bits) or by brazing of components together. The interface (not shown separately) between diamond layer **132** and substrate **134** may be non-planar or non-uniform, for example, to aid in reducing incidents of delamination of the diamond layer **132** from substrate **134** when in operation and to improve the strength and impact resistance of the element. One skilled in the art would appreciate that the interface may include one or more convex or concave portions, as known in the art of non-planar interfaces. Additionally, one skilled in the art would appreciate that use of some non-planar interfaces may allow for greater thickness in the diamond layer in the tip region of the layer. Further, it may be desirable to create the interface geometry such that the diamond layer is thickest at a critical zone that encompasses the primary contact zone between the diamond enhanced element and the formation.

[0036] Additional shapes and interfaces that may be used for substantially pointed cutting elements of the present disclosure include those described in U.S. Patent Publication No. 2008/0035380, which is herein incorporated by reference in its entirety. Further, the diamond layer **132** may be formed from any polycrystalline superabrasive material, including, for example, polycrystalline diamond, polycrystalline cubic boron nitride, thermally stable polycrystalline diamond (formed either by treatment of polycrystalline diamond formed from a metal such as cobalt or polycrystalline diamond formed with a metal having a lower coefficient of thermal expansion than cobalt).

[0037] The apex of the conical cutting element may have curvature, including a radius of curvature. In the embodiments shown in FIGS. **6-8**, the radius of curvature may range from about 0.050 to 0.125. Such curvature may also be present in the types of cutting elements illustrated in FIGS. **16** and **17**. In some embodiments, the curvature may comprise a variable radius of curvature, a portion of a parabola, a portion of a hyperbola, a portion of a catenary, or a parametric spline. Further, referring to FIGS. **6** and **7**, the cone angle **130** of the conical end may vary, and be selected based on the particular formation to be drilled. In a particular embodiment, the cone angle **130** may range from about 75 to 90 degrees.

[0038] Referring now to FIG. **8**, an asymmetrical or oblique conical cutting element is shown. As shown in FIG. **8**, the cutting conical cutting end portion **135** of the conical cutting element **128** has an axis that is not coaxial with the axis of the substrate **134**. In a particular embodiment, at least one asymmetrical conical cutting element may be used on any of the described drill bits or reamers. Selection of an asymmetrical conical cutting element may be selected to better align a normal or reactive force on the cutting element from the formation with the cutting tip axis or to alter the aggressiveness of the conical cutting element with respect to the formation. In a particular embodiment, the angle **131** formed between the cutting end or cone axis and the axis of the substrate may range from 37.5 to 45, with an angle on a trailing side of the cutting element being greater, by 5-20 degrees more than a leading angle (measured from the leading side of the cutting element).

[0039] Other designs of conical cutting elements may be used in embodiments of the present disclosure, such as described in, for example, U.S. Patent Application Nos. 61/441,319, 13/370,734, 61/499,851, 13/370,862, and 61/609,527, all of which are assigned to the present assignee and herein incorporated by reference in their entirety.

[0040] Further, non-planar cutting elements of the present disclosure may be attached to a bit or other downhole cutting tool by methods known in the art, such as brazing, or may be rotatably retained on the downhole tool. For example, a non-planar cutting element may be rotatably retained on a downhole tool by one or more retention mechanisms, such as by retention balls, springs, pins, etc. In one or more embodiments, a non-planar cutting element may be rotatably retained in a pocket formed in a blade of a downhole tool, such as drill bit or reamer, using a plurality of retention balls disposed between corresponding grooves formed around the outer side surface of the conical cutting element body and the inner side surface of a sleeve, which is attached to the pocket. In other embodiments, a non-planar cutting element may be rotatably retained in a pocket formed in a blade of a downhole tool using changes in the non-planar cutting element body's diameter. For example, a non-planar cutting element body or substrate may have a first diameter proximate to the non-planar cutting end and a second diameter axially distant from the non-planar cutting end, wherein the second diameter is larger than the first diameter. A sleeve surrounding the non-planar cutting element body (which may be attached to a pocket) or the pocket may have a first inner diameter corresponding with the first diameter of the non-planar cutting element. Thus, when the non-planar cutting element is assembled within the corresponding sleeve or pocket, the larger second diameter retains the non-planar cutting element. Various examples of retention mechanisms also include those disclosed in U.S. Patent Publication No. 2012/0132471 and U.S. Pat. Nos.

7,703,559 and 8,091,655, all of which are assigned to the present assignee and herein incorporated by reference in their entirety.

[0041] Further, although non-planar cutting elements of the present disclosure may be rotatably retained on a downhole cutting tool, such as a drill bit or reamer, the term "non-planar cutting elements," which refers to cutting elements having a non-planar cutting end, is distinct from the term "rotatable cutting elements," which may similarly be rotatably retained on a downhole cutting tool, but do not have non-planar cutting ends.

[0042] As used herein, the term "rotatable cutting elements" generally refers to cutting elements having at least one surface or portion of the cutting element rotate as it contacts a formation. As the rotatable cutting element contacts the formation, the cutting action may allow a portion of the cutting element to rotate around a cutting element axis extending through the cutting element. Rotation of at least a portion of the rotatable cutting element may allow for a cutting surface to cut the formation using the entire outer edge of the cutting surface rather than the same section of the outer edge, as observed in a conventional fixed cutting element. Rotatable cutting elements of the present disclosure may include various types and sizes of rotatable cutting elements. For example, rotatable cutting elements may be formed in sizes including, but not limited to, 9 mm, 13 mm, 16 mm and 19 mm. Further, rotatable cutting elements may include those held within an outer support element, held by a retention mechanism or blocker, or a combination of the two.

[0043] Examples of rotatable cutting elements that may be used in the present disclosure may be found at least in U.S. Publication Nos. 2007/0278017, 2011/0297454, and 2012/0132471 and U.S. Pat. Nos. 7,703,559 and 8,091,655, which are hereby incorporated by reference. For example, some rotatable cutting elements include an inner rotatable cutting element disposed within an outer shell or within a cutter pocket and a retention mechanism. The rotation of the inner rotatable cutting element may be controlled by the side cutting force and the frictional force between the bearing surfaces. If the side cutting force generates a torque which can overcome the torque from the frictional force, the rotatable portion will have rotating motion. The side cutting force may be affected by cutter side rake, back rake and geometry, including the working surface patterns disclosed herein. Additionally, the side cutting force may be affected by the surface finishing of the surfaces of the cutting element components, the frictional properties of the formation, as well as drilling parameters, such as depth of cut. The frictional force at the bearing surfaces may affected, for example, by surface finishing, mud intrusion, etc. The design of the rotatable cutting elements disclosed herein may be selected to ensure that the side cutting force overcomes the frictional force to allow for rotation of the rotatable portion. Various design considerations of the present disclosure are described below, as well as exemplary embodiments of rotatable cutting elements. However, the present disclosure is not so limited. One skilled in the art would appreciate that any cutting element capable of rotating about its own axis may be used with the drill bit or other cutting tool of the present disclosure.

[0044] According to embodiments of the present disclosure, a downhole cutting tool may have a tool body with a longitudinal axis extending there through and a cutting face. A plurality of blades may extend azimuthally from the tool body, and a plurality of cutting elements, including at least one rotatable cutting element and at least one conical cutting element, may be disposed on the plurality of blades. The conical cutting elements may be disposed on the blades in regions experiencing high impact during drilling operations, while the rotatable cutting elements may be disposed on the blades in regions experiencing high wear. For example, a plurality of conical cutting elements may be disposed on one or more blades in a region of the blade closest to the cutting face, and a plurality of rotatable cutting elements may be disposed in the remaining region of the blades. In other embodiments, a plurality of conical cutting elements may be disposed on one or more blades in a region of the blade closest to the longitudinal axis, or center line of the bit, and along the cutting face, and a plurality of rotatable cutting elements may be disposed in a region of each blade adjacent the conical cutting element region. As used herein, a conical cutting element region refers to an area having conical cutting elements disposed therein and a rotatable cutting element region refers to an area having rotatable cutting elements disposed therein.

[0045] For example, FIG. **4** shows non-planar cutting elements (specifically conical cutting elements, but other types may be used in one or more other embodiments) and rotatable cutting element placement on a drill bit according to an embodiment of the present disclosure. As shown, a drill bit **400** has a bit body **402** with a longitudinal axis **405** extending there through and a bit face **404**. A plurality of blades **410** extends radially along the bit face **404** from the longitudinal axis and axially along the bit body **402** from the bit face **404**. Particularly, the bit shown in FIG. **4** has a plurality of primary blades **417** and a plurality of secondary blades **418**, wherein the primary blades **417** extend from a point closer to the longitudinal axis than the secondary blades **418**. A plurality of conical cutting elements **420** and a plurality of rotatable cutting elements **430** are disposed on the blades **410**. As shown, the conical cutting elements **420** are disposed on at least one blade **410** in a region of the blade **410** closest to the longitudinal axis **405** and the rotatable cutting elements **430** are disposed in the remaining region of the blades **410**. The conical cutting element region extends a radial distance **411** from the longitudinal axis **405** around the bit face **404**, and the rotatable cutting element region extends a distance along the bit body **402** from the conical cutting element region.

[0046] A blade of a cutting tool may include a single type of cutting element or may include more than one type of cutting element. For example, referring to FIG. **4**, primary blades **417** have two types of cutting elements, including a plurality of conical cutting elements **420** and a plurality of rotatable cutting elements **430**, while secondary blades **418** have one type of cutting element, a plurality of rotatable cutting elements **430**. However, the present disclosure is not necessarily so limited. For example, according to some embodiments, a blade may include only conical cutting elements. In other embodiments, a blade may include more than two types of cutting elements, such as a combination of conical cutting elements, rotatable cutting elements and fixed cutters, which may be placed in the gage region of a drill bit, for example.

[0047] Further, as shown in FIG. **4**, the conical cutting elements **420** are disposed only on the primary blades **417**, wherein the radial distance of the conical cutting element region does not overlap the secondary blades **418**, as in rotated profile view. However, according to other embodiments, conical cutting elements may be disposed only on select blades to form a conical cutting element region that extends a radial distance overlapping with blades without conical cutting elements. In yet other embodiments, conical cutting elements may be disposed on all blades of a cutting tool. In such embodiments, the conical cutting element regions formed on each blade may be equally positioned radially, such that the conical cutting element region on each blade occupies the same area, as in a rotated profile view. Alternatively, in embodiments having conical cutting elements disposed on all blades of a cutting tool, the conical cutting element regions formed on each blade may be positioned differently and/or extend different radial distances, such that the conical cutting element regions occupy different areas, as in a rotated profile view.

[0048] A conical cutting element region and a rotatable cutting element region according to embodiments of the present disclosure are shown in a rotated profile view in FIG. **5**. Particularly, a profile of a bit **500** is shown as it would appear with all blades **510** and cutting faces of all cutting elements rotated into a single rotated profile **512**. In rotated profile view, the blade tops of all blades **510** of a bit **500** form and define a combined or composite blade profile **512** that extends radially from the longitudinal axis **505** to the outer radius of the bit **500** and axially along the longitudinal axis **505**. As shown, the blade profile **512** has a nose **514**, located at the axially uppermost point of the blade profile **512**. It should be noted that the term “uppermost” is a relative term and is used in reference to FIG. **5** as the uppermost part of the figure. A plurality of conical cutting elements **520** is disposed in a region **525** of the blades **510** between the longitudinal axis **505** and the nose **514**, wherein the conical cutting element region **525** extends a radial distance from the longitudinal axis **505**. A plurality of rotatable cutting elements **530** is disposed in a region **535** of the blades adjacent to the conical cutting element region **525**, wherein the rotatable cutting element region **535** extends a distance from the conical cutting element region **525** along the bit body. In some embodiments, the rotatable cutting element region **535** may extend from the conical cutting element region **525** and the remaining distance of the blades, and in other embodiments, the rotatable cutting element region **535** may extend a distance from the conical cutting element region **525** and less than the remaining distance of the blades.

[0049] According to some embodiments, a non-planar cutting element region may extend the entire distance from the longitudinal axis to the nose. As mentioned above, the nose of the profile portion which is substantially tangential to a plane that is perpendicular to the bit axis. However, in other embodiments, a non-planar cutting element region may extend a partial distance positioned between the longitudinal axis and the nose, such as the non-planar cutting element region **525** shown in FIG. **5**. For example, a non-planar cutting element region may extend from a position offset from the longitudinal axis to the nose, from a position offset from the longitudinal axis to a distance radially inward from the nose, or from the longitudinal axis to a distance radially inward from the nose. Thus, according to embodiments of the present disclosure, a non-planar cutting element region may extend various radial distances at various positions within the area of a bit face between the longitudinal axis and the nose.

[0050] Further, at or adjacent the bit longitudinal axis **505**, a non-planar cutting element (conical in one embodiment) may be included as a center coring element **524**. Such a coring element is attached directly to the bit body in a cavity formed between the blades instead of to a blade (as conical cutting elements **520** and rotatable cutting elements are attached). In accordance with the present disclosure, the center non-planar coring element **524** may be set to have its apex lower than the cutting edge of the first radial cutting element **522** (whether it is a non-planar cutting element or other type of cutting element). In a particular embodiment, the apex of conical coring element may be at a height less than the cutting edge of the first radial cutting element, ranging from 0 to 1 inch in some embodiments, from 0.1 inches up to (0.35*bit diameter) in other embodiments, or up to (0.1*bit diameter). Additionally, the conical coring element may have a cone angle ranging from 60 to 120 in some embodiments, or from 80 to 90 in yet other embodiments. The diameter of the conical coring element may range from 0.25 to 1.5 inches and from 0.3 to 0.7 inches in other embodiment. Further, the ratio of the height offset from the cutting edge to the diameter of the conical cutting element may range from about 0.1 to 6 or from about 0.5 to 3 in other embodiments Further, the diameter of a central core or cavity in which the conical coring element is disposed (i.e., the region between the plurality of blades) may be up to 3 times the diameter of the non-planar coring element. Coring elements are also described in U.S. application Ser. No. 13/528,518, which is assigned to the present assignee and herein incorporated by reference in its entirety.

[0051] A non-planar coring element may be disposed on a bit centerline or adjacent a bit centerline, i.e., spaced from 0 to up to the value of the radius of the non-planar coring insert (for symmetrical inserts). However, the present disclosure also includes the use of asymmetrical non-planar coring inserts (similar to the geometry shown in FIG. **8**), in which case the distance from the bit centerline may range from zero to up to the sum of the radius of the non-planar coring insert plus the offset between the apex of the conical cutting end and the insert centerline. Further, while the embodiment shown in FIG. **5** shows the non-planar coring element **524** being inserted so that its axis is coaxial with or parallel with a bit longitudinal axis **505**, it is also within the scope of the present disclosure that the centerline of the coring non-planar insert is angled with respect to the bit longitudinal axis. Such angled insertion may be useful when using an asymmetrical non-planar coring insert. Further, the non-planar coring insert may be inserted into a hole in the center region of a bit such that the upper extent of the cylindrical base **526** of the non-planar coring element **524** is ±0.1 inches from the bit surface, and is preferably flush with the bit surface in various embodiments.

[0052] In accordance with the present disclosure, the first radial cutting element **522** may be a conical cutting element. Such conical cutting elements may have a rounded apex having a radius of curvature ranging from 0.010 to 0.125 inches in particular embodiments. In some embodiments, the radius of curvature of the conical cutting element at the first radial position may range from a lower limit of any of 0.01, 0.02, 0.04, 0.05, 0.06, or 0.075 inches, and an upper limit of any of 0.05, 0.06, 0.075, 0.085, 0.10, or 0.0125 inches, where any lower limit may be used in combination with any upper limit. Additionally, particular embodiments may use an asymmetrical or oblique cutting element, as shown in FIG. **8**, where a conical cutting end portion **135** of the conical cutting element **128** has an axis that is not coaxial with the axis of the substrate **134**. Further, it may also be desirable to place the conical cutting element at a particular rake orientation on a blade (for the given degree of asymmetry as well as cone angle for the particular conical cutting element) such that there is an angle formed between the most radially interior portion of the conical cutting element and a line parallel to the bit longitudinal axis. In various embodiments, the angle may range from 0 to 45 degrees. In other embodiments, the angle may be greater than 0 degrees. In some embodiments, the angle may range from a lower limit of any of greater than 0, 2, 5, 10, 15, 20, or 30 degrees to an upper limit of any of 15, 20, 25, 30, 35, 40, or 45 degrees, where any lower limit may be used in combination with any upper limit. Placement of a conical cutting element in such a radial location may allow for weakening of the core strength of the rock core formed in the center region of the bit by allowing for the conical cutting element to create a score therein.

[0053] Referring to FIG. **9**, the present inventors have found that the use of rotatable cutting elements **930** in combination with non-planar cutting elements **920** may allow for a single bit to possess two types of cutting action (represented by dashed lines): cutting by compressive fracture or gouging of the formation by non-planar cutting elements **920** in addition to cutting by shearing the formation by rotatable cutting elements **930**, as shown in the schematics in FIG. **9**.

[0054] Generally, when positioning rotatable cutting elements on a blade of a downhole cutting tool such as a bit or reamer, the rotatable cutting elements may be inserted into cutter pockets (or holes in the case of non-planar cutting elements) to change the angle at which the cutter strikes the formation. For example, the back rake (i.e., a vertical orientation) and the side rake (i.e., a lateral orientation) of a cutter may be adjusted. Generally, back rake is defined as the angle **150** formed between the cutting face of the rotatable cutting element **142** and a line that is normal to the formation material being cut. As shown in FIG. **10**, with a rotatable cutting element **142** having zero back rake, the cutting face **44** is substantially perpendicular or normal to the formation material. A cutter **142** having negative back rake angle **150** has a cutting face **44** that engages the formation material at an angle that is less than 90° as measured from the formation material. Similarly, a rotatable cutting element having a positive back rake angle has a cutting face that engages the formation material at an angle that is greater than 90° when measured from the formation material. According to various embodiments of the present disclosure, the rotatable cutting elements may have a negative back rack of >5 degrees, >10 degrees, >15 degrees, >20 degrees, >25 degrees, >30 degrees, and/or <10 degrees, <15 degrees, <20 degrees, <25, <30 degrees, <35 degrees, with any upper limit being used with any lower limit.

[0055] Further, in one embodiment, a rotatable cutting element may have a side rake ranging from 0 to ±45 degrees, for example 5 to ±35 degrees, 10 to ±35 degrees or 15 to ±30 degrees. In a particular embodiment, the direction (positive or negative) of the side rake may be selected based on the cutting element distribution, i.e., whether the rotatable cutting elements are arranged in a forward or reverse spiral configuration. Additionally, the side rake may be selected based on the location of the cutting element along the blade, such as in the cone region, shoulder region, nose region, etc. For example, in some embodiments, each rotatable cutting element placed in the nose and/or shoulder region of the bit may have a side rake ranging from 10 to 30 degrees or −10 to 30 degrees. In other embodiments, each rotatable cutting element placed in the nose and/or shoulder region of the bit may have a side rake ranging from 20 to 30 degrees or −20 to −30 degrees. In some embodiments, rotatable cutting elements radially outside the shoulder, i.e., in the gage region, may range from 5 to 35 degrees or −5 to −35 degrees. In more particular embodiments, rotatable cutting elements in the gage region may be >5 degrees, >10 degrees, >15 degrees, >20 degrees, >25 degrees, >30 degrees, and/or <10 degrees, <15 degrees, <20 degrees, <25, <30 degrees, <35 degrees, with any of such angles being positive or negative, and any upper limit being used with any lower limit. Further, in some embodiments, rotatable cutting elements may be placed in the cone region of the bit may have a side rake of less than 20 degrees or ranging from 10 to 15 degrees in more particular embodiments. In various embodiments, cutting elements may be either fixedly attached or may be rolling, but may have such side rake range if fixed or rolling. It is specifically understood that any of the side rake angles for any region may be used in singly or in combination with any of the other ranges for other regions.

[0056] However, non-planar cutting elements do not have a cutting face and thus the orientation of non-planar cutting elements must be defined differently. When considering the orientation of conical cutting elements, in addition to the vertical or lateral orientation of the cutting element body, the non-planar geometry of the cutting end also affects how and the angle at which the non-planar cutting element strikes the formation. Specifically, in addition to the back rake affecting the aggressiveness of the non-planar cutting element-formation interaction, the cutting end geometry (specifically, geometry type, the apex angle, and radius of curvature) greatly affect the aggressiveness that a non-planar cutting element attacks the formation. In the context of a conical cutting element, as shown in FIG. **11**, back rake is defined as the angle **150** formed between the axis of the conical cutting element **144** (specifically, the axis of the conical cutting end) and a line that is normal to the formation material being cut. As shown in FIG. **11**, with a conical cutting element **144** having zero back rake, the axis of the conical cutting element **144** is substantially perpendicular or normal to the formation material. A conical cutting element **144** having negative back rake angle **150** has an axis that engages the formation material at an angle that is less than 90° as measured from the formation material. Similarly, a conical cutting element **144** having a positive back rake angle **150** has an axis that engages the formation material at an angle that is greater than 90° when measured from the formation material. Such orientation may be used to describe the back rake of all non-planar cutting elements. In a particular embodiment, the back rake angle of the non-planar cutting elements may be zero, or in another embodiment may be negative or positive. In embodiments, the back rake of the non-planar cutting elements may range from −35 to 35, from −10 to 10 in other embodiments, from zero to 10 in yet other embodiments, and from −5 to 5 in yet other embodiments. Further, the back rake angles of non-planar cutting elements used in embodiments disclosed herein may be selected from one or a combination of back rake angles within these ranges.

[0057] In addition to the orientation of the axis with respect to the formation, the aggressiveness of the non-planar cutting elements may also be dependent on the apex angle or specifically, the angle between the formation and the leading portion of the non-planar cutting element. In the case of a conical cutting element (although, applying to all non-planar shapes, including other pointed or dome shapes), because of the conical shape of the conical cutting elements, there does not exist a leading edge; however, the leading line of a conical cutting surface may be determined to be the firstmost points of the conical cutting element at each axial point along the conical cutting end surface as the bit rotates. Said in another way, a cross-section may be taken of a conical cutting element along a plane in the direction of the rotation of the bit, as shown in FIG. **12**. The leading line **145** of the conical cutting element **144** in such plane may be considered in relation to the formation. The strike angle of a conical cutting element **144** is defined to be the angle **155** formed between the leading line **145** of the conical cutting element **144** and the formation being cut. The strike angle will vary depending on the back rake and the cone angle, and thus, the strike angle of the conical cutting element may be calculated to be the back rake angle less one-half of the cone angle (i.e., strike angle=(0.5*cone angle)+back rake angle), where if the back rake angle **150** is negative, as described with respect to FIG. **11**, the equation will add the negative value to the (0.5*cone angle) value. In embodiments, strike angle **155** may range from about 5 to 100 degrees, and from about 20 to 65 in other embodiments. Further, the strike angles of the conical cutting elements (or other non-planar cutting element) in embodiments disclosed herein may be selected from these ranges.

[0058] Combinations of a non-planar cutting element region and a rotatable cutting element region, such as those described above, may be used on downhole cutting tools such as a drag bit (such as shown in FIG. **4**), a reamer or a bi-center bit, for example. According to embodiments of the present disclosure, a downhole cutting tool may have a tool body with a longitudinal axis extending there through and a cutting end. As used herein, the cutting end of a downhole tool refers to the longitudinal end of the tool that contacts and cuts the bottom of a wellbore, while a connection end is opposite from the cutting end and closest to the drill string that connects the tool to above ground equipment. A plurality of blades may extend azimuthally from the tool body, and a plurality of cutting elements may be disposed on the plurality of blades. The cutting elements include at least one rotatable cutting element and at least one non-planar cutting element, wherein the at least one non-planar cutting element is in a region of the blades closest to the cutting end. In one or more embodiments, the non-planar cutting elements may be conical cutting elements or other pointed cutting elements.

[0059] For example, in some embodiments, the downhole cutting tool may be a bi-centered bit having a tool body with a pilot section at the cutting end of the tool and a reamer section longitudinally offset from the pilot section. A plurality of pilot blades may extend from the pilot section of the tool body, and a plurality of reamer blades may extend from the reamer section of the tool body. For example, FIG. **13** shows a side view of a bi-center bit according to embodiments of the present disclosure. As shown, the bi-center bit **101** includes a pilot section **106** having pilot blades **108** extending therefrom and gauge pads **112** at the ends of the pilot blades **108** axially distant from the cutting end **103** of the bit **101**. A reamer section **107** having reaming blades **111** extending therefrom and gauge pads **117** is longitudinally offset from the pilot section **106**. As shown, the pilot section **106** is separated from the reamer section **107** by a longitudinal distance, which may include a spacer **102**. However, other bi-center bits may have a pilot section adjacent to the reamer section. Disposed on the pilot blades **108** and reamer blades **111** are a plurality of non-planar cutting elements (conical cutting elements in the embodiment shown) **116** and a plurality of rotatable cutting elements **110**. Further, the bi-center bit **101** has a body **114** and a threaded connection end **104** opposite from the cutting end **103**. The body **114** may include wrench flats **115** or the like for make up to a rotary power source such as a drill pipe or hydraulic motor.

[0060] According to embodiments of the present disclosure, at least one non-planar cutting element (conical cutting element in one or more embodiments) may be disposed on the pilot blades and/or the reamer blades, and at least one rotatable cutting element may be disposed on the pilot blades and/or the reamer blades. For example, FIG. **14** shows a rotated profile view of a bi-center bit **201** according to embodiments of the present disclosure. The bit **201** has a pilot section **206** having a plurality of pilot blades **208** extending therefrom and a reamer section **207** having a plurality of reamer blades **211** extending therefrom. A non-planar cutting element region **216** (an area of the cutting tool having non-planar cutting elements) may extend from the longitudinal axis of the bit **201** a distance along the bit face of the pilot section **206**, and a rotatable cutting element region **210** (an area of the cutting tool having rotatable cutting elements) may extend the remaining distance along the pilot blades **208** of the pilot section **206**. Additionally, as shown, a non-planar cutting element region **216** may extend from an area of the reamer blades **211** closest to the pilot section **206** a distance along the reamer blades **211**, and a rotatable cutting element region **210** may extend the remaining distance of the reamer blades **211**. However, in other embodiments, a non-planar cutting element region may extend the entire distance of the pilot blades **208**, and a rotatable cutting element region may extend the entire distance of the reamer blades **211**. Other combinations of non-planar cutting element regions and rotatable cutting element regions, such as described with reference to the drag bits of FIGS. **4** and **5**, may be used on the pilot section of a bi-centered bit.

[0061] Further, various combinations of one or more non-planar cutting element regions and one or more rotatable cutting element regions may be used on the reamer section of a bit-centered bit. For example, at least one non-planar cutting element may be disposed on the reamer blades in a non-planar cutting element region closest to the cutting end of the tool, and at least one rotatable cutting element may be disposed in a rotatable cutting element region adjacent to the non-planar cutting element region. In other embodiments, at least one non-planar cutting element may be disposed on the reamer blades in a non-planar cutting element region closest to a connection end of the tool, and at least one rotatable cutting element may be disposed in a rotatable cutting element region closest to the cutting end of the tool. Further, non-planar cutting element regions may be formed on one or more of the reamer blades. As described above with reference to FIG. **5**, non-planar cutting element regions may overlap, be adjacent to, or occupy the same position of the reamer blades when viewed in a rotated profile view.

[0062] Additionally, in some embodiments of the present disclosure, the downhole cutting tool may be a reamer having a tool body and a plurality of blades extending therefrom. Various combinations of one or more non-planar cutting element regions and one or more rotatable cutting element regions, such as described in reference to the reamer section of a bi-centered bit, may be used on reamer cutting tools.

[0063] Inventors of the present disclosure have found that cutting tool design using non-planar cutting elements in areas of the cutting tool subject to impact damage and rotatable cutting elements in areas of the cutting tool subject to wear may improve the life of the cutting tool. According to embodiments disclosed herein, non-planar cutting elements may provide improved impact resistance required for hard and heterogeneous drilling, while rotatable cutting elements may provide wear resistance in abrasive formations. For example, lab data and field testing have shown that conical cutting elements may have four times the impact resistance of conventional PDC cutters, and rotatable cutting elements may have improved wear resistance due to better heat dissipation than conventional PDC cutters.

[0064] 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.

What is claimed is:

1. A drill bit, comprising:
a bit body having a longitudinal axis extending there through and a bit face;
a plurality of blades extending from the bit body, wherein the plurality of blades has a blade profile comprising a nose;
a plurality of cutting elements disposed on the plurality of blades, the plurality of cutting elements comprising:
a plurality of non-planar cutting elements; and
a plurality of rotatable cutting elements;
wherein the plurality of non-planar cutting elements are disposed in a non-planar cutting element region on at least one of the blades between the longitudinal axis and the nose.

2. The drill bit of claim **1**, wherein the plurality of non-planar cutting elements have a cutting end with a conical, convex, or concave side surface terminating in a rounded apex.

3. The drill bit of claim **2**, wherein the plurality of non-planar cutting elements comprise a plurality of conical cutting elements.

4. The drill bit of claim **3**, wherein the plurality of conical cutting elements has a back rake angle ranging from −35 to 35.

5. The drill bit of claim **1**, wherein at least one rotatable cutting element comprises a substantially planar cutting face.

6. The drill bit of claim **1**, further comprising a center coring cutting element having a pointed end disposed in a region between at least two blades.

7. The drill bit of claim **1**, wherein a first radial cutting element disposed on a blade comprises an angle formed between the most radially interior portion of the first radial cutting element and a line parallel to the bit longitudinal axis, wherein the angle is greater than zero.

8. The drill bit of claim **1**, wherein the plurality of rotatable cutting elements is disposed in a rotatable cutting element region adjacent to the non-planar cutting element region.

9. The drill bit of claim **1**, wherein the plurality of rotatable cutting elements is disposed in a rotatable cutting element region overlapping with the non-planar cutting element region when viewed in a rotated profile view.

10. The drill bit of claim **1**, wherein at least one non-planar cutting element is rotatably retained to a blade.

11. The drill bit of claim **1**, wherein at least one fixed cutter is disposed in a gage region of the blade profile.

12. The drill bit of claim **1**, wherein at least one of the plurality of blades includes only non-planar cutting elements disposed thereon.

13. The drill bit of claim **1**, wherein at least one of the plurality of blades includes only rotatable cutting elements disposed thereon.

14. A downhole cutting tool, comprising:
a tool body having a longitudinal axis extending there through and a cutting end;
a plurality of blades extending from the tool body;
a plurality of cutting elements disposed on the plurality of blades, the plurality of cutting elements comprising:
at least one rotatable cutting element; and
at least one non-planar cutting element;
wherein the at least one non-planar cutting element is in a non-planar cutting element region of the blades closest to the cutting end.

15. The drill bit of claim **14**, wherein the plurality of non-planar cutting elements have a cutting end with a conical, convex, or concave side surface terminating in a rounded apex.

16. The drill bit of claim **15**, wherein the plurality of non-planar cutting elements comprise a plurality of conical cutting elements.

17. The cutting tool of claim **14**, wherein the at least one rotatable cutting element and the at least one non-planar cutting element are on the same blade.

18. The cutting tool of claim **14**, wherein the at least one rotatable cutting element is disposed in a rotatable cutting element region adjacent to the non-planar cutting element region.

19. The cutting tool of claim **14**, wherein the at least one rotatable cutting element is disposed in a rotatable cutting element region overlapping with the non-planar cutting element region when viewed in a rotated profile view.

20. The cutting tool of claim **14**, wherein the cutting tool is a bi-center bit comprising a pilot section and a reamer section longitudinally offset from the pilot section, and wherein the plurality of blades comprise pilot blades extending from the pilot section of the tool body and reamer blades extending from the reamer section of the tool body.

21. The cutting tool of claim **20**, wherein the at least one non-planar cutting element is disposed on the pilot blades and the at least one rotatable cutting element is disposed on the reamer blades.

22. The cutting tool of claim **20**, wherein at least one non-planar cutting element is disposed on the reamer blades in a non-planar cutting element region closest to the cutting end and at least one rotatable cutting element is disposed in a rotatable cutting element region adjacent to the non-planar cutting element region.

23. The cutting tool of claim **14**, wherein the cutting tool is a hole enlargement tool.

24. The cutting tool of claim **14**, wherein at least one non-planar cutting element is rotatably retained on a blade.

25. The cutting tool of claim **14**, wherein at least one of the plurality of blades includes only non-planar cutting elements disposed thereon.

26. The cutting tool of claim **14**, wherein at least one of the plurality of blades includes only rotatable cutting elements disposed thereon.

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