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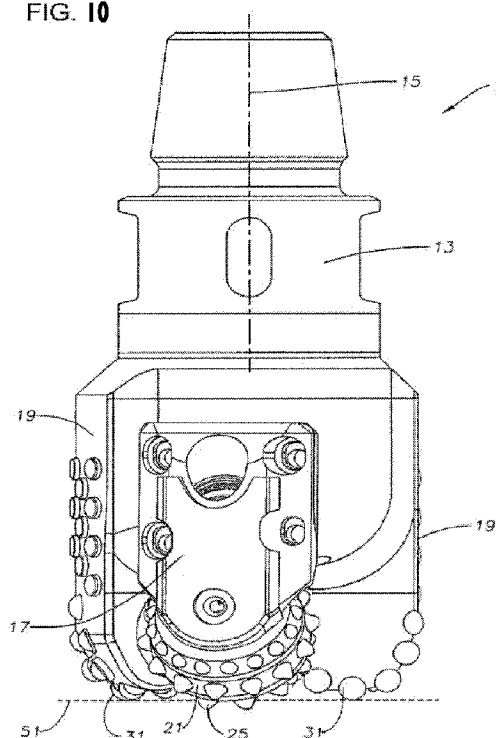
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[Continued on next page]

(54) Title: HYBRID DRILL BIT AND METHOD OF USING TSP OR MOSAIC CUTTERS ON A HYBRID BIT

FIG. 10



(57) Abstract: An earth boring drill bit comprising: a bit body; a plurality of fixed blades extending downwardly from the bit body, each blade having a leading edge; a plurality of fixed-blade cutting elements arranged on the leading edge of the fixed blades; at least one rolling cutter mounted for rotation on the bit body; and wherein the rolling cutter is configured to act as a depth-of-cut limiter, thereby reducing the risk of damage to the fixed-blade cutting elements. The fixed-blade cutting elements may include thermally stable polycrystalline diamond wafers mounted on tungsten carbide substrates and/or a mosaic of geometrically-shaped thermally stable diamond elements cooperatively arranged and bonded to form a unitary cutting surface. The rolling cutter may be positioned, relative to the fixed blades, to also limit rate of penetration and/or exposure of the fixed-blade cutting elements.



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TITLE OF THE INVENTION

Hybrid Drill Bit and Method of Using TSP or Mosaic Cutters on a Hybrid Bit

PRIORITY CLAIM

5 This application claims the benefit of U.S. Application No. 12/578,278 filed October 13, 2009. The above referenced application is incorporated herein by reference.

10 STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

REFERENCE TO APPENDIX

Not applicable.

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BACKGROUND OF THE INVENTION

Field of the Invention. The inventions disclosed and taught herein relate generally to earth-boring drill bits; and more specifically relate to a bit having a combination of rolling and fixed cutters and a method of using TSP and/or Mosaic cutters on such a bit.

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Description of the Related Art.

In the prior art, some earth-boring bits use a combination of one or more rolling cutters and one or more fixed blades. Some of these combination-type drill bits are referred to as hybrid bits. Previous designs of hybrid bits, such as is described in U.S. Pat. No. 4,343,371, to Baker, III, have provided for the rolling cutters to do most of the formation cutting, especially in the center of the hole or bit. Other types of combination bits are known as "core bits," such as U.S. Pat. No. 4,006,788, to Garner. Core bits typically have truncated rolling cutters that do not extend to the center of the bit and are designed to remove a core sample of formation by drilling down, but around, a solid cylinder of the formation to be removed from the borehole generally intact.

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Another type of hybrid bit is described in U.S. Pat. No. 5,695,019, to Shamburger, Jr., wherein the rolling cutters extend almost entirely to the center. Fixed cutter inserts 50 (FIGS. 2 and 3) are located in the dome area 2 or "crotch" of the bit to complete the removal of the drilled formation. Still
5 another type of hybrid bit is sometimes referred to as a "hole opener," an example of which is described in U.S. Pat. No. 6,527,066. A hole opener has a fixed threaded protuberance that extends axially beyond the rolling cutters for the attachment of a pilot bit that can be a rolling cutter or fixed cutter bit. In these latter two cases the center is cut with fixed cutter elements but the fixed
10 cutter elements do not form a continuous, uninterrupted cutting profile from the center to the perimeter of the bit.

U.S. Patent No. 4,006,788 discloses a "rock bit for recovering core samples is described, along with variations for drilling oil wells or the like. In each of these embodiments a plurality of diamond cutters are mounted on the bit body
15 for cutting rock by a shearing action. Each diamond cutter is in the form of a thin diamond plate bonded to a carbide slug that is inserted into the bit body. Means are also provided for limiting the depth of penetration of the diamond cutters into the rock formation being drilled preferably in the form of rolling cone cutters having a plurality of carbide insects protruding from their
20 surfaces. The protrusion of the carbide inserts from the surface of the cutter cones is less than the length of the diamond plate. This limits the depth that the diamond can penetrate in the rock and inhibits damage. Typically the diamond cutters are mounted for cutting one portion of the hole area by shearing action and the rolling cone cutters are mounted for cutting another
25 portion of its area by chipping-crushing action."

U.S. Patent No. 4,285,409 discloses a "hybrid rock bit is disclosed which consists of a pair of cone cutters mounted to legs 120.degree. apart with an extended drag bit leg occupying the remaining 120.degree. segment. Several synthetic diamond stand-off type studs are strategically located and inserted
30 in insert holes formed in the face of the drag bit leg. Nozzles are placed in front of the cutting face of the diamond studs to cool and clean the studs as the bit works in a borehole."

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U.S. Patent No. 4,343,371 discloses a “hybrid rock bit is disclosed wherein a pair of opposing extended nozzle drag bit legs are positioned adjacent a pair of opposed tungsten carbide roller cones. The extended nozzle face nearest the hole bottom has a multiplicity of diamond inserts mounted therein. The diamond inserts are strategically positioned to remove the ridges between the kerf rows in the hole bottom formed by the inserts in the roller cones.”

U.S. Patent No. 4,444,281 discloses a “rotary drill bit comprising a bit body having at least one depending leg at its lower end and at least one roller cutter rotatably mounted on the leg. The roller cutter comprises a frustoconical roller cutter body and a plurality of cutting elements projecting from the cutter body to tips adapted to bear on the bottom of the well bore, with the tips defining, upon rotation of the bit, a first cutting surface of the bit extending over substantially the entire area of the bottom of the well bore. At least one drag cutter extends down from the bit body and comprises a support and a plurality of drag cutting elements on the support, each having a lower cutting edge. The cutting edges of these elements are so arranged relative to the tips of the hard metal cutting elements as to define, upon rotation of the bit, a second cutting surface of generally the same configuration as the first but spaced above it, whereby upon drilling a relatively brittle formation only the hard metal cutting elements bear on the formation for cutting the formation by fracturing it thereby protecting the drag cutting elements, and upon drilling a relatively plastically deformable material which the hard metal cutting elements penetrate to a relatively deep depth without causing substantial fracturing of the formation, the drag cutting elements also engage the formation for improved drill bit cutting action and increased rates of drilling penetration.”

U.S. Patent No. 4,726,718 discloses a “diamond cutter for use in a drill bit having a geometric size and shape normally characterized by unleached diamond product, such as STRATAPAX diamond cutters, can be fabricated by assembling a plurality of prefabricated leached polycrystalline diamond (PCD) elements in an array in a cutting slug. A cutting slug is formed of matrix material which in one embodiment is impregnated with diamond grit. The

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cutting face of the cutting slug is characterized by exposing at least one surface of each of the PCD elements disposed therein. The diamonds may be set within the cutting slug either in a compact touching array or in a spaced-apart relationship. More than one type of array may also be employed within a single cutting slug. The PCD elements can assume a variety of polyhedral shapes such as triangular prismatic elements, rectangular elements, hexagonal elements and the like. The plurality of diamond elements and the cutting slug are fabricated using hot pressing or infiltration techniques.”

U.S. Patent No. 4,943,488 discloses an “improved temperature stable synthetic polycrystalline diamond (PCD) product includes at least one temperature stable PCD integrally and chemically bonded to a matrix carrier support through a carbide forming layer which is of a thickness of at least about 1 micron, the layer on at least one surface of the PCD is in turn bonded to the matrix carrier. A wide variety of shapes, sizes and configurations of such products is achieved through relatively low temperature and relatively low pressure processing. Various products of various geometries are described as well as the details of the processing to achieve chemical bonding of the PCD elements in a variety of support matrix carrier materials to form a unitary structure having a temperature stability up to about 1,200 degrees C.”

U.S. Patent No. 5,027,912 discloses drill bits that “may include cutting members which have cutting faces formed of segments of differing cutting materials. The faces of the cutting members may include two or more segments, with the segments formed from at least two different materials. For example, a first segment could be formed of a polycrystalline diamond compact surface while a second segment could be formed of a thermally stable diamond product material.”

U.S. Patent No. 5,028,177 discloses a “diamond cutter for use in a drill bit having a geometric size and shape normally characterized by unleached diamond product, such as STRATAPAX diamond cutters, can be fabricated by assembling a plurality of prefabricated leached polycrystalline diamond

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(PCD) elements in an array in a cutting slug. A cutting slug is formed of matrix material which in one embodiment is impregnated with diamond grit. The cutting face of the cutting slug is characterized by exposing at least one surface of each of the PCD elements disposed therein. The diamonds may be set within the cutting slug either in a compact touching array or in a spaced-apart relationship. More than one type of array may also be employed within a single cutting slug. The PCD elements can assume a variety of polyhedral shapes such as triangular prismatic elements, rectangular elements, hexagonal elements and the like. The plurality of diamond elements and the cutting slug are fabricated using hot pressing or infiltration techniques.”

U.S. Patent No. 5,030,276 discloses an “improved temperature stable synthetic polycrystalline diamond (PCD) product includes at least one temperature stable PCD integrally and chemically bonded to a matrix carrier support through a carbide forming layer which is of a thickness of at least about 1 micron, the layer on at least one surface of the PCD is in turn bonded to the matrix carrier. A wide variety of shapes, sizes and configurations of such products is achieved through relatively low temperature and relatively low pressure processing. Various products of various geometries are described as well as the details of the processing to achieve chemical bonding of the PCD elements in a variety of support matrix carrier materials to form a unitary structure having a temperature stability up to about 1,200 degrees C.”

U.S. Patent No. 5,116,568 discloses an “improved temperature stable synthetic polycrystalline diamond (PCD) product includes at least one temperature stable PCD integrally and chemically bonded to a matrix carrier support through a carbide forming layer which is of a thickness of at least about 1 micron, the layer on at least one surface of the PCD is in turn is bonded to the matrix carrier. A wide variety of shapes, sizes and configurations of such products is achieved through relatively low temperature and relatively low pressure processing. Various products of various geometries are described as well as the details of the processing to achieve chemical bonding of the PCD elements in a variety of support matrix carrier

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materials to form a unitary structure having a temperature stability up to about 1,200 degrees C.”

U.S. Patent No. 5,238,074 discloses a “cutter for a rotating drag bit which has a cutting face formed from a plurality of polycrystalline diamond compact
5 (PCD) elements. The elements can be of varying thickness and/or varying hardness to provide a cutting edge having a nonuniform wear pattern. Also provided is a cutter which includes two layers of PCD elements. The PCD elements can be of varying thickness and/or hardness to provide a cutter which presents a cutting edge having a wear ratio which varies with cutter
10 wear. Also provided is an impact cutter having a cutting surface formed from one or more layers of PCD elements.”

European Patent No. EP157278 discloses a “diamond cutting table having the geometric characteristics of larger unleached diamond compact products and yet characterised by the physical properties of smaller leached diamond
15 products is fabricated by forming a diamond cutter incorporating a plurality of polycrystalline diamond (PCD) leached disks (12). The PCD leached disks (12) are disposed in array in a cutting slug (10) formed of matrix material (14). The matrix material is disposed between and around the plurality of diamond disks (12) and in one embodiment incorporates a volume distribution of
20 diamond grit. The cutting slug is hot pressed or infiltrated to form an integral mass or table. The diamond table is then bonded to a cutter or directly molded into an integral tooth within a matrix body bit.”

European Patent No. EP225101 discloses a “rotary drill bit for drilling deep holes in subsurface formations comprises a bit body (10) having a shank for
25 connection to a drill string and a plurality of elements (16,22) mounted on the bit body (10) for cutting, abrading or bearing on the formation being drilled. The bit body (10) includes a fixed structure (11) and a movable structure (17), each carrying elements (16,22) for acting on the formation, the movable structure (17) being capable of reversible movement relatively to the fixed
30 structure (11) between two limiting positions, the relative movement providing at least two configurations in which there are different distributions, between

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said elements (16,22), of the loads applied to the bit during its engagement with the formation.; Control means, such as hydraulic means (29,30), are provided to control the movement of the movable structure (17), and hence the load distribution between the elements (16,22), automatically in response to the torque and/or axial loads applied to the bit.”

United Kingdom Patent Application No. GB 2183694 discloses a “rotary drill bit for drilling deep holes in subsurface formations comprises a bit body 10 having a shank 14 for connection to a drill string and a plurality of elements 22,16 mounted on the bit body for cutting, abrading or bearing on the formation being drilled. The bit body includes a fixed structure 11 and a movable structure 17, each carrying elements for acting on the formation, the movable structure being capable of reversible movement relatively to the fixed structure between two limiting positions, the relative movement providing at least two configurations in which there are different distributions, between said elements 22,16, of the loads applied to the bit during its engagement with the formation. Control means, such as hydraulic means 29,30 or spring means, are provided to control the movement of the movable structure 17, and hence the load distribution between the elements 22,16, automatically in response to the torque and/or axial loads applied to the bit. ”

The inventions disclosed and taught herein are directed to an improved drill bit having a combination of rolling and fixed cutters and a method of using TSP and/or Mosaic cutters on such a bit.

BRIEF SUMMARY OF THE INVENTION

An earth boring drill bit comprising: a bit body; a plurality of fixed blades extending downwardly from the bit body, each blade having a leading edge and a trailing edge; a plurality of fixed-blade cutting elements arranged on the leading edge of the fixed blades; at least one rolling cutter mounted for rotation on the bit body; and wherein the rolling cutter is configured to act as a depth-of-cut limiter, thereby reducing the risk of damage to the fixed-blade cutting elements. The fixed-blade cutting elements may include thermally

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stable polycrystalline diamond wafers mounted on tungsten carbide substrates and/or a mosaic of geometrically-shaped thermally stable diamond elements cooperatively arranged and bonded to form a unitary cutting surface. The rolling cutter may be positioned, relative to the fixed blades, such that any rolling-cutter cutting elements and the fixed-blade cutting elements cooperate up to a maximum depth-of-cut. The rolling cutter may be positioned, relative to the fixed blades, to limit depth-of-cut, rate of penetration, and/or exposure of the fixed-blade cutting elements. The rolling cutter may be positioned, relative to the fixed blades, such that any rolling-cutter cutting elements extend beyond the fixed blades and/or the fixed-blade cutting elements. The rolling cutter may be aligned with the fixed-blade cutting elements or between the fixed blades and the fixed-blade cutting elements.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 illustrates a bottom plan view of an embodiment of the hybrid earth-boring bit constructed in accordance with certain aspects of the present inventions;

Figure 2 illustrates a side elevation view of the embodiment of the hybrid earth-boring bit of FIG. 1 constructed in accordance with certain aspects of the present inventions;

Figure 3 illustrates a side elevation view of the hybrid earth-boring bit of FIG. 1 constructed in accordance with certain aspects of the present inventions;

Figure 4 illustrates a bottom plan view of the embodiment of the hybrid earth-boring bit of FIGS. 1 through 3 showing streams of fluid directed from the nozzles;

Figure 5 illustrates a side elevation view of the embodiment of the hybrid earth-boring bit of FIGS. 1 through 3 showing streams of fluid directed from the nozzles;

Figure 6 illustrates a first side elevation view of the rolling cutters employed in the embodiment of the hybrid earth-boring bit of FIGS. 1 through 3;

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Figure 7 illustrates a second side elevation view of the rolling cutters employed in the embodiment of the hybrid earth-boring bit of FIGS. 1 through 3;

Figure 8 illustrates a composite view of all of the rolling-cutter cutting elements and the fixed-blade cutting elements on the embodiment of the hybrid drill bit of FIGS. 1 through 3 rotated about the central axis of the bit body and into one plane, and commonly known as a "cutting profile";

Figure 9 illustrates a superimposition of the cutting profile of FIG. 8 onto a cutting profile of a typical rolling-cutter earth-boring bit; and

Figure 10 illustrates a side elevation view of another embodiment of the hybrid earth-boring bit constructed in accordance with certain aspects of the present inventions.

DETAILED DESCRIPTION OF THE INVENTION

The Figures described above and the written description of specific structures and functions below are not presented to limit the scope of what Applicants have invented or the scope of the appended claims. Rather, the Figures and written description are provided to teach any person skilled in the art to make and use the inventions for which patent protection is sought. Those skilled in the art will appreciate that not all features of a commercial embodiment of the inventions are described or shown for the sake of clarity and understanding. Persons of skill in this art will also appreciate that the development of an actual commercial embodiment incorporating aspects of the present inventions will require numerous implementation-specific decisions to achieve the developer's ultimate goal for the commercial embodiment. Such implementation-specific decisions may include, and likely are not limited to, compliance with system-related, business-related, government-related and other constraints, which may vary by specific implementation, location and from time to time. While a developer's efforts might be complex and time-consuming in an absolute sense, such efforts would be, nevertheless, a routine undertaking for those of skill in this art having benefit of this disclosure. It must be understood that the inventions disclosed and taught herein are susceptible to numerous and various modifications and alternative

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forms. Lastly, the use of a singular term, such as, but not limited to, "a," is not intended as limiting of the number of items. Also, the use of relational terms, such as, but not limited to, "top," "bottom," "left," "right," "upper," "lower," "down," "up," "side," and the like are used in the written description for clarity in specific reference to the Figures and are not intended to limit the scope of the invention or the appended claims.

Applicants have created an earth boring drill bit comprising: a bit body; a plurality of fixed blades extending downwardly from the bit body, each blade having a leading edge and a trailing edge; a plurality of fixed-blade cutting elements arranged on the leading edge of the fixed blades; at least one rolling cutter mounted for rotation on the bit body; and wherein the rolling cutter is configured to act as a depth-of-cut limiter, thereby reducing the risk of damage to the fixed-blade cutting elements. The fixed-blade cutting elements may include thermally stable polycrystalline diamond wafers mounted on tungsten carbide substrates and/or a mosaic of geometrically-shaped thermally stable diamond elements cooperatively arranged and bonded to form a unitary cutting surface. The rolling cutter may be positioned, relative to the fixed blades, such that any rolling-cutter cutting elements and the fixed-blade cutting elements cooperate up to a maximum depth-of-cut. The rolling cutter may be positioned, relative to the fixed blades, to limit depth-of-cut, rate of penetration, and/or exposure of the fixed-blade cutting elements. The rolling cutter may be positioned, relative to the fixed blades, such that any rolling-cutter cutting elements extend beyond the fixed blades and/or the fixed-blade cutting elements. The rolling cutter may be aligned with the fixed-blade cutting elements or between the fixed blades and the fixed-blade cutting elements.

Referring to FIGS. 1-8, an earth-boring bit 11 according to an embodiment of the present invention is disclosed. Bit 11 comprises a bit body 13 having a central longitudinal axis 15 that defines an axial center of the bit body 13. In the illustrated embodiment, the bit body 13 is steel, but could also be formed of matrix material with steel reinforcements, or of a sintered carbide material.

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Bit body 13 includes a shank at the upper or trailing end thereof threaded or otherwise configured for attachment to a hollow drillstring (not shown), which rotates bit 11 and provides pressurized drilling fluid to the bit and the formation being drilled.

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The radially outermost surface of the bit body 13 is known as the gage surface and corresponds to the gage or diameter of the borehole (shown in phantom in FIG. 1) drilled by bit 11. At least one (two are shown) bit leg 17 extends downwardly from the bit body 13 in the axial direction. The bit body 13 also has a plurality (e.g., also two shown) of fixed blades 19 that extend downwardly in the axial direction. The number of bit legs 17 and fixed blades 19 is at least one but may be more than two. In the illustrated embodiment, bit legs 17 (and the associated rolling cutters) are not directly opposite one another (are about 191 degrees apart measured in the direction of rotation of bit 11), nor are fixed blades 19 (which are about 169 degrees apart measured in the direction of rotation of bit 11). Other spacings and distributions of legs 17 and blades 19 may be appropriate.

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A rolling cutter 21 is mounted on a sealed journal bearing that is part of each bit leg 17. According to the illustrated embodiment, the rotational axis of each rolling cutter 21 intersects the axial center 15 of the bit 11. Sealed or unsealed journal or rolling-element bearings may be employed as cutter bearings. Each of the rolling cutters 21 is formed and dimensioned such that the radially innermost ends of the rolling cutters 21 are radially spaced apart from the axial center 15 (FIG. 1) by a minimal radial distance 23 of about 0.60 inch. As shown in particular in FIGS. 6 and 7, rolling cutters 21 are not conical in configuration as is typical in conventional rolling cutter bits. Further, the radially outermost surface of each rolling cutter 21 (typically called the gage cutter surface in conventional rolling cutter bits), as well as the bit legs 17, are "off gage" or spaced inward from the outermost gage surface of bit body 13. In the illustrated embodiment, rolling cutters 21 have no skew or angle and no offset, so that the axis of rotation of each rolling cutter 21 intersects the axial center (central axis) 15 of the bit body 13 (as shown in FIG. 8). Alternatively,

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the rolling cutters 21 may be provided with skew angle and (or) offset to induce sliding of the rolling cutters 21 as they roll over the borehole bottom. In some embodiments, the rolling cutters 21 may be constructed from cast carbide, hard faced steel, or some other type of plain metal.

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At least one (a plurality are illustrated) rolling-cutter cutting inserts or elements 25 are arranged on the rolling cutters 21 in generally circumferential rows thereabout such that each cutting element 25 is radially spaced apart from the axial center 15 by a minimal radial distance 27 of about 0.30 inch. The minimal radial distances 23, 27 may vary according to the application and bit size, and may vary from cone to cone, and/or cutting element to cutting element, an objective being to leave removal of formation material at the center of the borehole to the fixed-blade cutting elements 31 (rather than the rolling-cutter cutting elements 25). Rolling-cutter cutting elements 25 need not be arranged in rows, but instead could be "randomly" placed on each rolling cutter 21. Moreover, the rolling-cutter cutting elements may take the form of one or more discs or "kerf-rings," which would also fall within the meaning of the term rolling-cutter cutting elements.

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Tungsten carbide inserts, secured by interference fit into bores in the rolling cutter 21 are shown, but a milled- or steel-tooth cutter having hardfaced cutting elements (25) integrally formed with and protruding from the rolling cutter could be used in certain applications and the term "rolling-cutter cutting elements" as used herein encompasses such teeth. The inserts or cutting elements may be chisel-shaped as shown, conical, round, or ovoid, or other shapes and combinations of shapes depending upon the application. Rolling-cutter cutting elements 25 may also be formed of, or coated with, superabrasive or super-hard materials such as polycrystalline diamond, cubic boron nitride, and the like. The bit 11 may include one or more rolling cutters 21, without or without rolling-cutter cutting elements 25, preferably with one rolling cutter 21 mounted on each bit leg 17.

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In addition, a plurality of fixed or fixed-blade cutting elements 31 are arranged in a row and secured to each of the fixed blades 19 at the leading edges thereof (leading being defined in the direction of rotation of bit 11). Each of the fixed-blade cutting elements 31 comprises a polycrystalline diamond layer or table on a rotationally leading face of a supporting substrate, the diamond layer or table providing a cutting face having a cutting edge at a periphery thereof for engaging the formation. At least a portion of at least one of the fixed cutting elements 31 is located near or at the axial center 15 of the bit body 13 and thus is positioned to remove formation material at the axial center of the borehole (typically, the axial center of the bit will generally coincide with the center of the borehole being drilled, with some minimal variation due to lateral bit movement during drilling). In a 7 7/8 inch bit as illustrated, the at least one of the fixed cutting elements 31 has its laterally innermost edge tangent to the axial center of the bit 11 (as shown in FIG. 8). In any size bit, at least the innermost lateral edge of the fixed-blade cutting element 31 adjacent the axial center 15 of the bit should be within approximately 0.040 inches of the axial center 15 of the bit (and, thus, the center of the borehole being drilled).

Fixed-blade cutting elements 31 radially outward of the innermost cutting element 31 are secured along portions of the leading edge of blade 19 at positions up to and including the radially outermost or gage surface of bit body 11. In addition to fixed-blade cutting elements 31 including polycrystalline tables mounted on tungsten carbide substrates, such term as used herein encompasses thermally stable polycrystalline diamond (TSP) wafers or tables mounted on tungsten carbide substrates, and other, similar superabrasive or super-hard materials such as cubic boron nitride and diamond-like carbon. Fixed-blade cutting elements 31 may be brazed or otherwise secured in recesses or "pockets" on each blade 19 so that their peripheral or cutting edges on cutting faces are presented to the formation.

Four nozzles 63, 65 are generally centrally located in receptacles in the bit body 13. A pair of fixed blade nozzles 63 is located close or proximal to the

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axial center 15 of the bit 11. Fixed blade nozzles 63 are located and configured to direct a stream of drilling fluid from the interior of the bit to a location at least proximate (preferably forward of to avoid unnecessary wear on elements 31 and the material surrounding and retaining them) at least a
5 portion of the leading edge of each fixed blade 19 and the fixed-blade cutting elements 31 carried thereon (FIGS. 4 and 5). Another pair of rolling cutter nozzles 65 are spaced-apart from the central axis 15 of the bit body 13 (radially outward of fixed blade nozzles 63) and are located and configured to direct a stream of drilling fluid to a location at least proximate the trailing side of each
10 rolling cutter 21 and rolling-cutter cutting elements 25 (FIGS. 4 and 5). The streams of drilling fluid cool the cutting elements and remove cuttings from blades 19 and rolling cutters 21 and their associated cutting elements 25, 31. Nozzles 63, 65 may be conventional cylinders of tungsten carbide or similar hard metal that have circular apertures of selected dimension. Nozzles 63, 65
15 are threaded to retain them in their respective receptacles. Nozzles 63, 65 may also take the form of "ports" that are integrally formed at the desired location and with the correct dimension in the bit body 13.

In connection with the nozzles, a pair of junk slots 71 are provided between
20 the trailing side of each rolling cutter 21, and the leading edge of each fixed blade 19 (leading and trailing again are defined with reference to the direction of rotation of the bit 11). Junk slots 71 provide a generally unobstructed area or volume for clearance of cuttings and drilling fluid from the central portion of the bit 11 to its periphery for return of these materials to the surface. As
25 shown in FIGS. 2, 4 and 5, junk slots 71 are defined between the bit body 13 and the space between the trailing side of each cutter 21 and the leading edge of each blade 19. The volume of the junk slot exceeds the open volume of other areas of the bit, particularly in the angular dimension 73 of the slot, which is much larger than the angular dimension (and volume defined)
30 between the trailing edge of each blade 19 and the leading edge of each rolling cutter 21. The increased volume of junk slots 71 is partially accomplished by providing a recess in the trailing side of each fixed blade 19 (see FIG. 1) so that the rolling cutters 21 can be positioned closer to the

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trailing side of each fixed blade than would be permitted without the clearance provided by the recess.

Also provided on each fixed blade 19, between the leading and trailing edges,
5 are a plurality of backup cutters or cutting elements 81 arranged in a row that is generally parallel to the leading edge of the blade 19. Backup cutters 81 are similar in configuration to fixed blade cutters or cutting elements 31, but may be smaller in diameter or more recessed in a blade 19 to provide a reduced exposure above the blade surface than the exposure of the primary fixed-
10 blade cutting elements 31 on the leading blade edges. Alternatively, backup cutters 81 may comprise BRUTE™ cutting elements as offered by the assignee of the present invention through its Hughes Christensen operating unit, such cutters and their use being disclosed in U.S. Pat. No. 6,408,958, which is incorporated herein by specific reference. As another alternative,
15 rather than being active cutting elements similar to fixed blade cutters 31, backup cutters 81 could be passive elements, such as round or ovoid tungsten carbide or superabrasive elements that have no cutting edge (although still referred to as backup cutters or cutting elements). Such passive elements would serve to protect the lower surface of each blade 19 from
20 wear.

Preferably, backup cutters 81 are radially spaced along the blade 19 to concentrate their effect in the nose, shoulder, and gage areas (as described below in connection with FIG. 8). Backup cutters 81 can be arranged on
25 blades 19 to be radially "aligned" with fixed blade cutters 31 so that the backup cutters 81 cut in the same groove or kerf made by the fixed blade cutters 31 on the same blade 19. Alternatively, backup cutters 81 can be arranged to be radially offset from the fixed blade cutters 31 on the same blade 19, so that they cut between the grooves made by cutters 31. Backup
30 cutters 81 add cutting elements to the cutting profile (FIG. 1) and increase cutter "coverage" in terms of redundancy at each radial position on the bottom of the borehole. Whether active cutting elements as illustrated or passive elements, backup cutters 81 can help reduce wear of and damage to cutting

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elements 31, and well as reduce the potential for damage to or wear of fixed blades 19. Additionally, backup cutters 81 create additional points of engagement between bit 11 and the formation being drilled. This enhances bit stability, for example making the two-fixed-blade configuration illustrated exhibit stability characteristics similar to a four-bladed fixed-cutter bit.

In addition to backup cutters 81, a plurality of wear-resistant elements 83 are present on the gage surface at the outermost periphery of each blade 19 (FIGS. 1 and 2). These elements 83 may be flat-topped or round-topped tungsten-carbide or other hard-metal inserts interference fit into apertures on the gage surface of each blade 19. The primary function of these elements 83 is passive and is to resist wear of the blade 19. In some applications, it may be desirable to place active cutting elements on the bit leg, such as super-hard (polycrystalline diamond) flat-topped elements with a beveled edge for shear-cutting the sidewall of the borehole being drilled.

FIGS. 6 and 7 illustrate each of the rolling cutters 21, which are of different configuration from one another, and neither is generally conical, as is typical of rolling cutters used in rolling-cutter-type bits. Cutter 91 of FIG. 6 has four surfaces or lands on which cutting elements or inserts are located. A nose or innermost surface 93 is covered with flat-topped, wear-resistant inserts or cutting elements. A second surface 95 is conical and of larger diameter than the first 91, and has chisel-shaped cutting elements on it. A third surface 97 is conical and of smaller diameter than the second surface 95 and again has chisel-shaped inserts. A fourth surface 99 is conical and of smaller diameter than the second 95 and third 97 surfaces, but is larger than the first 93. Fourth surface 99 has round-topped inserts or cutting elements that are intended primarily to resist wear.

Cutter 101 of FIG. 7 also has four surfaces or lands on which cutting elements are located. A nose or first surface 103 has flat-topped, wear-resistant cutting elements on it. A second surface 105 is conical and of larger diameter than the first surface 103. Second surface 105 has chisel-shaped cutting elements

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on it. A third surface 107 is generally cylindrical and of larger diameter than second surface 105. Again, chisel-shaped cutting elements are on the third surface 107. A fourth surface 109 is conical and of smaller diameter than third surface 107. Round-topped wear-resistant inserts are placed on fourth surface 109.

FIG. 8 is a schematic superimposition of the cutter and fixed cutting elements 25, 31 on each of the cutters and blades obtained by rotating the elements about the central axis 15 into a single plane. FIG. 8 is known as a "cutting profile." As shown in FIG. 8, the rolling-cutter cutting elements 25 and the fixed-blade cutting elements 31 combine to define a cutting profile 41 that extends from the axial center 15 through a "cone region," a "nose region," and a "shoulder region" (see FIG. 9) to a radially outermost perimeter or gage surface 43 with respect to the axis (backup cutters 81 are not shown for clarity). In the illustrated embodiment, only the fixed-blade cutting elements 31 form the cutting profile 41 at the axial center 15 and the gage surface 43. However, the rolling-cutter cutting elements 25 overlap or combine with the fixed-blade cutting elements 31 on the cutting profile 41 to produce substantially congruent surfaces or kerfs in the formation being drilled between the cone region near the axial center 15 and the gage region at the gage of the borehole 43. The rolling-cutter cutting elements 25 thus are configured to cut at the nose 45 and shoulder 47 of the cutting profile 41, where the nose 45 is the axially leading part of the profile (i.e., located between the axial center 15 and the shoulder 47) facing the borehole wall and located adjacent the gage surface 43. In this context, "shoulder" is used to describe the transition between the nose region 45 and the gage region and the cutting profile.

FIG. 9 is a superimposition of the cutting profile of FIG. 8 (noted by curved line 141) with a representative profile generated by a similarly sized (77/8 inch) three-cone rolling cutter bit (noted by the curved line 151). The two profiles are aligned at gage 133, that is, the radially outermost surfaces of each bit are aligned for comparison. The profile of the hybrid bit according to

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the present invention divides into three regions, as alluded to previously: a generally linear cone region 143 extending from the axial center radially outward; a nose region 141 that is curved at a selected radius and defines the leading portion of the bit; and a shoulder region 147 that is also curved at a selected radius and is connects the nose region to the gage of the bit 133. The cone region 141 describes an angle α with the horizontal bottom of the borehole of between about 10 and 30 degrees, preferably about 20 degrees. The selected radii in the nose 145 and shoulder 147 regions may be the same (a single radius) or different (a compound radius). In either case, the profile curve of the hybrid bit is tangent to gage 133 at the point at which it intersects the gage. As can be seen, the rolling cutter profile 151 defines a generally sweeping curve (typically of multiple compound radii) that extends from the axial center to the gage and is not tangent to gage 133 where it intersects gage. The curve described by the profile of the hybrid bit according to the present invention thus more resembles that of a typical modern fixed-cutter diamond bit than that of a rolling-cutter bit.

As illustrated and previously mentioned, the radially innermost fixed-blade cutting element 31 preferably is substantially tangent to the axial center 15 of the bit 11. The radially innermost lateral or peripheral portion of the innermost fixed cutting element should preferably be no more than 0.040 inch from the axial center 15. The radially innermost rolling-cutter cutting element 25 (other than the cutter nose elements, which do not actively engage the formation), is spaced apart a distance 29 of about 2.28 inch from the axial center 15 of the bit for the 77/8 inch bit illustrated.

Thus, the rolling-cutter cutting elements 25 and the fixed-blade cutting elements 31 combine to define a congruent cutting face in the nose 45 and shoulder 47 (FIG. 8), which are known to be the most difficult to drill portions of a borehole. The nose or leading part of the profile is particularly highly loaded when drilling through transitions from soft to hard rock when the entire bit load can be concentrated on this small portion of the borehole. The shoulder, on the other hand, absorbs the lateral forces, which can be

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extremely high during dynamic events such as bit whirl, and stick-slip. In the nose and shoulder area, the cutting speed is the highest and more than half the cuttings volume is generated in this region. The rolling-cutter cutting elements 25 crush and pre- or partially fracture formation in the highly stressed nose and shoulder sections, easing the burden on fixed blade cutter elements 31.

A reference plane 51 (FIGS. 2 and 3) is located at the leading or distal-most axial end of the hybrid drill bit 11. At least one of each of the rolling-cutter cutting elements 25 and the fixed cutting elements 31 extend in the axial direction at the reference plane 51 at a substantially equal dimension, but are radially offset from each other. However, such alignment in a common plane 51 perpendicular to the central axis 15 between the distal-most elements rolling and fixed cutter cutting elements 25, 31 is not required such that elements 25, 31 may be axially spaced apart (or project a different distance) by a significant distance (0.125 inch) when in their distal-most position. The fixed-blade cutting elements 31 are axially spaced apart from and distal from (e.g., lower than) the bit body 13.

In another embodiment, rolling-cutter cutting elements 25 may extend beyond (e.g., by approximately 0.060-0.125 inch) the distal-most position of the fixed blades 19 and fixed-blade cutting elements 31 to compensate for the difference in wear between those components. As the profile 41 transitions from the shoulder 47 to the gage 43 of the hybrid bit 11, the rolling-cutter elements 25 no longer engage the formation (see FIG. 8), and multiple rows of vertically-staggered (i.e., axially) fixed-blade cutting elements 31 ream out a smooth borehole wall. Rolling-cutter cutting elements 25 are much less efficient in reaming at the gage and can cause undesirable borehole wall damage. Indeed, both the portion of each bit leg 17 above the rolling cutter and the rolling cutters 21 themselves are radially spaced-apart from the sidewall of the borehole so that contact between rolling-cutter cutting elements 25 and the sidewall of the borehole is minimized or eliminated entirely.

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The invention has several advantages and includes providing a hybrid drill bit that cuts at the center of the hole solely with fixed cutting elements and not with rolling cutters. The fixed-blade cutting elements are highly efficient at cutting the center of the hole. Moreover, due to the relatively low cutting velocity of the fixed-blade cutting elements in the center due to their proximity to the central axis of the bit body, the polycrystalline diamond compact or other superabrasive cutting elements are subject to little or no wear. The rolling cutters and their cutting elements are configured to cut a nearly congruent surface (with the cutting elements on the fixed blade) and thereby enhance the cutting action of the blades in the most difficult to drill nose and shoulder areas, which are the leading profile section (axially speaking) and thus are subjected to high wear and vibration damage in harder, more abrasive formations. The crushing action of the tungsten carbide rolling cutter inserts drives deep fractures into the hard rock, which greatly reduces its strength. The pre- or partially fractured rock is easier to remove and causes less damage and wear to the fixed-blade cutting elements than pristine formation material commonly drilled by conventional diamond or PDC cutting element-equipped drag bits. The perimeter or gage of the borehole is generated with multiple, vertically-staggered rows of fixed-blade cutting elements. This leaves a smooth borehole wall and reduces the sliding and wear on the less wear-resistant rolling cutter inserts.

As discussed above, the fixed-blade cutting elements 31 may include thermally stable polycrystalline diamond (TSP) wafers or tables mounted on tungsten carbide substrates. Alternatively, or additionally, the fixed-blade cutting elements 31 may include mosaic cutters which may be formed of a plurality of geometrically-shaped thermally stable diamond elements cooperatively arranged and bonded in a desired shape, to form a unitary cutting surface. Of course, TSP and/or mosaic fixed-blade cutting elements 31, may be more susceptible to breakage. In any case, in some embodiments, the TSP and/or mosaic fixed-blade cutting elements 31 may be similar to any one or more of those shown in the following United States and

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European patent documents, each of which is incorporated herein be specific reference:

US4664705	US6592985	US7462003	US20060254830
US4726718	US6601662	US7473287	US20060266558
US4943488	US6739214	US7493973	US20060266559
US5028177	US6749033	US7517589	US20070029114
US5030276	US6797326	US7533740	US20070079994
US5116568	US6861098	US7568534	US20070187155
US5238074	US6861137	EP157278	US20090114454
US6544308	US6878447	EP2089187	US20090178855
US6562462	US7350601	US20050263328	US20090183925
US6585064	US7377341	US20060032677	
US6589640	US7435478	US20060162969	

Therefore, in one embodiment, the rolling cutters 21 may be configured to act
 5 as a depth of cut (DOC) control, or limiter, thereby reducing the risk of
 damage to the TSP and/or mosaic fixed-blade cutting elements 31. More
 specifically, the rolling cutters 21 may be positioned, relative to the fixed
 blades 19, such that the rolling-cutter cutting elements 25 and the fixed-blade
 cutting elements 31 cooperate up to a maximum DOC, at which point the
 10 rolling cutters 21 themselves engage the formation, thereby holding the drill
 bit 11 back and protecting the TSP and/or mosaic fixed-blade cutting
 elements 31. As the rolling-cutter cutting elements 25 and the fixed-blade
 cutting elements 31 are rotated through the formation, they continue to
 remove formation material, and therefore allow the drill bit 11 to advance.
 15 However, in this embodiment, the rolling cutters 21 may be positioned,
 relative to the fixed blades 19, to prevent excessive rate of penetration (ROP)
 which may otherwise expose the TSP and/or mosaic fixed-blade cutting
 elements 31 to impact damage.

20 For example, rather than the rolling-cutter cutting elements 25 and the fixed-
 blade cutting elements 31 being aligned at the reference plane 51, as shown
 in FIG. 2 and FIG. 3, the rolling cutters 21 may be positioned, or may extend,

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beyond the fixed blades 19, as shown in FIG. 10. In other words, the rolling-cutter cutting elements 25 may be positioned, or may extend, beyond the fixed-blade cutting elements 31, as shown in FIG. 10. More specifically, the rolling cutters 21, themselves, may be aligned at the reference plane 51, with the rolling-cutter cutting elements 25 extending beyond the reference plane 51. Alternatively, the rolling cutters 21 may be positioned, relative to the fixed blades 19, virtually anywhere between the alignment shown in FIG. 2 and FIG. 3 and that shown in FIG. 10. In other words, a deepest point of the rolling cutters 21 may extend beyond a deepest point of the fixed blades 19, and may or may not extend beyond a deepest point of the fixed-blade cutting elements 31.

Other and further embodiments utilizing one or more aspects of the inventions described above can be devised without departing from the spirit of Applicant's invention. For example, other structures may be used for DOC control and/or prevent excessive ROP, thereby protecting the TSP and/or mosaic fixed-blade cutting elements 31 from impact damage. Alternatively and/or additionally, the rolling-cutter cutting elements 25 may extend beyond the rolling cutters 21 less than the fixed-blade cutting elements 31 extend beyond the fixed blades 19, thereby limiting DOC and/or impact damage to the TSP and/or mosaic fixed-blade cutting elements 31. Of course, the rolling cutter(s) 21 may include few or no rolling-cutter cutting elements 25, and/or may not meaningfully contribute to ROP other than to act as DOC control and/or prevent excessive ROP, thereby protecting the TSP and/or mosaic fixed-blade cutting elements 31 from damage. Further, the various methods and embodiments of the present invention can be included in combination with each other to produce variations of the disclosed methods and embodiments. Discussion of singular elements can include plural elements and vice-versa.

The order of steps can occur in a variety of sequences unless otherwise specifically limited. The various steps described herein can be combined with other steps, interlineated with the stated steps, and/or split into multiple steps.

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Similarly, elements have been described functionally and can be embodied as separate components or can be combined into components having multiple functions.

5 While the invention has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the scope of the invention as hereinafter claimed, and legal equivalents thereof. The inventions have been described in the context of preferred and other
10 embodiments and not every embodiment of the invention has been described. Obvious modifications and alterations to the described embodiments are available to those of ordinary skill in the art. The disclosed and undisclosed embodiments are not intended to limit or restrict the scope or applicability of the invention conceived of by the Applicants, but rather, in conformity with the
15 patent laws, Applicants intend to fully protect all such modifications and improvements that come within the scope or range of equivalent of the following claims.

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WHAT IS CLAIMED IS:

1. An earth boring drill bit comprising:
5 a bit body;
a plurality of fixed blades extending downwardly from the bit body,
each blade having a leading edge and a trailing edge;
a plurality of fixed-blade cutting elements arranged on the leading edge
of the fixed blades;
10 at least one rolling cutter mounted for rotation on the bit body; and
wherein the rolling cutter is configured to act as a depth-of-cut limiter
and/or a rate of penetration limiter, thereby reducing the risk of
damage to the fixed-blade cutting elements.
- 15 2. The bit as set forth in claim 1, wherein the fixed-blade cutting elements
include thermally stable polycrystalline diamond wafers mounted on tungsten
carbide substrates.
- 20 3. The bit as set forth in claim 1, wherein the fixed-blade cutting elements
include mosaic cutters formed of a plurality of geometrically-shaped thermally
stable diamond elements cooperatively arranged and bonded to form a
unitary cutting surface.
- 25 4. The bit as set forth in claim 1, wherein the rolling cutter is positioned,
relative to the fixed blades, such that a plurality of rolling-cutter cutting
elements and the fixed-blade cutting elements cooperate up to a maximum
depth-of-cut.
- 30 5. The bit as set forth in claim 1, wherein the rolling cutter is positioned,
relative to the fixed blades, to limit rate of penetration.

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6. The bit as set forth in claim 1, wherein the rolling cutter is positioned, relative to the fixed blades, to prevent overexposure of the fixed-blade cutting elements.

5 7. The bit as set forth in claim 1, wherein the rolling cutter is positioned, relative to the fixed blades, such that a plurality of rolling-cutter cutting elements extend beyond the fixed blades.

10 8. The bit as set forth in claim 1, wherein the rolling cutter is positioned, relative to the fixed blades, such that a plurality of rolling-cutter cutting elements extend beyond the fixed-blade cutting elements.

9. The bit as set forth in claim 1, wherein the rolling cutter is aligned with the fixed-blade cutting elements.

15

10. The bit as set forth in claim 1, wherein the rolling cutter is aligned between the fixed blades and the fixed-blade cutting elements.

20 11. The bit as set forth in claim 1, wherein the rolling cutter is positioned, relative to the fixed blades, to limit depth-of-cut.

12. The bit as set forth in claim 1, wherein the rolling cutter is configured to not meaningfully contribute to rate of penetration, thereby protecting the fixed-blade cutting elements from damage.

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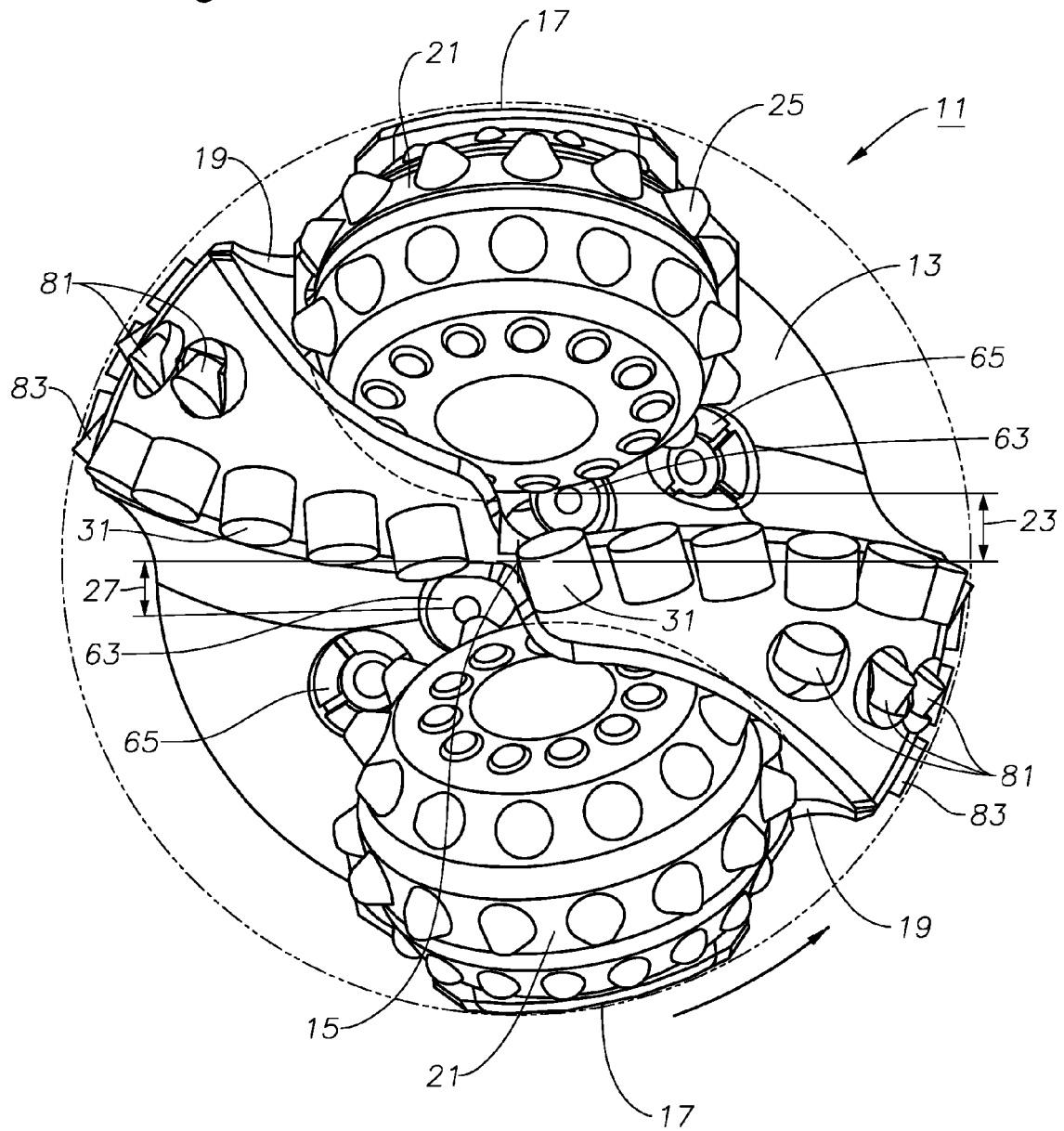
13. The bit as set forth in claim 1, wherein the rolling cutter is configured to act as depth-of-cut control, thereby protecting the TSP and/or mosaic fixed-blade cutting elements from damage.

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14. The bit as set forth in claim 1, wherein the rolling cutter is configured to prevent excessive ROP, thereby protecting the TSP and/or mosaic fixed-blade cutting elements from damage.

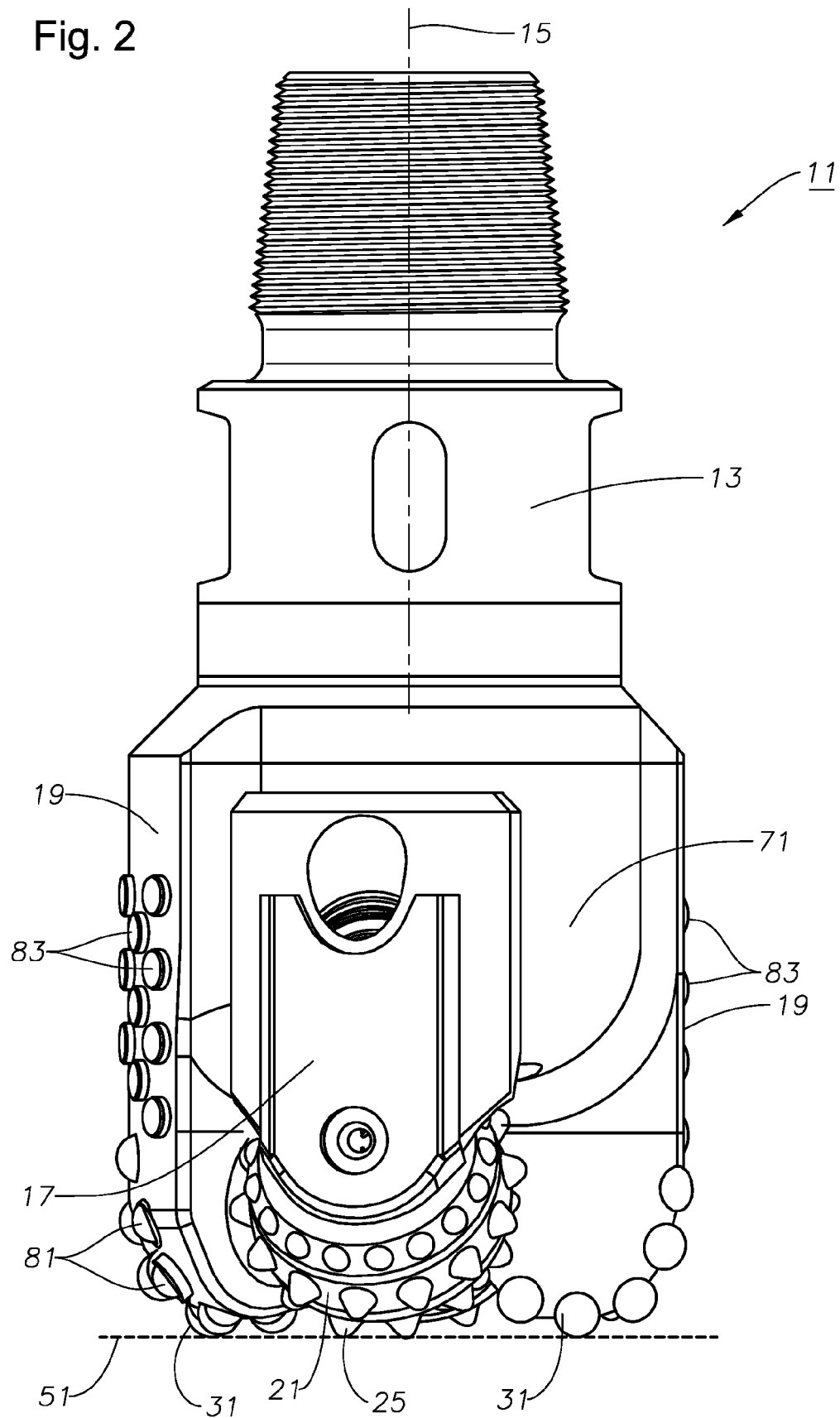
- 5 15. The bit as set forth in claim 1, wherein the rolling cutter has no cutting elements and is thus configured to not meaningfully contribute to rate of penetration but to act as a depth-of-cut control and prevent excessive ROP, thereby protecting the fixed-blade cutting elements from damage.

Fig. 1



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Fig. 2



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Fig. 3

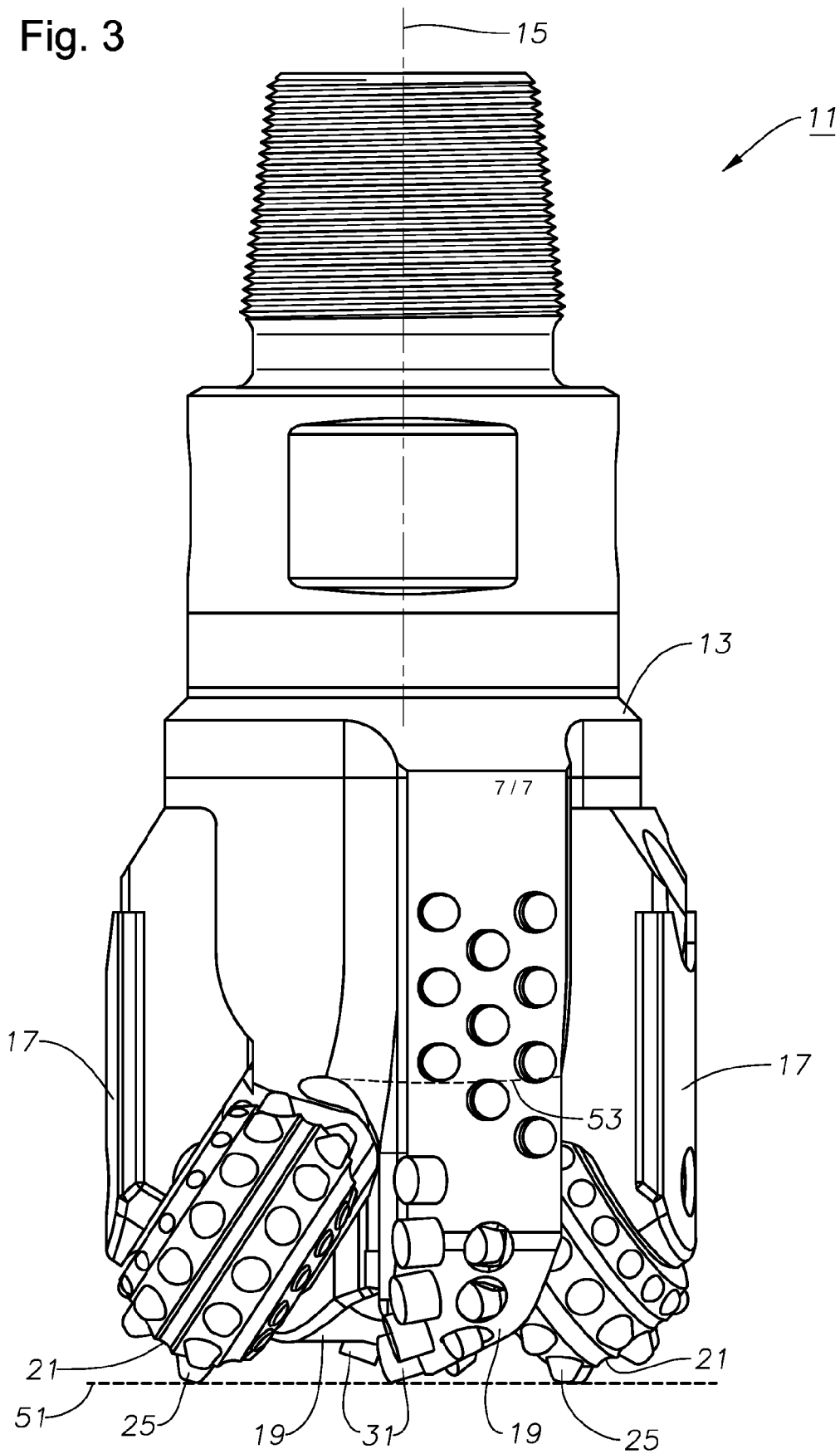


Fig. 4

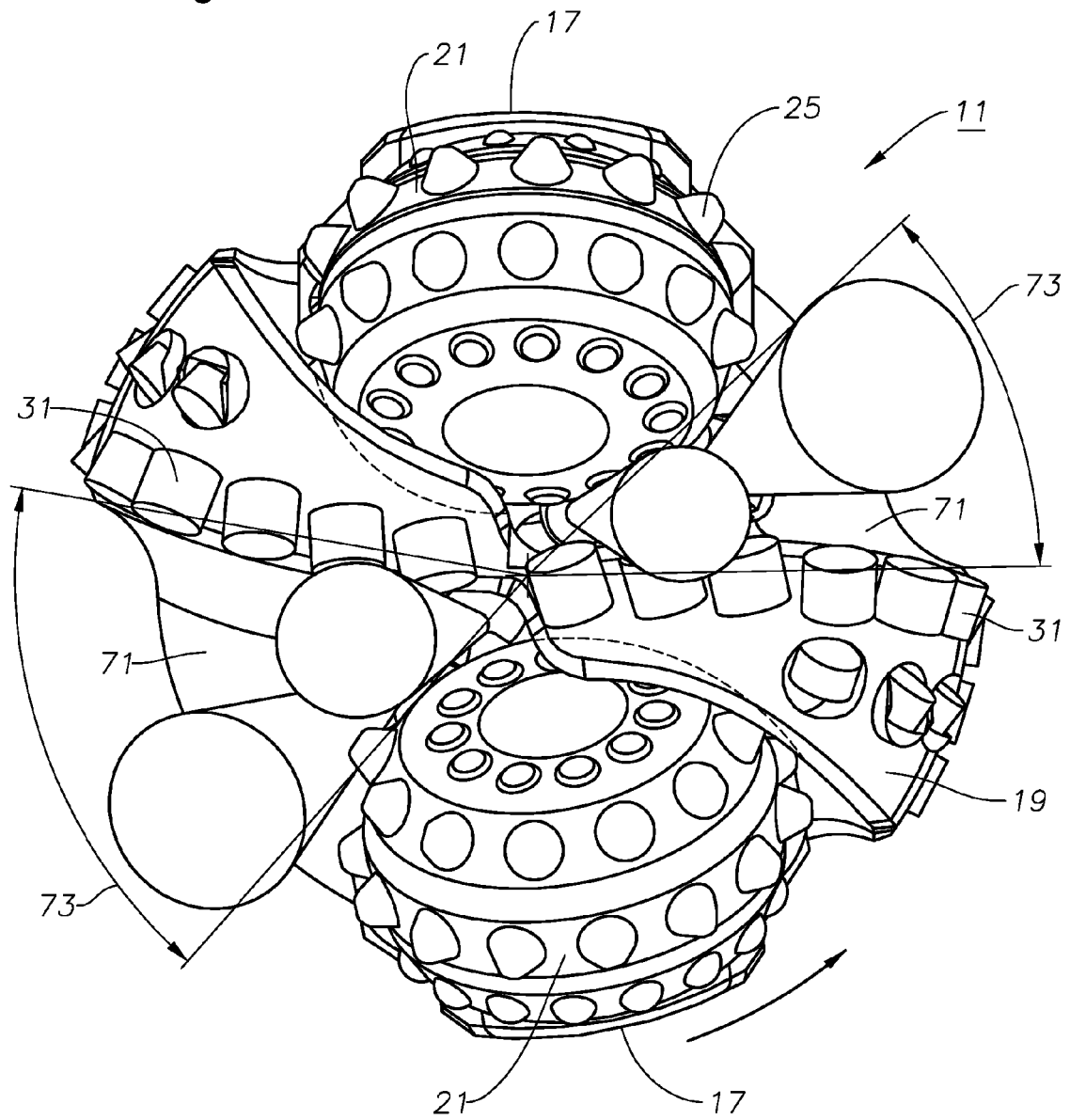


Fig. 5

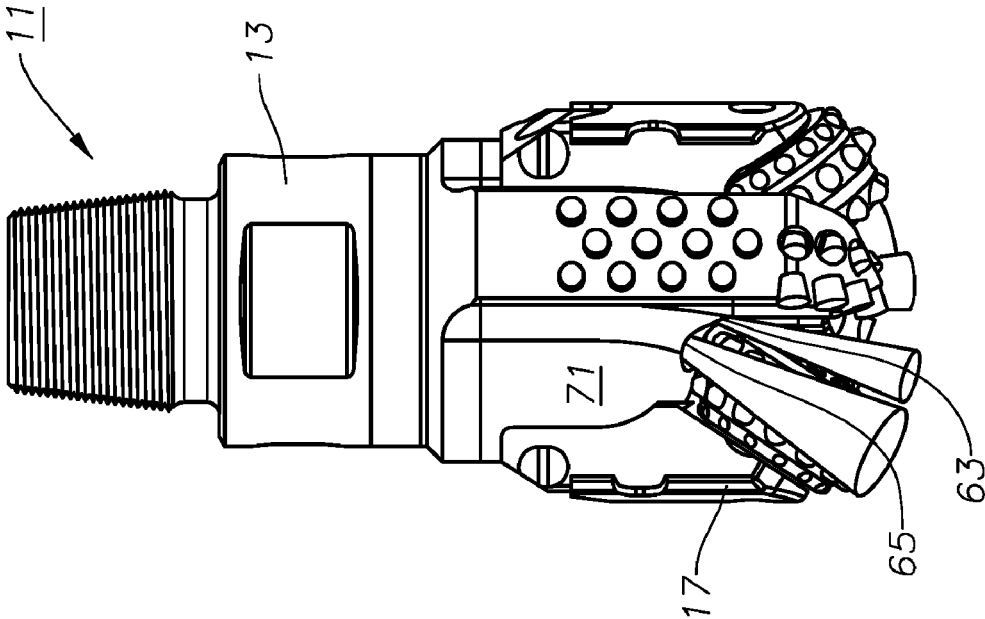


Fig. 6

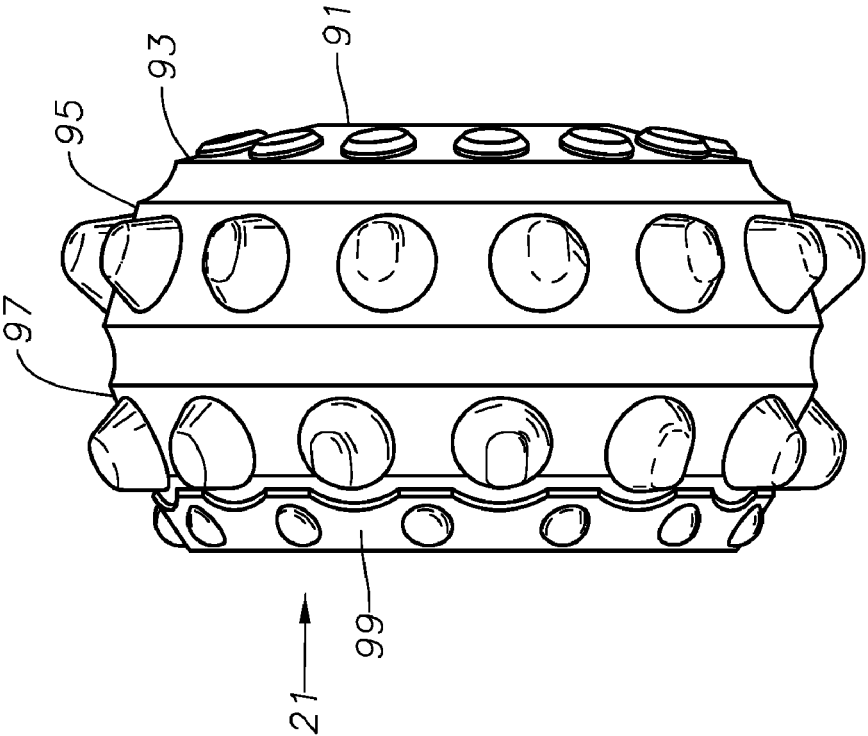


Fig. 8

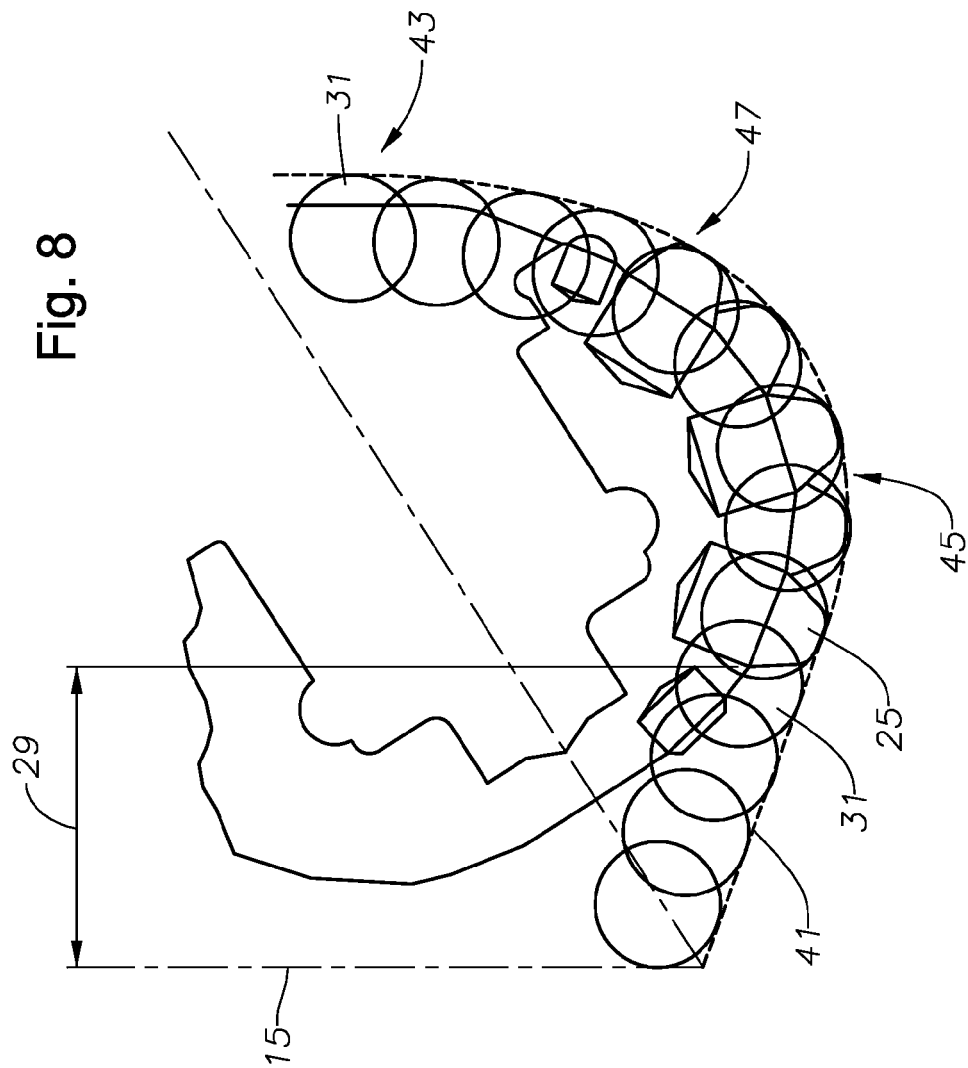


Fig. 7

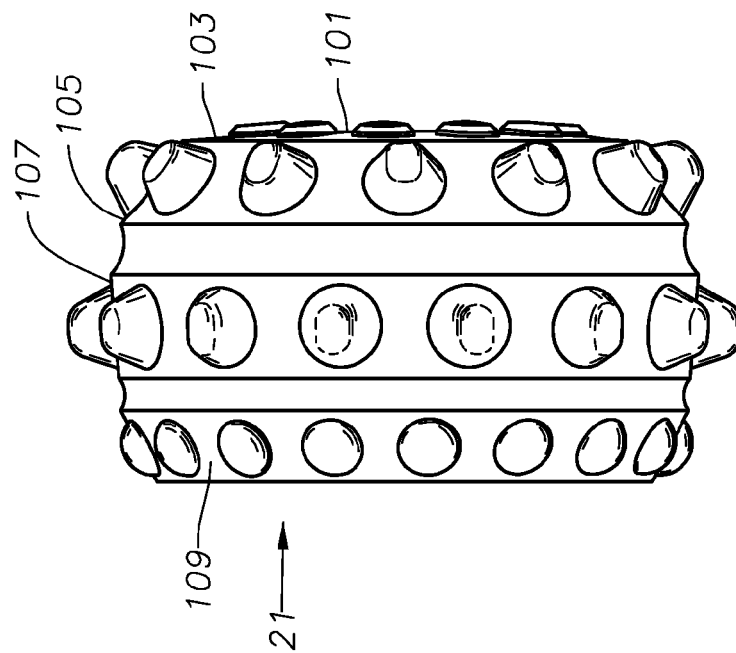
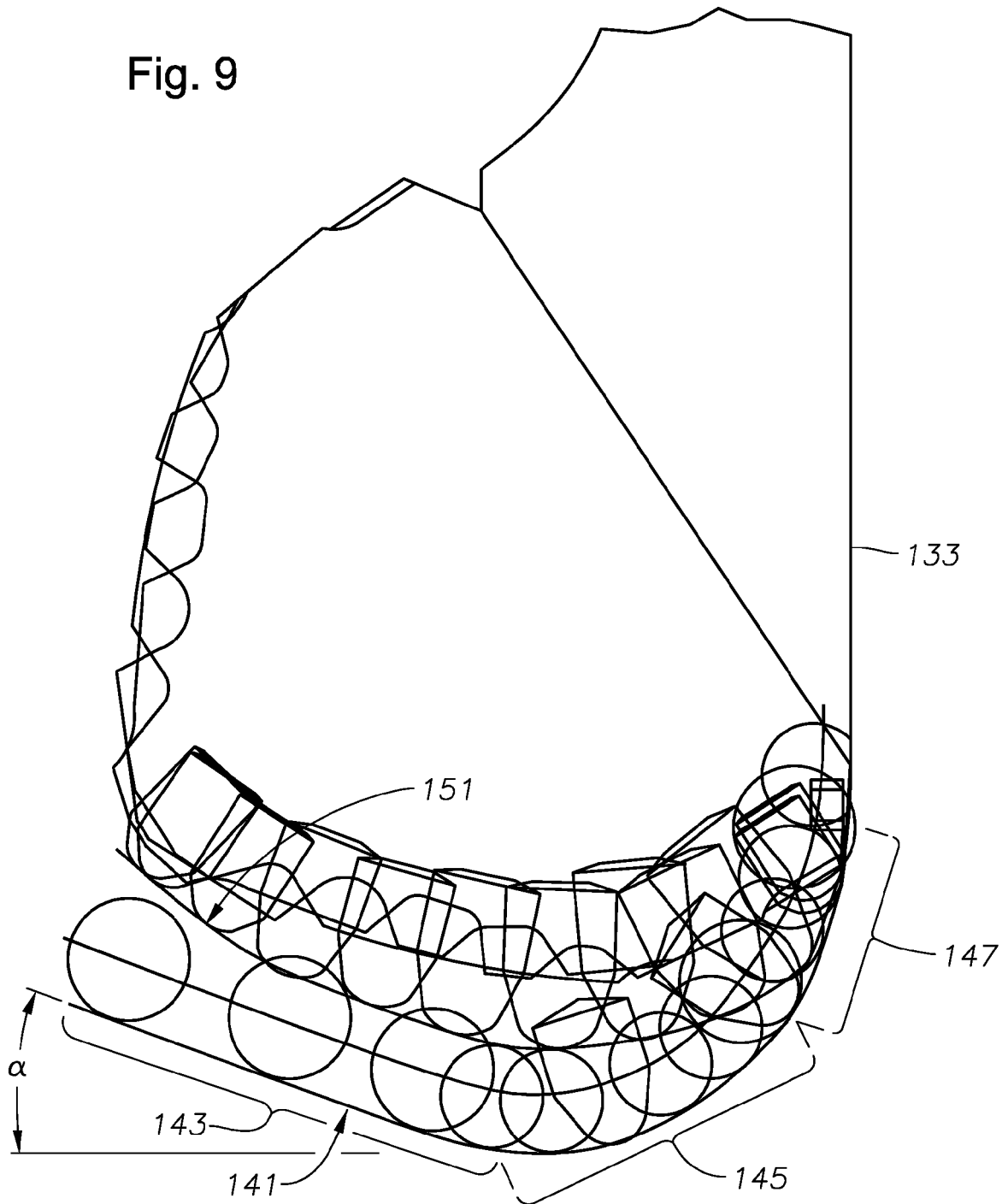


Fig. 9



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FIG. 10

