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(54) ROTARY DRILL BITS FOR DIRECTIONAL DRILLING EXHIBITING VARIABLE WEIGHT-ON-BIT DEPENDENT CUTTING CHARACTERISTICS

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Publication Classification

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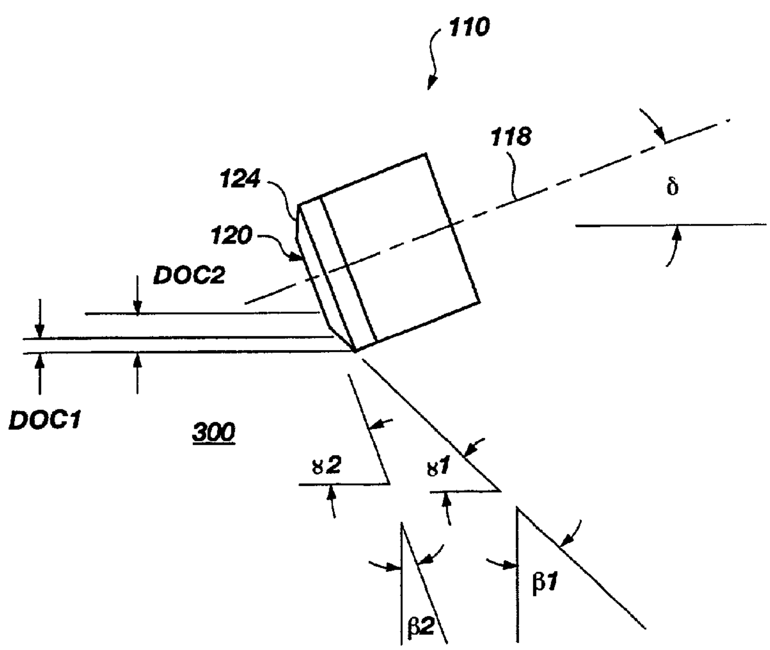
(57) ABSTRACT

A PDC-equipped rotary drag bit especially suitable for directional drilling. Cutter chamfer size and backrake angle, as well as cutter backrake, may be varied along the bit profile between the center of the bit and the gage to provide a less aggressive center and more aggressive outer region on the bit face, to enhance stability while maintaining side cutting capability, as well as providing a high rate of penetration under relatively high weight on bit.



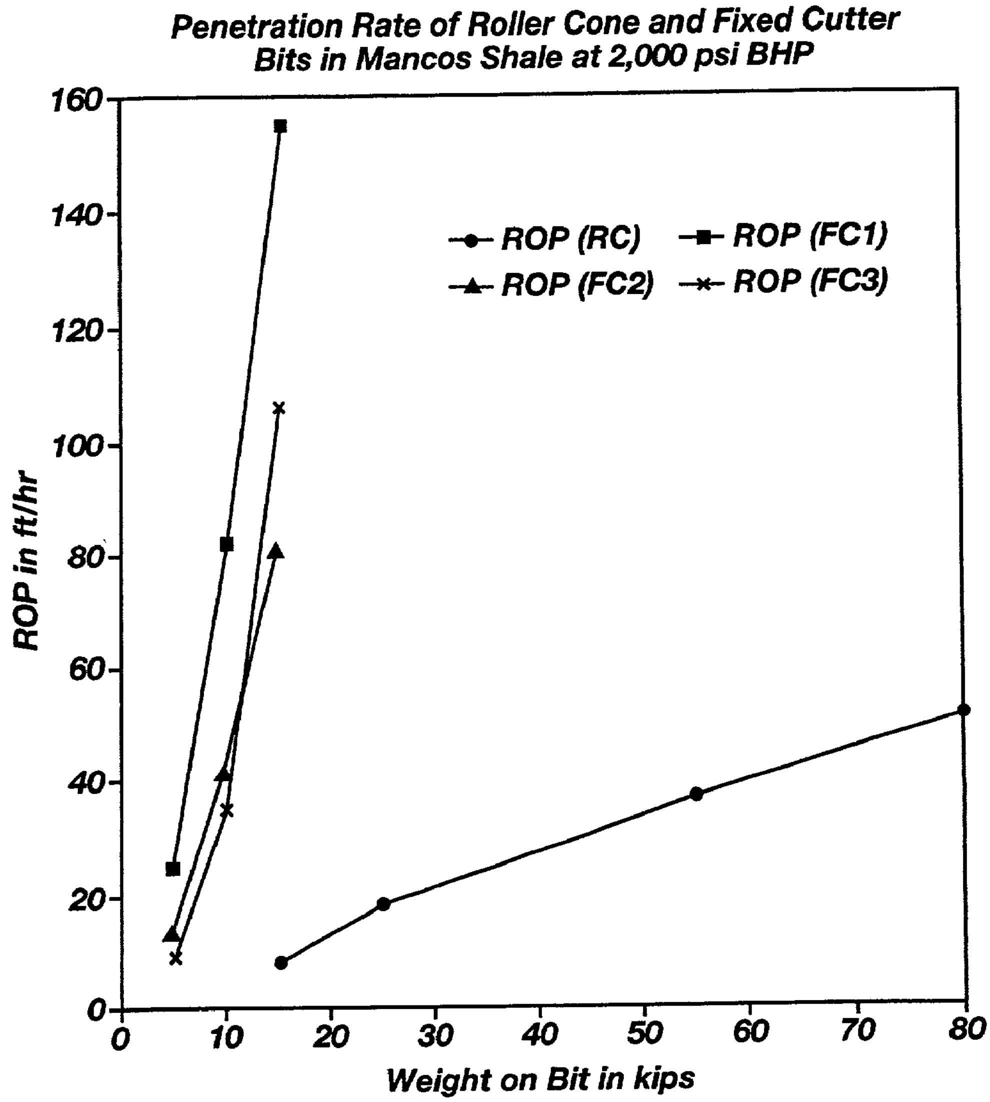

Penetration Rate of Roller Cone and Fixed Cutter Bits in Mancos Shale at 2,000 psi BHP
ROP (RC)
ROP (FC1)
ROP (FC2)
ROP (FC3)
ROP in ft/hr
Weight on Bit in kips
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
70
80

Fig. 1

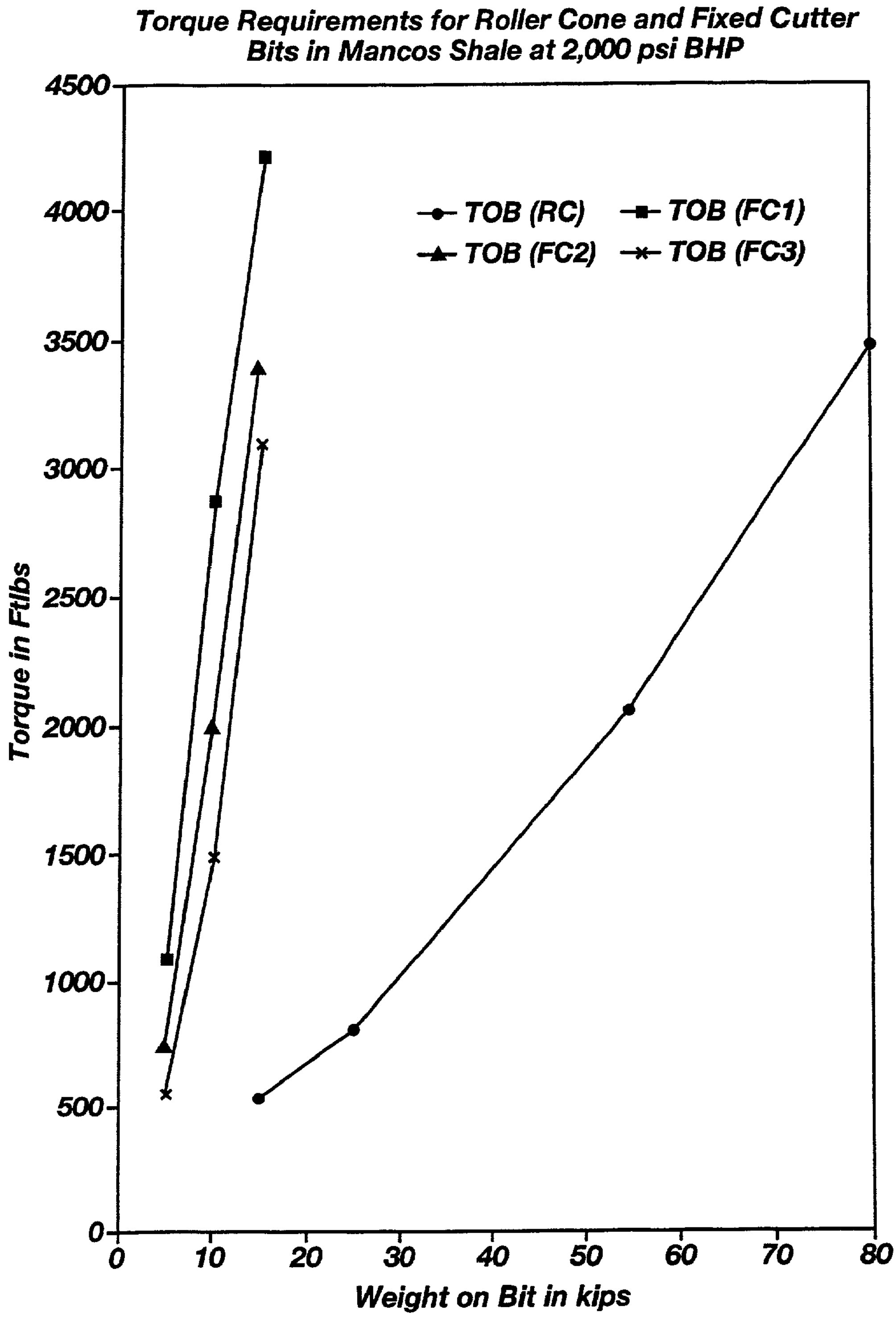

Torque Requirements for Roller Cone and Fixed Cutter Bits in Mancos Shale at 2,000 psi BHP
TOB (RC)
TOB (FC1)
TOB (FC2)
TOB (FC3)
Torque in Ftlbs
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
Weight on Bit in kips

Fig. 2

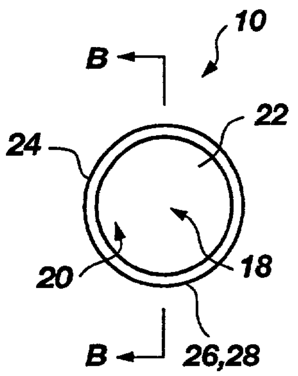


Fig. 3A

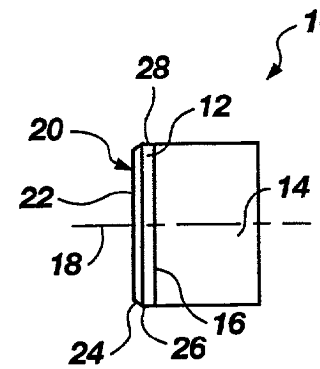


Fig. 3B

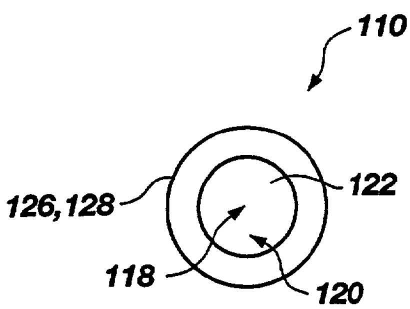


Fig. 4

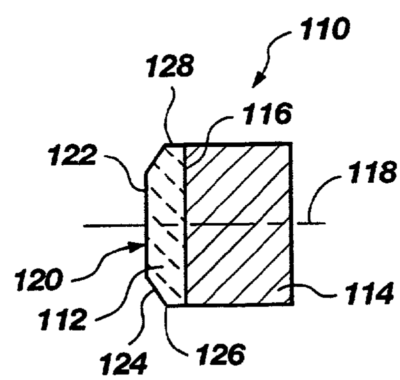


Fig. 5

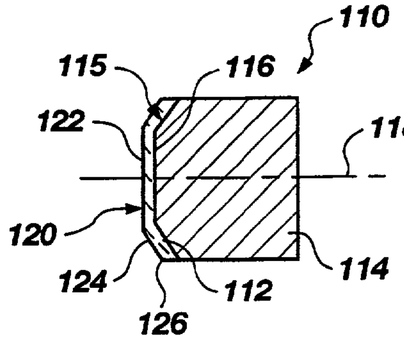


Fig. 6

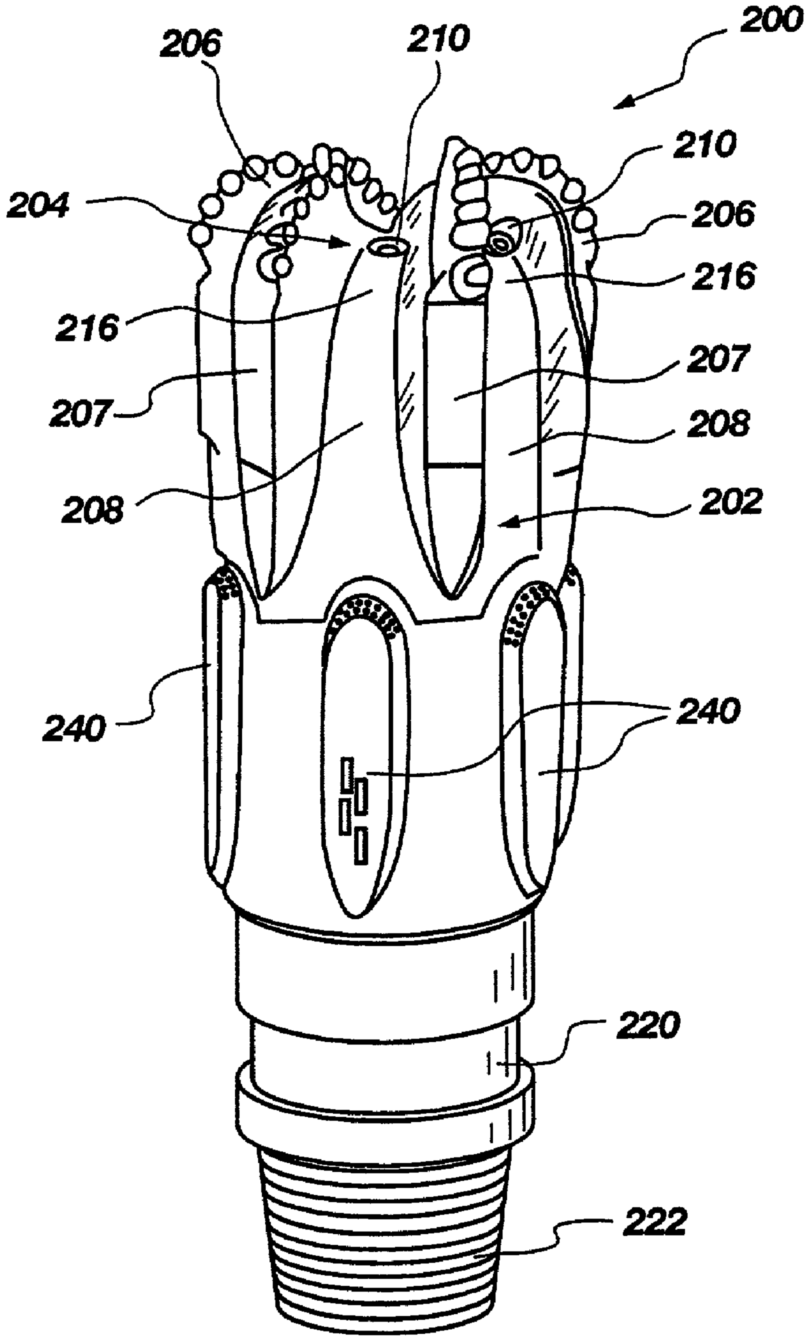

200
206
210
210
204
206
216
216
207
207
208
208
202
240
240
220
222

Fig. 7

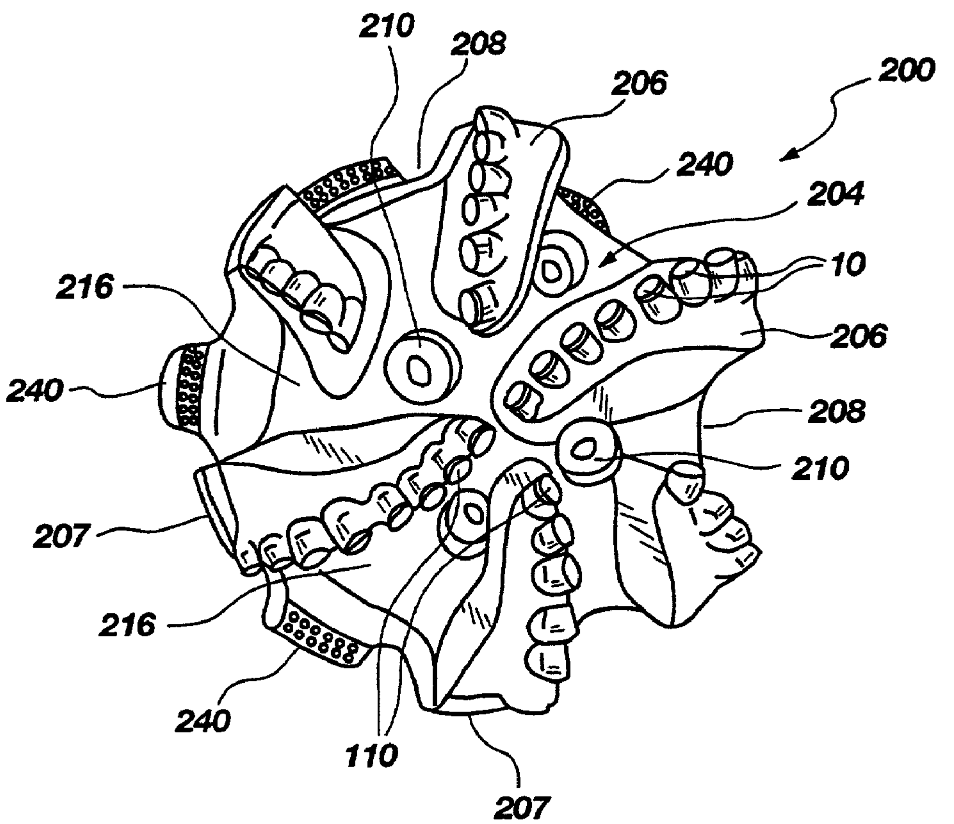

210
208
206
200
240
204
10
216
206
240
208
210
207
216
240
110
207

Fig. 8

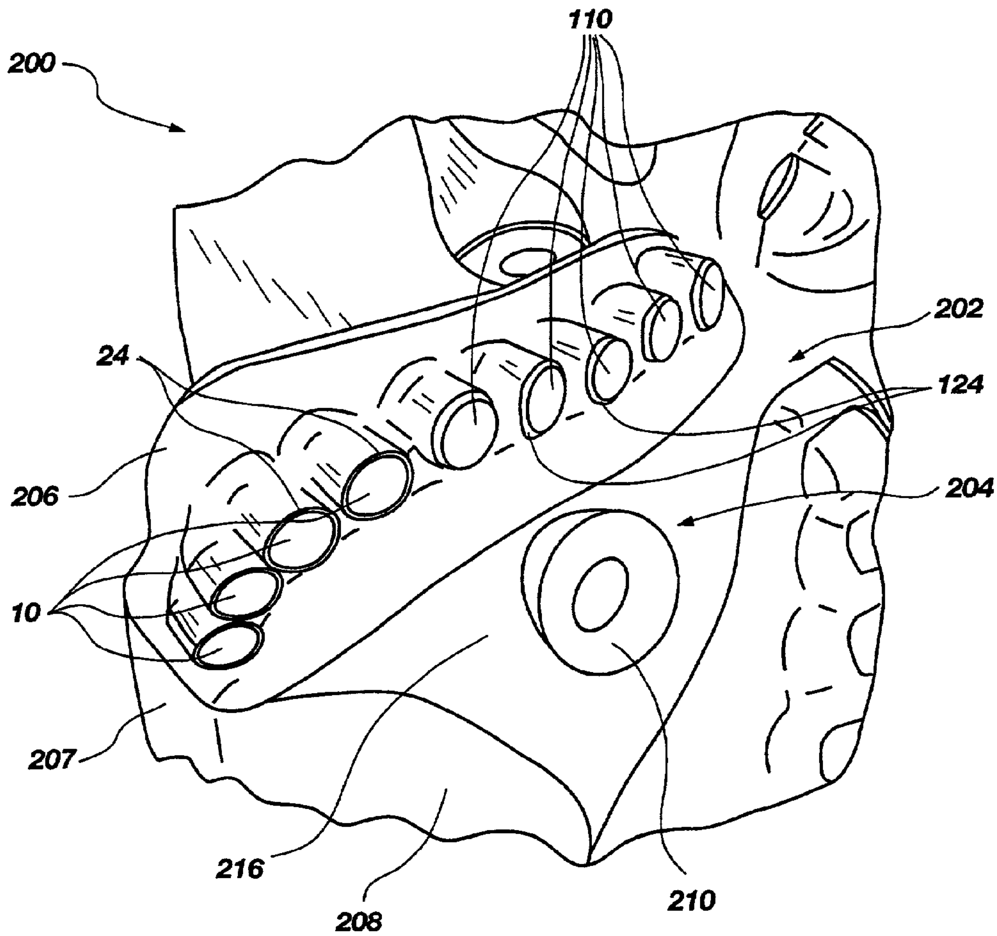


Fig. 9

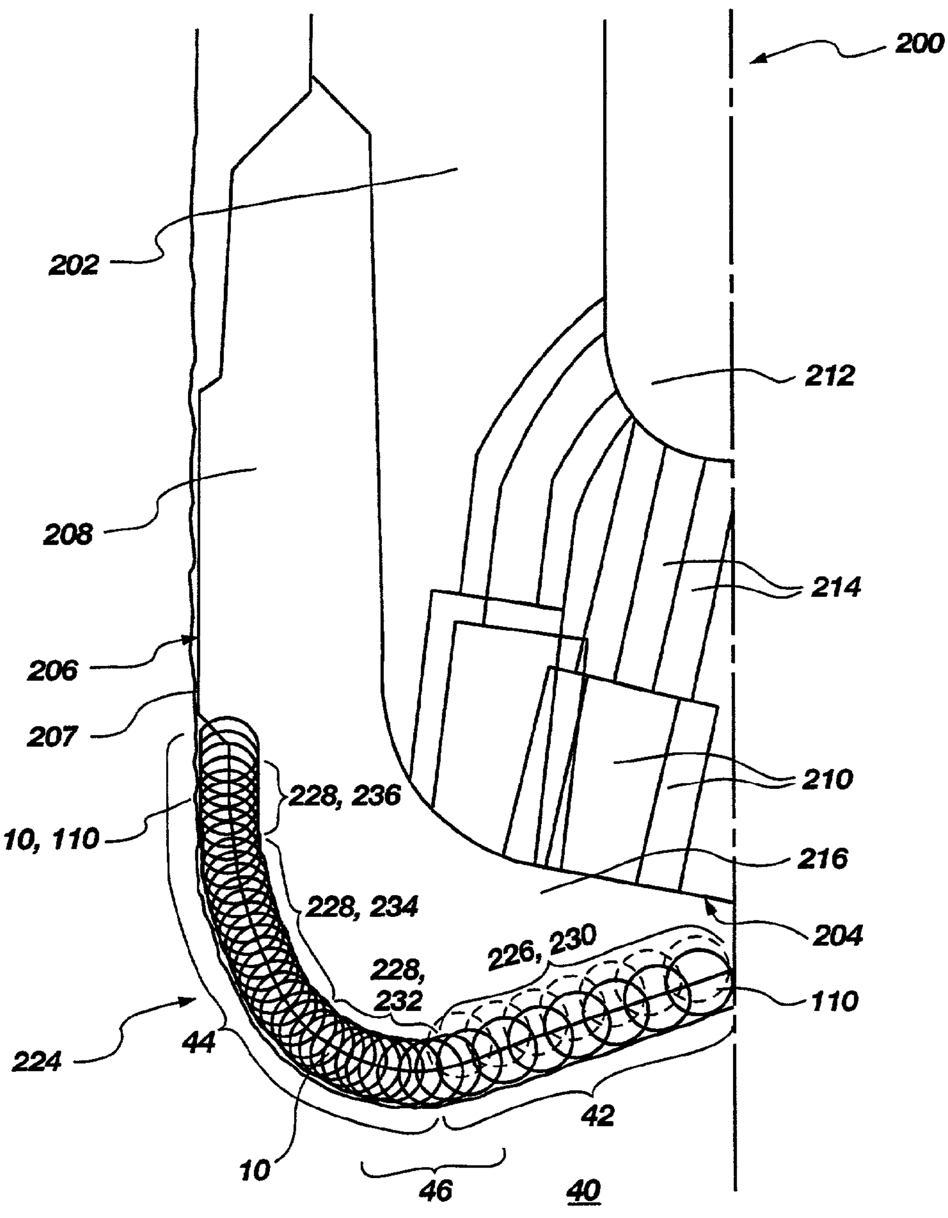

200
202
212
208
214
206
207
210
228, 236
10, 110
216
228, 234
204
226, 230
228,
232
110
224
44
42
10
46
40

Fig. 10

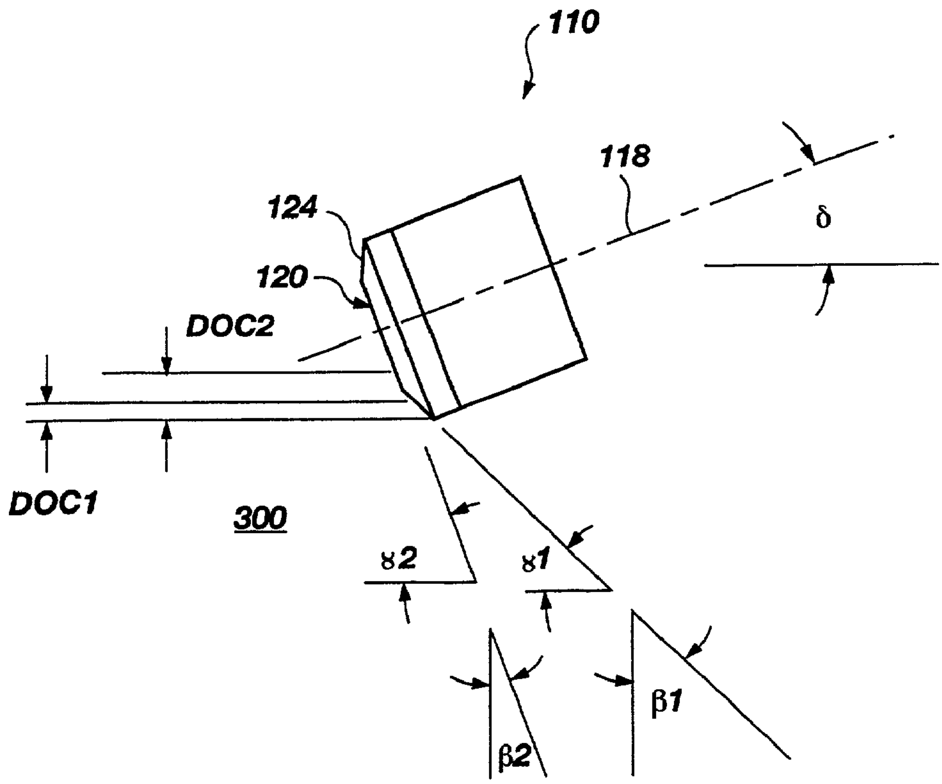


Fig. 11

ROTARY DRILL BITS FOR DIRECTIONAL DRILLING EXHIBITING VARIABLE WEIGHT-ON-BIT DEPENDENT CUTTING CHARACTERISTICS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation of application Ser. No. 08/925,525, filed Sep. 8, 1997, pending.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates generally to rotary bits for drilling subterranean formations. More specifically, the invention relates to fixed cutter or so-called "drag" bits suitable for directional drilling, wherein cutting edge chamfer geometries are varied at different locations or zones on the face of the bit, the variations being tailored to enhance response of the bit to sudden variations in load and improve stability of the bit as well as rate of penetration (ROP).

[0004] 2. State of the Art

[0005] In state-of-the-art directional drilling of subterranean formations, also sometimes termed steerable or navigational drilling, a single bit disposed on a drill string, usually connected to the drive shaft of a downhole motor of the positive-displacement (Moineau) type, is employed to drill both linear and non-linear borehole segments without tripping of the string from the borehole. Use of a deflection device such as a bent housing, bent sub, eccentric stabilizer, or combinations of the foregoing in a bottonhole assembly (BRA), including a motor, permits a fixed rotational orientation of the bit axis at an angle to the drill string axis for non-linear drilling when the bit is rotated solely by the motor drive shaft. When the drill string is rotated in combination with rotation of the motor shaft, the superimposed rotational motions cause the bit to drill substantially linearly. Other directional methodologies employing non-rotating BHAs using lateral thrust pads or other members immediately above the bit also permit directional drilling using drill string rotation alone.

[0006] In either case, for directional drilling of non-linear borehole segments, the face aggressiveness (aggressiveness of the cutters disposed on the bit face) is a critical feature, since it is largely determinative of how a given bit responds to sudden variations in bit load. Unlike roller cone bits, rotary drag bits employing fixed superabrasive cutters (usually comprising polycrystalline diamond compacts, or "PDCs") are very sensitive to load, which sensitivity is reflected in a much steeper rate of penetration (ROP) versus weight on bit (WOB) and torque on bit (TOB) versus WOB curves, as illustrated in **FIGS. 1 and 2** of the drawings. Such high WOB sensitivity causes problems in directional drilling, wherein the borehole geometry is irregular and resulting "sticktion" of the BHA when drilling a non-linear path renders a smooth, gradual transfer of weight to the bit extremely difficult. These conditions frequently cause motor stalling and loss or swing of tool face orientation. When tool face is lost, borehole quality declines. In order to establish a new tool face reference point before drilling is recommenced, the driller must stop drilling ahead and pull the bit off the bottom of the borehole, with a resulting loss of time and thus ROP. Conventional methods to reduce rotary drag bit face aggressiveness include greater cutter densities, higher (negative) cutter backrakes and the addition of wear knots to the bit face.

[0007] Of the bits referenced in **FIGS. 1 and 2** of the drawings, RC comprises a conventional roller cone bit for reference purposes, while FC1 is a conventional polycrystalline diamond compact (PDC) cutter-equipped rotary drag bit having cutters backraked at 20°, while FC2 is the directional version of the same bit with 30° backraked cutters. As can be seen from **FIG. 2**, the TOB at a given WOB for FC2, which corresponds to its face aggressiveness, can be as much as 30% less than for FC1. Therefore, FC2 is less affected by the sudden load variations inherent in directional drilling. However, referencing **FIG. 1**, it can also be seen that the less aggressive FC2 bit exhibits a markedly reduced ROP for a given WOB, in comparison to **FIG. 2**.

[0008] Thus, it may be desirable for a bit to demonstrate the less aggressive characteristics of a conventional directional bit such as FC2 for non-linear drilling without sacrificing ROP to the same degree when WOB is increased to drill a linear borehole segment.

[0009] For some time, it has been known that forming a noticeable, annular chamfer on the cutting edge of the diamond table of a PDC cutter has enhanced durability of the diamond table, reducing its tendency to spall and fracture during the initial stages of a drilling operation before a wear flat has formed on the side of the diamond table and supporting substrate contacting the formation being drilled.

[0010] U.S. Pat. Re 32,036 to Dennis discloses such a chamfered cutting edge, disc-shaped PDC cutter comprising a polycrystalline diamond table formed under high pressure and high temperature conditions onto a supporting substrate of tungsten carbide. For conventional PDC cutters, a typical chamfer size and angle would be 0.010 inch (measured radially and looking at and perpendicular to the cutting face) oriented at a 45° angle with respect to the longitudinal cutter axis, thus providing a larger radial width as measured on the chamfer surface itself . Multi-chamfered PDC cutters are also known in the art, as taught by Cooley et al. U.S. Pat. No. 5,437,343, assigned to the assignee of the present invention. Rounded, rather than chamfered, cutting edges are also known, as disclosed in U.S. Pat. No. 5,016,718 to Tandberg.

[0011] For some period of time, the diamond tables of PDC cutters were limited in depth or thickness to about 0.030 inch or less, due to the difficulty in fabricating thicker tables of adequate quality. However, recent process improvements have provided much thicker diamond tables, in excess of 0.070 inch, up to and including 0.150 inch. U.S. patent application Ser. No. 08/602,076, now U.S. Pat. No. 5,706,906, assigned to the assignee of the present invention, discloses and claims several configurations of a PDC cutter employing a relatively thick diamond table. Such cutters include a cutting face bearing a large chamfer or "rake land" thereon adjacent the cutting edge, which rake land may exceed 0.050 inch in width, measured radially and across the surface of the rake land itself Other cutters employing a relatively large chamfer without such a great depth of diamond table are also known.

[0012] Recent laboratory testing, as well as field tests, have conclusively demonstrated that one significant parameter affecting PDC cutter durability is the cutting edge geometry. Specifically, larger leading chamfers (the first chamfer on a cutter to encounter the formation when the bit is rotated in the normal direction) provide more durable cutters. The robust character of the above-referenced "rake land" cutters corroborates these findings. However, it was also noticed that cutters exhibiting large chamfers would also slow the overall performance of a bit so equipped, in terms of ROP. This characteristic of large chamfer cutters was perceived as a detriment.

BRIEF SUMMARY OF THE INVENTION

[0013] The inventors herein have recognized that varying chamfer size and chamfer rake angle of various PDC cutters as a function of, or in relationship to, cutter redundancy at varying radial locations on the bit face may be employed to provide a bit exhibiting relatively low aggressiveness and good stability while affording adequate side cutting capability for non-linear drilling, as well as providing greater ROP when drilling linear borehole segments than conventional directional or steerable bits with highly backraked cutters.

[0014] The present invention comprises a rotary drag bit equipped with PDC cutters, wherein cutters in the low cutter redundancy center region of the bit exhibit a relatively large chamfer and are oriented at a relatively large backrake, while chamfer size as well as chamfer rake angle decreases in cutters located more toward the outer region, or gage, of the bit, wherein higher cutter redundancy is employed.

[0015] Such a bit design noticeably changes the ROP and TOB versus WOB characteristics for the bit from the linear, single slope curves shown in **FIGS. 1 and 2** for FC1 and FC**2** to exponential, dual-slope curves as shown with respect to a bit FC**3** according to the invention.

[0016] It is the dual-slope characteristics which are desirable for directional drilling, demonstrating that a bit such as FC**3** is slow and drills smoothly with less applied torque at a relatively low WOB such as is applied during oriented drilling of a non-linear well bore segment, while regaining its full ROP potential at relatively higher WOB levels such as are applied during linear drilling.

[0017] It has been found that the chamfer size predominantly determines at which ROP or WOB level the break in between the two slopes occurs, while the chamfer backrake angle predominantly determines curve slopes at low WOB, and cutter backrake angles dictate the slopes at high WOB. The chamfer backrake angle with respect to the formation being cut may be modified by actually changing the chamfer angle on the cutter, changing the backrake angle of the cutter itself, or a combination of the two. Thus, different slopes at low WOB may be achieved for bits employing cutters with similar chamfer angles, but disposed at different cutter backrake angles, or bits employing cutters with different chamfer angles but disposed at similar cutter backrake angles. Generally, placing relatively less aggressive cutters in the center of the bit face and relatively more aggressive cutters toward the gage makes the bit more stable. In a broad concept of the invention, chamfer size and angle of cutters placed at a variety of radial locations over the face of a bit may be varied as a function of, or in relation to, cutter redundancy at the various locations.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0018] **FIG. 1** comprises a graphical representation of ROP versus WOB characteristics of various rotary drill bits in drilling Mancos Shale at 2000 psi bottomhole pressure;

[0019] **FIG. 2** comprises a graphical representation of TOB versus WOB characteristics of various rotary drill bits in drilling Mancos Shale at 2,000 psi bottomhole pressure;

[0020] **FIG. 3A** comprises a frontal view of a small chamfer PDC cutter usable with the present invention and **FIG. 3B** comprises a side sectional view of the small chamfer PDC cutter of **FIG. 3**A, taken along section lines B-B;

[0021] **FIG. 4** comprises a frontal view of a large chamfer PDC cutter usable with the present invention;

[0022] **FIG. 5** comprises a side sectional view of a first internal configuration for the large chamfer PDC cutter of **FIG. 4**;

[0023] **FIG. 6** comprises a side sectional view of a second internal configuration for the large chamfer PDC cutter of **FIG. 4**;

[0024] **FIG. 7** comprises a side perspective view of a PDC-equipped rotary drag bit according to the present invention;

[0025] **FIG. 8** comprises a face view of the bit of **FIG. 7**;

[0026] **FIG. 9** comprises an enlarged, oblique face view of a single blade of the bit of **FIG. 7**, illustrating the varying cutter chamfer sizes and angles and cutter rake angles employed;

[0027] **FIG. 10** comprises a quarter-sectional side schematic of a bit having a profile such as that of **FIG. 7**, with the cutter locations rotated to a single radius extending from the bit centerline to the gage to show the radial bit face locations of the various cutter chamfer sizes and angles, and cutter backrake angles, employed in the bit; and

[0028] **FIG. 11** comprises a side view of a PDC cutter as employed with the present invention, depicting the effects of chamfer backrake and cutter backrake.

DETAILED DESCRIPTION OF THE INVENTION

[0029] As used in the practice of the present invention, and with reference to the size of the chamfers employed in various regions of the exterior of the bit, it should be recognized that the terms "large" and "small" chamfers are relative, not absolute, and that different formations may dictate what constitutes a relatively large or small chamfer on a given bit. The following discussion of "small" and "large" chamfers is, therefore, merely exemplary and not limiting, in order to provide an enabling disclosure and the best mode of practicing the invention as currently understood by the inventors.

[0030] **FIGS. 3A and 3B** depict an exemplary "small chamfer" cutter **10** comprised of a superabrasive, PDC table **12**, supported by a tungsten carbide (WC) substrate **14**, as known in the art. The interface **16** between the PDC diamond table **12** and the substrate **14** may be planar or non-planar, according to many varying designs for same as known in the art. Cutter **10** is substantially cylindrical, and symmetrical about longitudinal axis **18**, although such symmetry is not required and non-symmetrical cutters are known in the art. Cutting face **20** of cutter **10**, to be oriented on a bit facing generally in the direction of bit rotation, extends substantially transversely to such direction, and to axis **18**. The surface **22** of the central portion of cutting face **20** is planar as shown, although concave, convex, ridged or other substantially, but not exactly, planar surfaces may be employed. A chamfer **24** extends from the periphery of surface **22** to cutting edge **26** at the sidewall **28** of PDC table **12**. Chamfer **24** and cutting edge **26** may extend about the entire periphery of PDC table **12**, or only along a periphery portion to be located adjacent the formation to be cut. Chamfer **24** may comprise the aforementioned 0.010 inch by 45° angle conventional chamfer, or the chamfer may lie at some other angle, as referenced with respect to the chamfer **124** of cutter **110** described below. While 0.010 inch chamfer size is referenced as an example (within conventional tolerances), chamfer sizes within a range of 0.005 to about 0.020 inch are contemplated as generally providing a "small" chamfer for the practice of the invention. It should also be noted that cutters exhibiting substantially no visible chamfer may be employed for certain applications in selected outer regions of the bit.

[**0031**] **FIGS. 4 through 6** depict an exemplary "large chamfer" cutter **110** comprised of a superabrasive, PDC table **112** supported by a WC substrate **114**. The interface **116** between the PDC diamond table **112** and the substrate **114** may be planar or non-planar, according to many varying designs for same as known in the art (see especially **FIGS. 5 and 6**). Cutter **110** is substantially cylindrical, and symmetrical about longitudinal axis **118**, although such symmetry is not required and non-symmetrical cutters are known in the art. Cutting face **120** of cutter **110**, to be oriented on a bit facing generally in the direction of bit rotation, extends substantially transversely to such direction, and to axis **118**. The surface **122** of the central portion of cutting face **120** is planar, as shown, although concave, convex, ridged or other substantially, but not exactly, planar surfaces may be employed. A chamfer **124** extends from the periphery of surface **122** to cutting edge **126** at the sidewall **128** of PDC table **112**. Chamfer **124** and cutting edge **126** may extend about the entire periphery of PDC table **112**, or only along a periphery portion to be located adjacent the formation to be cut. Chamfer **124** may comprise a surface oriented at 45° to axis **118**, of a width, measured radially and looking at and perpendicular to the cutting face **120**, ranging upward in magnitude from about 0.030 inch, and generally lying within a range of about 0.030 to 0.060 inch in width. Chamfer angles of about 10° to about 80° to axis **118** are believed to have utility, with angles in the range of about 30° to about 60° being preferred for most applications. The effective angle of a chamfer relative to the formation face being cut may also be altered by changing the backrake of a cutter.

[**0032**] **FIG. 5** illustrates one internal configuration for cutter **110**, wherein PDC table **112** is extremely thick, on the order of 0.070 inch or greater, in accordance with the teachings of the aforementioned '076 application.

[**0033**] **FIG. 6** illustrates a second internal configuration for cutter **110**, wherein the front face **115** of substrate **114** is frustoconical in configuration, and PDC table **112**, of substantially constant depth, substantially conforms to the shape of front face **115** to provide a large chamfer of a desired width without requiring the large PDC diamond mass of the '076 application.

[**0034**] **FIGS. 7 through 10** depict a rotary drag bit **200** according to the invention. Bit **200** includes a body **202** having a face **204** and including a plurality (in this instance, six) of generally radially oriented blades **206** extending above the bit face **204** to a gage **207**. Junk slots **208** lie between adjacent blades **206**. A plurality of nozzles **210** provides drilling fluid from plenum **212 (FIG. 10)** within the bit body **202** and received through passages **214 (FIG. 10)** to the bit face **204**. Formation cuttings generated during a drilling operation are transported by the drilling fluid across bit face **204** through fluid courses **216** communicating with respective junk slots **208**. Secondary gage pads **240** are rotationally and substantially longitudinally offset from blades **206**, and provide additional stability for bit **200** when drilling both linear and non-linear borehole segments. Such added stability reduces the incidence of ledging of the borehole sidewall, and spiraling of the borehole path. Shank **220** includes a threaded pin connection **222** as known in the art, although other connection types may be employed.

[**0035**] The profile **224** of the bit face **204**, as defined by blades **206**, is illustrated in **FIG. 10**, wherein bit **200** is shown adjacent a subterranean rock formation **40** at the bottom of the well bore. First region **226** and second region **228** on profile **224** face adjacent rock zones **42** and **44** of formation **40** and respectively carry large chamfer cutters **110** and small chamfer cutters **10**. First region **226** may be said to comprise the cone **230** of the bit profile **224**, as illustrated, whereas second region **228** may be said to comprise the nose **232**, and flank **234** and extend to shoulder **236** of profile **224**, terminating at gage **207**.

[**0036**] In a currently preferred embodiment of the invention and with particular reference to **FIGS. 9 and 10**, large chamfer cutters **110** may comprise cutters having PDC tables in excess of 0.070 inch depth, and preferably about 0.080 to 0.090 inch depth, with chamfers **124** of about a 0.030 to 0.060 inch width, looking at and perpendicular to the cutting face **120**, and oriented at a 45° angle to the cutter axis **118**. The cutters themselves, as disposed in first region **226**, are backraked at 20° to the bit profile (see cutters **110** shown partially in broken lines in **FIG. 10** to denote 20° backrake) at each respective cutter location, thus providing chamfers **124** with a 65° backrake. Cutters **10**, on the other hand, disposed in second region **228**, may comprise conventionally-chamfered cutters having about a 0.030 inch PDC table thickness, and about a 0.010 to 0.020 inch chamfer width looking at and perpendicular to cutting face **20**, with chamfers **24** oriented at a 45° angle to the cutter axis **18**. Cutters **10** are themselves backraked at 15° on nose **232**, providing a 60° chamfer backrake, while cutter backrake is further reduced to 10° at the flank **234**, shoulder **236** and on the gage **207** of bit **200**, resulting in a 55° chamfer backrake. The PDC cutters **10** immediately above gage **207** include preformed flats thereon oriented parallel to the longitudinal axis of the bit **200**, as known in the art. In steerable applications requiring greater durability at the shoulder **236**, large chamfer cutters **110** may optionally be employed, but oriented at a 10° cutter backrake. Further, the chamfer angle of cutters **110** in each of first region **226** and shoulder **236** may be other than 45°. For example, 70° chamfer angles may be employed with chamfer widths (looking vertically at the cutting face of the cutter) in the range of about 0.035 to 0.045 inch, cutters **110** being disposed at appropriate backrakes to achieve the desired chamfer rake angles in the respective regions.

[**0037**] A boundary region, rather than a sharp boundary, may exist between first and second regions **226** and **228**. For example, rock zone **46** bridging the adjacent edges of rock zones **42** and **44** of formation **40**, may comprise an area wherein demands on cutters and the strength of the formation are always in transition due to bit dynamics. Alternatively, the rock zone **46** may initiate the presence of a third region on the bit profile, wherein a third size of cutter chamfer is desirable. In any case, the annular area of profile **224** opposing zone **46** may be populated with cutters of both types (i.e., width and chamfer angle) and employing backrakes respectively employed in first region **226** and those of second region **228**, or cutters with chamfer sizes, angles and cutter backrakes intermediate those of the cutters in first and second regions **226** and **228** may be employed.

[**0038**] Bit **200**, equipped as described with a combination of small chamfer cutters **10** and large chamfer cutters **110**, will drill with an ROP approaching that of conventional, non-directional bits equipped only with small chamfer cutters, but will maintain superior stability, and will drill far faster than a conventional directional drill bit equipped only with large chamfer cutters.

[**0039**] It is believed that the benefits achieved by the present invention result from the aforementioned effects of selective variation of chamfer size, chamfer backrake angle and cutter backrake angle. For example and with specific reference to **FIG. 11**, the size (width) of the chamfer **124** of the large chamfer cutters **110** at the center of the bit can be selected to maintain non-aggressive characteristics in the bit up to a certain WOB or ROP, denoted in **FIGS. 1 and 2** as the "break" in the curve slopes for bit FC3. For equal chamfer backrake angles β**1**, the larger the chamfer **124**, the greater WOB must be applied before the bit enters the second, steeper-slope portions of the curves. Thus, for drilling non-linear borehole segments, wherein applied WOB is generally relatively low, it is believed that a non-aggressive character for the bit may be maintained by drilling to a first depth of cut (DOC**1**) associated with low WOB, wherein the cut is taken substantially within the chamfer **124** of the large chamfer cutters **110** disposed in the center region of the bit. In this instance, the effective backrake angle of the cutting face **120** of cutter **110** is the chamfer backrake β**1**, and the effective included angle γ**1** between the cutting face **120** and the formation **300** is relatively small. For drilling linear borehole segments, WOB is increased so that the depth of cut (DOC**2**) extends above the chamfers **124** on the cutting faces **120** of the large chamfer cutters to provide a larger effective included angle γ**2** (and smaller effective cutting face backrake angle β**2**) between the cutting face **120** and the formation **300**, rendering the cutters **110** more aggressive and thus increasing ROP for a given WOB above the break point of the curve of **FIG. 1**. As shown in **FIG. 2**, this condition is also demonstrated by a perceptible increase in the slope of the TOB versus WOB curve above a certain WOB level. Of course, if a chamfer **124** is excessively large, excessive WOB may have to be applied to cause the bit to become more aggressive and increase ROP for linear drilling.

[**0040**] The chamfer backrake angle β**1** of the large chamfer cutters **110** may be employed to control DOC for a given WOB below a threshold WOB wherein DOC exceeds the chamfer depth perpendicular to the formation. The smaller the included angle γ**1** between the chamfer **124** and the formation **300** being cut, the more WOB is required to effect a given DOC. Further, the chamfer rake angle β**1** predominantly determines the slopes of the ROP\WOB and TOB\WOB curves of **FIGS. 1 and 2** at low WOB and below the breaks in the curves, since the cutters **110** apparently engage the formation to a DOC**1** residing substantially within the chamfer **124**.

[**0041**] Further, selection of the backrake angles δ of the cutters **110** themselves (as opposed to the backrake angles β**1** of the chamfers **124**) may be employed to predominantly determine the slopes of the ROP\WOB and TOB\WOB curves at high WOB and above the breaks in the curves, since the cutters **110** will be engaged with the formation to a DOC**2** such that portions of the cutting face centers of the cutters **110** (i.e., above the chamfers **124**) will be engaged with the formation **300**. Since the central areas of the cutting faces **120** of the cutters **110** are oriented substantially perpendicular to the longitudinal axes **118** of the cutters **110**, cutter backrake δ will largely dominate effective cutting face backrake angles (now β**2**) with respect to the formation **300**, regardless of the chamfer rake angles β**1**. As noted previously, cutter backrake angles δ may also be used to alter the chamfer rake angles β**1** for purposes of determining bit performance during relatively low WOB drilling.

[**0042**] It should be appreciated that appropriate selection of chamfer size and chamfer backrake angle of the large chamfer cutters may be employed to optimize the performance of a drill bit with respect to the output characteristics of a downhole motor driving the bit during steerable or non-linear drilling of a borehole segment. Such optimization may be effected by choosing a chamfer size so that the bit remains non-aggressive under the maximum WOB to be applied during steerable or non-linear drilling of the formation or formations in question, and choosing a chamfer backrake angle so that the torque demands made by the bit within the applied WOB range during such steerable drilling do not exceed torque output available from the motor, thus avoiding stalling.

[**0043**] With regard to the placement of cutters exhibiting variously-sized chamfers on the exterior, and specifically the face of a bit, the chamfer widths employed on different regions of the bit face may be selected in proportion to cutter redundancy or density at such locations. For example, a center region of the bit, such as within a cone surrounding the bit centerline (see **FIGS. 7 through 10** and above discussion), may have only a single cutter (allowing for some radial cutter overlap) at each of several locations extending radially outward from the centerline or longitudinal axis of the bit. In other words, there is only "single" cutter redundancy at such cutter locations. An outer region of the bit, portions of which may be characterized as comprising a nose, flank and shoulder, may, on the other hand, exhibit several cutters at substantially the same radial location. It may be desirable to provide three cutters at substantially a single radial location in the outer region, providing substantially triple cutter redundancy. In a transition region between the inner and outer regions, such as on the boundary between the cone and the nose, there may be an intermediate cutter redundancy, such as substantially double redundancy, or two cutters at substantially each radial location in that region.

[0044] Relating cutter redundancy to chamfer width for exemplary purposes in regard to the present invention, cutters at single redundancy locations may exhibit chamfer widths of between about 0.030 to 0.060 inch, while those at double redundancy locations may exhibit chamfer widths of between about 0.020 and 0.040 inch, and cutters at triple redundancy locations may exhibit chamfer widths of between about 0.010 and 0.020 inch.

[0045] Rake angles of cutters in relation to their positions on the bit face have previously been discussed with regard to **FIGS. 7 through 10**. However, it will be appreciated that differences in the chamfer angles from the exemplary 45° angles discussed above may necessitate differences in the relative cutter backrake angles employed in and within the different regions of the bit face in comparison to those of the example.

[0046] While the present invention has been described in light of the illustrated embodiment, those of ordinary skill in the art will understand and appreciate it is not so limited, and many additions, deletions and modifications may be effected to the invention as illustrated without departing from the scope of the invention as hereinafter claimed.

What is claimed is:

1. A rotary drag bit for drilling a subterranean formation, comprising:

a bit body comprising at least a first region and a second region over a face to be oriented toward the subterranean formation during drilling; and

a plurality of cutters secured to the bit body in the first and second regions, the cutters each comprising a cutting face having a preselected effective cutting face backrake angle, and being positioned substantially transverse to a direction of cutter movement during drilling and including a cutting edge located to engage the subterranean formation, wherein the respective cutting faces of a majority of cutters located in the first region exhibit substantially larger effective cutting face backrake angles than the effective cutting face backrake angles of the respective cutting faces of a majority of cutters located in the second region.

2. The rotary drag bit of claim 1, wherein the first region lies within a cone on the face of the bit body, and the second region extends at least over a nose and flank on the face of the bit body.

3. The rotary drag bit of claim 2, wherein the second region extends to the gage of the bit body.

4. The rotary drag bit of claim 1, wherein the cutting faces are formed on polycrystalline diamond compact tables.

5. The rotary drag bit of claim 4, wherein the polycrystalline diamond compact tables are supported by metallic substrates.

6. The rotary drag bit of claim 1, further including a boundary region on the bit face lying between the first and second regions, and at least one cutter located in the boundary region having a preselected effective cutting face backrake angle intermediate the preselected effective cutting face backrake angles of the majority of first region cutters and the majority of second region cutters.

7. The rotary drag bit of claim 1, wherein the bit body further includes a plurality of generally radially oriented blades extending over the bit face and to the gage, and wherein the first region cutters and the second region cutters are located on the blades.

8. The rotary drag bit of claim 1, wherein the effective cutting face backrake angles of the cutters are determined at least in part by cutter backrake angles of the cutters.

9. The rotary drag bit of claim 8, wherein each of the plurality of cutters in the first region are oriented at greater backrake angles than each of the backrake angles of the plurality of cutters in the second region.

10. The rotary drag bit of claim 1, wherein at least one cutter proximate the gage is backraked at an angle less than a cutter backrake angle of at least one cutter in the first region.

11. The rotary drag bit of claim 1, wherein the first region lies within a cone on the face of the bit body, and the second region extends at least over a nose on the face of the bit body.

12. The rotary drag bit of claim 1, wherein the effective cutting face backrake angles of the cutters in both regions are determined at least in part by cutter backrake angle and each of the cutters in the first region have effective cutter backrake angles greater than the effective backrake angles of each of the cutters in the second region; and

wherein the plurality of cutters in the second region comprise cutters located relatively closer to the first region having greater cutter backrake angles than cutter backrake angles of other cutters in the second region but which are farther away from the first region.

13. A rotary drag bit for drilling a subterranean formation, comprising:

a bit body bearing a cutting structure thereon comprised of a plurality of superabrasive cutters, wherein at least some of the superabrasive cutters are configured and oriented to provide different ROP versus WOB characteristics for the bit below and above about a threshold WOB.

14. A rotary drag bit for drilling a subterranean formation, comprising a bit body bearing a cutting structure thereon comprised of a plurality of superabrasive cutters, wherein at least some of the superabrasive cutters are configured and oriented to provide different TOB versus WOB characteristics for the bit below and above about a threshold WOB.

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