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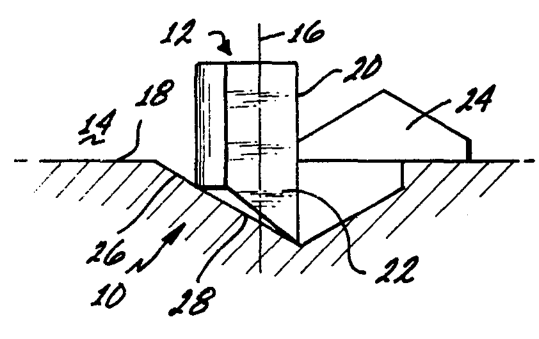
(54) **Improved tooth design using cylindrical diamond cutting elements.**

(57) The cutting performance of cylindrical polycrystalline synthetic diamond elements (12) is improved by segmenting such cylindrically shaped elements (12) along a plane or planes parallel to the longitudinal axis (16) of the cylindrically shaped elements (12). In the prefered embodiments half cylinder or quarter cylinder shaped segments are incorporated as the diamond cutting elements (12) within teeth (10) disposed on a rotating bit. The planar surface or surfaces (12) characterizing the cylindrical segments are oriented within the tooth (10) to provide the leading and cutting face of the diamond cutting element (12). Typically, such planar surfaces (22) are entirely exposed and disposed adjacent to and form one wall of an adjacent and preceding fluid channel (24) whereby cleaning and cooling efficiency is also improved.



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IMPROVED TOOTH DESIGN USING CYLINDRICAL DIAMOND CUTTING ELEMENTS

Background of the Invention

1. Field of the Invention

The present invention relates to the field of earth boring tools and in particular to rotating bits incorporating diamond elements.

2. Description of the Prior Art

The use of diamonds in drilling products is well known. More recently synthetic diamonds both single crystal diamonds (SCD) and polycrystalline diamonds (PCD) have become commercially available from various sources and have been used in such products, with recognized advantages. For example, natural diamond bits effect drilling with a plowing action in comparison to crushing in the case of a roller cone bit, whereas synthetic diamonds tend to cut by a shearing action. In the case of rock formations, for example, it is believed that less energy is required to fail the rock in shear than in compression.

More recently, a variety of synthetic diamond products has become available commercially some of which are available as polycrystalline products. Crystalline diamonds preferentially fractures on (111), (110) and (100) planes whereas PCD tends to be isotropic and exhibits this same cleavage but on a microscale and therefore resists catastrophic large scale cleavage failure. The result is a retained sharpness which appears to resist polishing and aids in cutting. Such products are described, for example, in U.S. Patents 3,913,280; 3,745,623; 3,816,085; 4,104,344 and 4,224,380.

In general, the PCD products are fabricated from synthetic and/or appropriately sized natural diamond crystals under heat and pressure and in the presence of a solvent/catalyst to form the polycrystalline structure. In one form of product, the polycrystalline structures includes sintering aid material distributed essentially in the interstices where adjacent crystals have not bonded together.

In another form, as described for example in U. S. Patents 3,745,623; 3,816,085; 3,913,280; 4,104,223 and 4,224,380 the resulting diamond sintered product is porous, porosity being achieved by dissolving out the nondiamond material or at least a portion thereof, as disclosed for example, in U. S. 3,745,623; 4,104,344 and 4,224,380. For convenience, such a material may be described as a porous PCD, as referenced in U.S. 4,224,380.

Polycrystalline diamonds have been used in drilling products either as individual compact elements or as relatively thin PCD tables supported on a cemented tungsten carbide (WC) support backings. In one form, the PCD compact is supported on a cylindrical slug about 13.3 mm in diameter and about 3 mm long, with a PCD table of about 0.5 to 0.6 mm in cross section on the face of the cutter. In another version, a stud cutter, the PCD table also is supported by a cylindrical substrate of tungsten carbide of about 3 mm by 13.3 mm in diameter by 26mm in overall length. These cylindrical PCD table faced cutters have been used in drilling products intended to be used in soft to medium-hard formations.

Individual PCD elements of various geometrical shapes have been used as substitutes for natural diamonds in certain applications on drilling products. However, certain problems arose with PCD elements used as individual pieces of a given carat size or weight. In general, natural diamond, available in a wide variety of shapes and grades, was placed in predefined locations in a mold, and production of the tool was completed by various conventional techniques. The result is the formation of a metal carbide matrix which holds the diamond in place, this matrix sometimes being referred to as a crown, the latter attached to a steel blank by a metallurgical and mechanical bond formed during the process of forming the metal matrix. Natural diamond is sufficiently thermally stable to withstand the heating process in metal matrix formation.

In this procedure above described, the natural diamond could be either surface-set in a predetermined orientation, or impregnated, i.e., diamond is distributed throughout the matrix in grit or fine particle form.

With early PCD elements, problems arose in the production of drilling products because PCD elements especially PCD tables on carbide backing tended to be thermally unstable at the temperature used in the furnacing of the metal matrix bit crown, resulting in catastrophic failure of the PCD elements if the same procedures as were used with natural diamonds were used with them. It was believed that the catastrophic failure was due to thermal stress cracks from the expansion of residual metal or metal alloy used as the sintering aid in the formation of the PCD element.

Brazing techniques were used to fix the cylindrical PCD table faced cutter into the matrix using temperature unstable PCD products. Brazing materials and procedures were used to assure that temperatures were not reached which would cause catastrophic failure of the PCD element during the manufacture of the drilling tool. The result was that sometimes the PCD components separated from the metal matrix, thus adversely affecting performance of the drilling tool.

With the advent of thermally stable PCD elements, typically porous PCD material, it was believed that such elements could be surface-set into the metal matrix much in the same fashion as natural diamonds, thus simplifying the manufacturing process of the drill tool, and providing better performance due to the fact that PCD elements were believed to have advantages of less tendency to polish, and lack of inherently weak cleavage planes as compared to natural diamond.

Significantly, the current literature relating to porous PCD compacts suggests that the element be surface-set. The porous PCD compacts, and those said to be temperature stable up to about 1200°C are available in a variety of shapes, e.g., cylindrical and triangular. The triangular material typically is about 0.3 carats in weight, measures 4mm on a side and is about 2.6mm thick. It is suggested by the prior art that the triangular porous PCD compact be surface-set on the face with a minimal point exposure, i.e., less than 0.5mm above the adjacent metal matrix face for rock drills. Larger one per carat synthetic triangular diamonds have also become available, measuring 6 mm on a side and 3.7 mm thick, but no recommendation has been made as to the degree of exposure for such a diamond. In the case of abrasive rock, it is suggested by the prior art that the triangular element be set completely below the metal matrix. For soft nonabrasive rock, it is suggested by the prior art that the triangular element be set in a radial orientation with the base at about the level of the metal matrix. The degree of exposure recommended thus depended on the type of rock formation to be cut.

The difficulties with such placements are several. The difficulties may be understood by considering the dynamics of the drilling operation. In the usual drilling operation, be it mining, coring, or oil well drilling, a fluid such as water, air or drilling mud is pumped through the center of the tool, radially outwardly across the tool face, radially around the outer surface (gage) and then back up the bore. The drilling fluid clears the tool face of cuttings and to some extent cools the cutter face. Where there is insufficient clearance between the formation cut and the bit body, the cuttings may not be cleared from the face, especially where the formation is soft or brittle. Thus, if the clearance between the cutting surface-formation interface and the tool body face is relatively small and if no provision is made for chip clearance, there may be bit clearing problems.

Other factors to be considered are the weight on the drill bit, normally the weight of the drill string and principally the weight of the drill collar, and the effect of the fluid which tends to lift the bit off the bottom. It has been reported, for example, that the pressure beneath a diamond bit may be as much as 1000 psi greater than the pressure above the bit, resulting in a hydraulic lift, and in some cases the hydraulic lift force exceeds 50% of the applied load while drilling.

One surprising observation made in drill bits having surface-set thermally stable PCD elements is that even after sufficient exposure of the cutting face has been achieved, by running the bit in the hole and after a fracion of the surface of the metal matrix was abraded away, the rate of penetration often decreases. Examination of the bit indicates unexpected polishing of the PCD elements. Usually ROP can be increased by adding weight to the drill string or replacing the bit. Adding weight to the drill string is generally objectionable because it increases stress and wear on the drill rig. Further, tripping or replacing the bit is expensive since the economics of drilling in normal cases are expressed in cost per foot of penetration. The cost calculation takes into account the bit cost plus the rig cost including trip time and drilling time divided by the footage drilled.

Clearly, it is desirable to provide a drilling tool having thermally stable PCD elements and which can be manufactured at reasonable costs and which will perform well in terms of length of bit life and rate of penetration.

It is also desirable to provide a drilling tool having thermally stable PCD elements so located and positioned in the face of the tool as to provide cutting without a long run-in period, and one which provides a sufficient clearance between the cutting elements and the formation for effective flow of drilling fluid and for clearance of cuttings.

Run-in in diamond bits is required to break off the tip or point of the triangular cutter before efficient cutting can begin. The amount of tip loss is approximately equal to the total exposure of natural diamonds. Therefore, an extremely large initial exposure is required for synthetic diamonds as compared to natural diamonds. Therefore, to accommodate expected wearing during drilling, to allow for tip removal during run-in, and to provide flow clearance necessary, substantial initial clearance is needed.

Still another advantage is the provision of a drilling tool in which thermally stable PCD elements of a defined predetermined geometry are so positioned and supported in a metal matrix as to be effectively locked into the matrix in order to provide reasonably long life of the tooling by preventing loss of PCD elements other than by normal wear.

It is also desirable to provide a drilling tool having thermally stable PCD elements so affixed in the tool that it is usable in specific formations without the necessity of significantly increased drill string weight, bit torque, or significant increases in drilling fluid flow or pressure, and which will drill at a higher ROP than conventional fits under the same drilling conditions.

Brief Summary of the Invention

The present invention is an improvement in a rotating bit having a bit face wherein the improvement comprises a plurality of teeth disposed on the bit and wherein each tooth includes a diamond cutting element. The diamond cutting element is particularly characterized by having the shape of a segment of a cylinder. The segment includes at least one planar surface and the planar surface forms, at least in part, a leading surface of the tooth.

More specifically, the cylindrical segment is a split half cylinder or a split quarter cylinder. The diamond cutting element is characterized by having a longitudinal axis lying along the length of the cylinder and wherein the cylindrical shape is a half cylinder shape, the planar surface is a planar surface lying along a diameter of the cylindrical shape. In the case where the cylindrical segment is a quarter segment of a full cylinder, the quarter segment includes an apical edge which lies along the longitudinal axis of the cylinder. In each case, the apical edge of the quarter cylinder and the planar surface of the half cylinder diamond cutting element serves as an exposed leading surface of the tooth and is disposed adjacent to a fluid channel thereby forming in whole or in part one edge or wall of the fluid channel. As a result of these improvements a cutting tooth is provided using cylindrical elements characterized by improved cutting efficiency, cleaning and cooling efficiency, and less tendency to dull or polish than is the case with prior art fully cylindrical elements used in rotating bits.

The present invention and its various embodiments are better understood by first considering the following drawings wherein like elements are referenced by like numerals.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a tooth incorporating a cylindrical diamond segment according to the present invention.

Figure 2 is a plan view of three teeth of the type showi in Figure 1.

Figure 3 is a cross-sectional view through a rotating bit showing the area of a gage-to-shoulder transition incorporating the teeth of Figure 1.

Figure 4 is a plan view in reduced scale showing a coring bit incorporating the teeth of Figures 1 and 2.

Figure 5 is a half profile view of the coring bit of Figure 4.

Figure 6 is a plan view of the gage-to-shoulder transition of the coring bit in Figure 4 in conformity with the teaching of Figure 3.

Figure 7 is a cross-sectional view in enlarged scale of a tooth incorporating a second embodiment of the present invention.

Figure 8 is a plan view of three teeth devised according to the second embodiment shown in Figure 7.

The present invention and its various embodiments may be better understood by viewing the above figures in light of the following detailed description.

Detailed Description of the Preferred Embodiments

The present invention is an improvement in a tooth design used in rotating bits, particularly rotary bits, wherein the tooth includes a diamond cutting element and in particular a diamond cutting element derived from cylindrical polycrystalline synthetic diamond (PCD). Such full cylindrical elements are generally commercially available but not in segment form. Such synthetic diamond is formed in the shape of a full circular cylinder having one planar end perpendicular to the longitudinal axis of the cylindrical shape and an opposing domed end, generally formed in the shape of a circular cone. Such elements are typically available in a variety of sizes with the above described shape.

According to the present invention, the full cylindrical

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diamond element is segmented to form a cylindrical segment wherein the segment is then axially disposed within a bit tooth. Such segmented or split cylindrical elements thus provide a cutting element with improved cutting efficiency with less use o diamond material and less tendency to dull or polish. The present invention and its various embodiments may be better understood by now turning to Figure 1.

Figure 1 is a cross-sectional view of a first embodimen of the present invention showing a tooth, generally denoted by reference numeral 10, incorporating a diamond cutting element, generally denoted by reference numeral 12. Element 12 is axiall disposed within the tungsten-carbide matrix material 14 of the rotating bit. In other words, longitudinal axis 16 of element 1 is oriented to be approximately perpendicular to bit surface 18 at the location of tooth 10. Bit surface 18 may be bit face of crown of a rotating bit or may be the superior surface of a raised land or pad disposed upon a bit crown. In either case, bit surface 18 is taken in the present description as the basal surface upon which tooth 10 is disposed.

As better seen in Figure 2, element 12 is approximately a quarter section or 90 degrees of the full cylindrical shape of the PCD element normally available. Element 12 is cut using a conventional laser cutter. For example, deep cuts are made every 90 degrees parallel to the longitudinal axis 16 of a full cylindrical diamond element. Although the laser could be used t completely cut through the diamond element, it has been found possible that with deep scoring, the diamond can then be fractured with propagation of the fracture lying approximately along the continuation of the plane of the laser cut. For example, the laser may cut a millimeter or less into and along the length of the full cylindrical diamond element. A diametrically opposed cut of equal depth is also provided on the cylinder. Thereafter, the cylinder may be split in half and then later quartered on another laser cut by fracturing the diamond element using an impulsive force and chisel.

Diamond element 12 is disposed within tooth 10 as isshown in Figure 2 so that the apical edge 20 of diamond 12 formed by the cleavage planes or laser cuts which have formed radial surfaces 22, is oriented in the leading or forward direction of tooth 10 as defined by the rotation of the bit upon which tooth 10 is disposed.

Turning again to Figure 1, it can be seen that a portion of element 12 is fully exposed above bit surface 18 and in particular, that apical edge 20 forms the foremost portion of diamond element 12 as the tooth moves forwardly in the plane of the figure. Surfaces 22 define a dihedral angle and the tangential direction of movement of tooth 10 during normal cutting operation is generally along the direction of the bisector of the dihedral angle. In the illustrated embodiment a channel 24 is defined immediately in front of apical edge 20 to serve as a waterway or collector as appropriate. Thus, leading surfaces 22 and edge 20 can be placed virtually in channel 24 or immediately next thereto, forming as shown in Figure 1, one wall of channel 24 or a portion thereof, whereby hydraulic fluid supplied to and flowing through channel 24 during normal drilling operations will serve to cool and clean the cutting face of tooth 10 and in particular the leading edge and surfaces of diamond element 12.

Further, in the illustrated embodiment, tooth 10 is shown as having a trailing support 26 of matrix material integrally formed with matrix material 14 of the bit and extending above bit surface 18 to the trailing surface of diamond element 12. The slope of trailing support 26 is chosen so as to substantially match the slope of the top conical surface 28 of element 12 with the opposing end of element 12, which is a right circular plane, being embedded within matrix material 14. However, it must be understood that the exact shape and placement of trailing support 26 can be varied without departing from the spirit and scope of the present invention. For example, with larger diameter elements 12, cut from large diameter synthetic cylinders, no trailing support 26 may be provided at all and element 12 may be totally free standing above bit surface 18 like an embedded stud. In the cases of thinner cylindrical elements 12, trailing support 26 may be even more substantial than that shown in Figure 1 and may assume a slope different from surface 28 of element 12 to thereby provide additional matrix reinforcing material behind and on top of conical surface 28 and leading surfaces 22.

Figure 2 illustrates in plan view the tooth of Figure 1 in a double row or triad configuration. In other words, a first row of teeth including teeth 10a and 10b is succeeded by a trailing tooth or second row of teeth including tooth 10c, wherein tooth 10c is placed halfway between the spacing of teeth 10a and 10b. Therefore, it can be appreciated that as the teeth 10a-c move forward during cutting of a rock formation, the diamond cutting elements incorporated within each of the teeth effectively overlap and provide a uniform annular swath cut into the rock formation as the bit rotates. Figure 4, which shows in plan view a coring bit incorporating the teeth of Figures 1 and 2 illustrates the disposition of such a double row of configured teeth, collectively denoted by reference numeral 32, on pad 30.

Bit 34 also includes an inner gage 44 wherein the inner and outer gage are connected by waterways 31. Each pad 30 begins at or near inner gage 44 and is disposed across the bit face in a generally radial direction as seen in Figure 4 and splits into two pads which then extend to outer gage 36. The bifurcated pads are separated by a collector 33 which communicates with a gage collector 35 or junk slot 37 as may be appropriate. Clearly, other types of coring bits and petroleum bits could have been illustrated to show the use of the teeth of Figures 1-3 other than the particular bit illustrated in Figure 4. Therefore, the invention is not to be limited to any particular bit style or in fact, even to rotating bits.

Turning now to Figure 3, a cross-sectional view of the shoulder-to-gage transition utilizing the teeth of Figures 1 and 2 is illustrated. The bit, generally denoted by reference numeral 34, is characterized by having a vertical cylindrical section or gage 36 which serves to define and maintain the diameter of the bore drilled by bit 34. Below gage 36, bit 34 will slope inwardly along a designed curve toward the center of the bit. In the example of coring bit of Figure 4, a half profile is shown in Figure 5 and is a simple elliptical cross section characterized by an outer shoulder 38, nose 40 and inner shoulder 42. Inner diameter of the core is then defined by inner gage 44. Turning again to Figure 3, outer gage 36 is shown as incorporating a half cylindrical segment 46, which is surface set and embedded into gage 36 so that the rounded cylindrical surface 48 is exposed above bit surface 50 of gage 36 with the flat longitudinal face 52 of the half cylindrical segment embedded within matrix material 54 of bit 34. Half cylindrical diamond crystalline element 46 is more clearly depicted in cross-sectional view in Figure 4 on gage 36.

Moving from gage 36 to outer shoulder 38, teeth 32 as shown in Figure 4 include quarter cylindrical segments, shown in rear view in Figure 3 as exemplified by diamond elements 56 and 58. Each element 56 is disposed within bit 34 so as to extend therefrom in a perpendicular direction as defined by the normal to bit surface at each point where such element is located.

In the preferred embodiment each element 56 and 58 is exposed by a uniform amount, namely, 2.7 mm (0.105") above the bit face. Element 56 which is the diamond element closest to gage 36 is placed upon shoulder 38 at such a position next to the beginning of gage 36 so that its outermost radially extending point, namely, apex 60, extends radially from the longitudinal axis of rotation of bit 34 by an amount equal to the radial distance from the longitudinal axis of bit 34 by the gage diamonds, in particular diamond 46. For example, in the preferred embodiment, gage diamond 46 extends above bit surface 50 by 0.64 mm (0.025"). While element 56 extends above bit face 50 by 2.7 mm (0.105") it is placed as the first tooth on the bit face at such a distance from the gage 36 that the radially outermost exposed portion of diamond element 56 will equal the radial distance of the gage diamonds 46 from the axis of rotatioı of bit 34.

Thus, as illustrated in Figure 6, which shows a plan view of the gage of the bit of Figure 4, a double row of gage diamonds 46a is disposed at and slightly below gage level 62 on ‹ type I gage column corresponding to a type I pad 30 shown in plaı view in Figure 4. Gage diamonds 46b are thus placed adjacent to a pad of type II and gage diamonds 46c placed on a gage section correspondingg to a type III pad. Gage diamonds 46a-c thus form a staggered pattern as best illustrated in Figure 6 which effectively presents a high cutting element density as the bit rotates. Above gage diamonds 46a-46b are conventional natural diamonds surface set in broaches, namely, kickers which are typical of the order of 6 per carat in size. Whereas the double row of diamonds within one gage section are offset from each other by approximately half a unit spacing, a unit spacing being defined as the length of a gage diamond 46, the adjacent row of teeth on the next adjacent gage section begins at a quarter spacing displaced from the corresponding row of gage diamonds on the adjacent pad. In other words, while type I pad corresponds to gage diamonds 46a having two rows with each row offset by half a space between each other, pad II corresponds to gage diamonds 46b which are similarly offset with respect to each other and are spaced down the gage one quarter of a spacing as compared to gage diamonds 46a on pad type I.

Turning now to Figure 7, a second embodiment of the present invention is illustrated wherein a tooth, generally denoted by reference numeral 66, incorporates a half cylindrical segment diamond element 68 extending from and embedded in matrix material 14 in much the same manner as illustrated in connection with the first embodiment of Figures 1 and 2. As better seen in plan view of Figure 8, PCD element 68 is characterized by a half cylindrical surface 70 and a planar leading surface 72, which is formed as described above by cleaving a full cylinder along the diameter.

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Turning again to Figure 7, diamond element 68 also includes a conical or domed upper surface 74 forming the apical point 76 of element 68. A trailing support 78 of integrally formed matrix material is smoothly fared from surface 74 to bit face 18 to provide tangential reinforcement and support for diamond element 68 against the cutting forces to which element 68 is subjected. As better seen in plan view in Figure 8, trailing supports 78 are tapered to a point 80 on bit face 18 thereby forming a teardrop shaped plan outline for tooth 66.

As shown in Figure 7, diamond element 68 is placed immediately adjacent to and forms one side of a channel 80 formed into matrix material 14 which channel 80 serves as a conventional waterway or collector as may be appropriate with the same advantages as described in connection with the first embodiment of Figure 1.

As described in connection with Figure 2, the second embodiment of Figure 8 similarly consists of two rows of teeth 66a and 66b followed by a second row represented by tooth 66c. Tooth 66c is located halfway between the spacing between tooth 66a and 66b as defined with respect to the direction of tangential movement during normal drilling operations. The double row of teeth are disposed on a petroleum or coring bit in the same manner as illustrated in connection with the first embodiment of the invention in Figure 4. Teeth 66 are thus disposed within matrix material 14 and used on a bit in the same manner as are teeth 10 of Figures 1 and 2. However, teeth 66 as shown in Figure 8, clearly provide a broader cutting surface and a diamond element 68 containing twice the diamond material and structural bulk as compared to diamond elements 12 of the first embodiment. Therefore, in those applications where a larger cutting bite is required or where greater structural strength is needed in the diamond element, the half cylindrical split elements 68 of the second embodiment may be more advantageously used than the quarter split diamond elements of the first embodiment.

Many alterations and modifications may be made to the present invention without departing from its spirit and scope. For example, although the split cylindrical segment has been shown as perpendicularly embedded into the matrix material, it is clearly contemplated that it may be either forwardly or rearwardly raked if required by design objectives. Therefore, the illustrated embodiment must be understood as presented only as an example of the invention and should not be taken as limiting the invention as set forth in the following claim.

CLAIMS

We claim:

1. In a rotating bit having a bit face, an improvement comprising:

a plurality of teeth disposed on said bit wherein each said tooth includes a diamond cutting element having a longitudinal axis, said diamond cutting element being characterized in shape as a segment of a cylinder including at least one planar surface, said planar surface forming at least in part a leading surface of said tooth.

2. The improvement of Claim 1 wherein said cylindrical shape of said diamond cutting element is a circular cylinder.

3. The improvement of Claim 1 wherein said segment of said cylindrical shape is a half cylinder shape, said planar surface being a planar surface lying along a diameter of said cylindrical shape.

4. The improvement of Claim 3 wherein said planar surface is oriented and exposed to form said leading surface of said tooth.

5. The improvement of Claim 1 wherein said segment of said cylindrical shape of said diamond cutting element is

characterized by an apical edge defining a dihedral angle of less than 180 degrees.

6. The improvement of Claim 5 wherein said segment of cylindrically shaped diamond cutting element is a quarter segment of a full cylinder and wherein said apical edge lies along said longitudinal axis.

7. The improvement of Claim 6 wherein said diamond cutting element is disposed within each tooth so that each apical edge provides the leading portion of said diamond cutting element.

8. The improvement of Claim 7 wherein the tangential direction of movement of said tooth lies approximately along the bisector of said dihedral angle defining said apical edge.

9. The improvement of Claim 1 wherein said tooth further includes a trailing support disposed behind said diamond cutting element is contiguous thereto and is substantially congruous with a trailing surface of said diamond cutting element, said trailing support tapering from said trailing surface of said diamond cutting element to said bit face.

10. The improvement of Claim 1 wherein said diamond cutting element forms one wall of an adjacent fluid channel defined into said bit face in front of said tooth.

11. The improvement of Claim 1 wherein said bit includes a gage and a sloping shoulder, said teeth being disposed on said shoulder near said gage and extending above said bit face by a first predetermined distance, said gage including cutting elements disposed above said bit face of said gage by a second predetermined distance and said bit further being characterized by a longitudinal axis of rotation, the radial distance from ssaid longitudinal axis of rotation of said cutting elements disposed and extending above said gage being approximately equal to the radial distance from said longitudinal axis of rotation of an uppermost one of said diamond cutting elements disposed on said shoulder, said uppermost diamond cutting element on said shoulder being positioned on said shoulder next to said gage at a location such that said radial distances from said longitudinal axis of rotation of said cutting elements on said gage and of said uppermost diamond cutting element are set approximately equal.

12. In a rotating bit having a bit face and a plurality of teeth disposed thereon, an improvement comprising a cylindrically shaped polycrystalline diamond element incorporated within each said tooth, said diamond cutting element characterized by a shape assumed in the form of a segment of a cylinder and further characterized by having one end of said cylindrical shape formed into a conical segment, said segment of said cylindrical shape of said diamond cutting element providing at least one planar surface, said planar surface of said diamond

cutting element oriented within said tooth to provide at least in part a leading surface of said tooth as defined by the direction of movement of said tooth during normal cutting operation when said bit rotates, whereby said cylindrically shaped diamond cutting element provides improved cutting efficiency and bit lifetime.

13. The improvement of Claim 12 wherein said segment of said cylindrically shaped diamond cutting element is a half cylindrical segment, thereby defining a planar leading surface lying along a diameter of said cylindrical shape.

14. The improvement of Claim 12 wheren said segment of said cylindrically shaped diamond cutting element is a quarter segment, thereby defining an apical edge and two leading surfaces forming a dihedral angle behind said edge, said dihedral angle being approximately 90 degrees.

15. The improvement of Claim 14 wherein said cylindrically shaped diamond cutting element is characterized by a longitudinal axis lying along said apical edge and wherein said diamond cutting element is oriented with respect to said bit face so that said longitudinal axis is approximately perpendicular thereto.

16. The improvement of Claim 15 wherein a channel is defined into said bit face immediately in front of said diamond

cutting element and wherein said apical edge is disposed on and serves at least as part of an adjacent wall of said fluid channel.

17. The improvement of Claim 16, further including a trailing support integrally formed with said bit face and extending in a tapered fashion from said bit face to a trailing surface of said diamond cutting element.

18. The improvement of Claim 17 wherein an end of said diamond cutting element exposed above said bit face is formed in the shape of a segment of a cone, the slope of said cone shaped segment approximately matching the slope of said trailing support.

19. The improvement of Claim 12 wherein a plurality of rows of said teeth are disposed on said bit and wherein said rows are paired to form a first and second related row, the distance of spacing between teeth within said first and second row being substantially constant, said teeth of said second row being disposed behind said teeth of said first row as defined by tangential motion of said teeth during rotation of said bit during normal cutting operations, said teeth of said second row being readily disposed halfway between said teeth of said first row, whereby said teeth of said first and second rows cut a uniform annular swath as said bit rotates of a higher effective tooth density than achievable by tooth density within said first

or second row alone, said teeth of said second row following behind said teeth of said first row in the gaps between and behind said teeth of said first row.

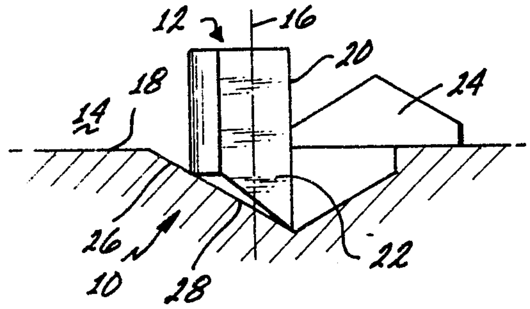


Fig.1

Fig.2

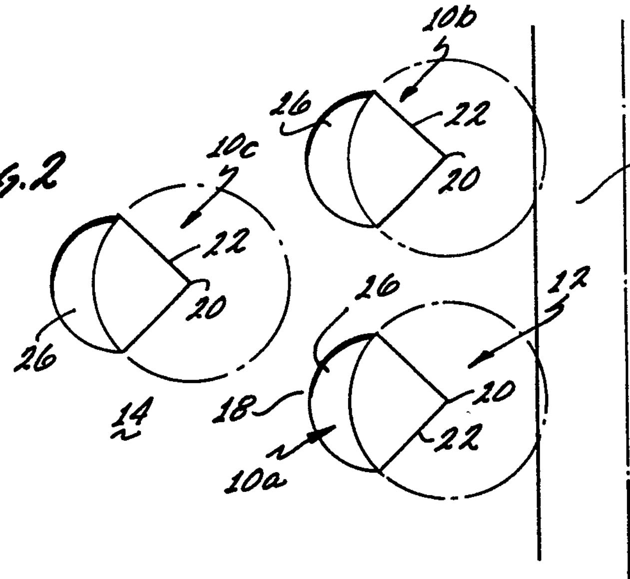
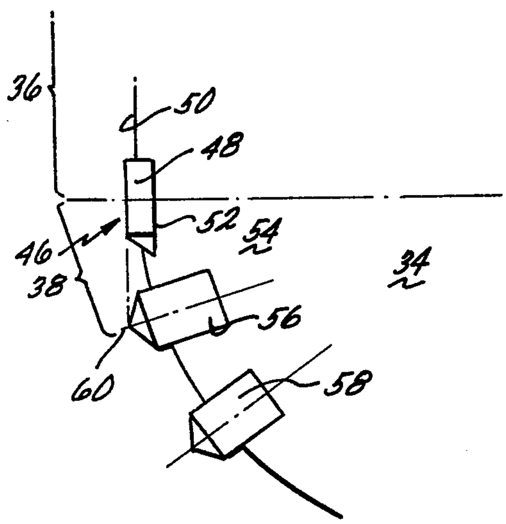


Fig.3



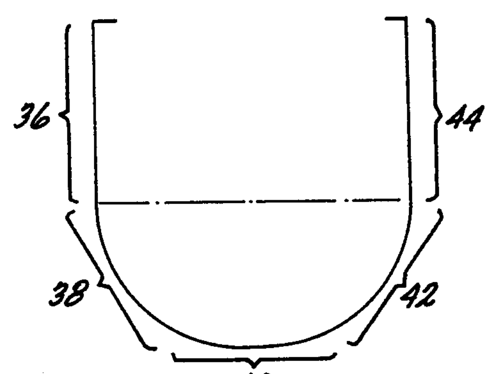
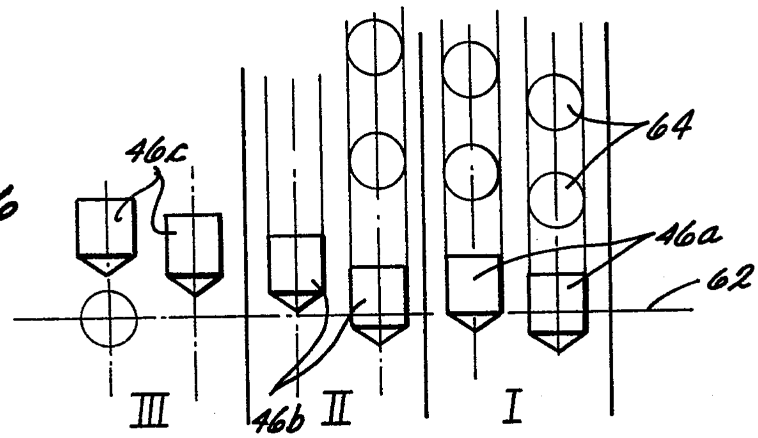


Fig.5

Fig.6



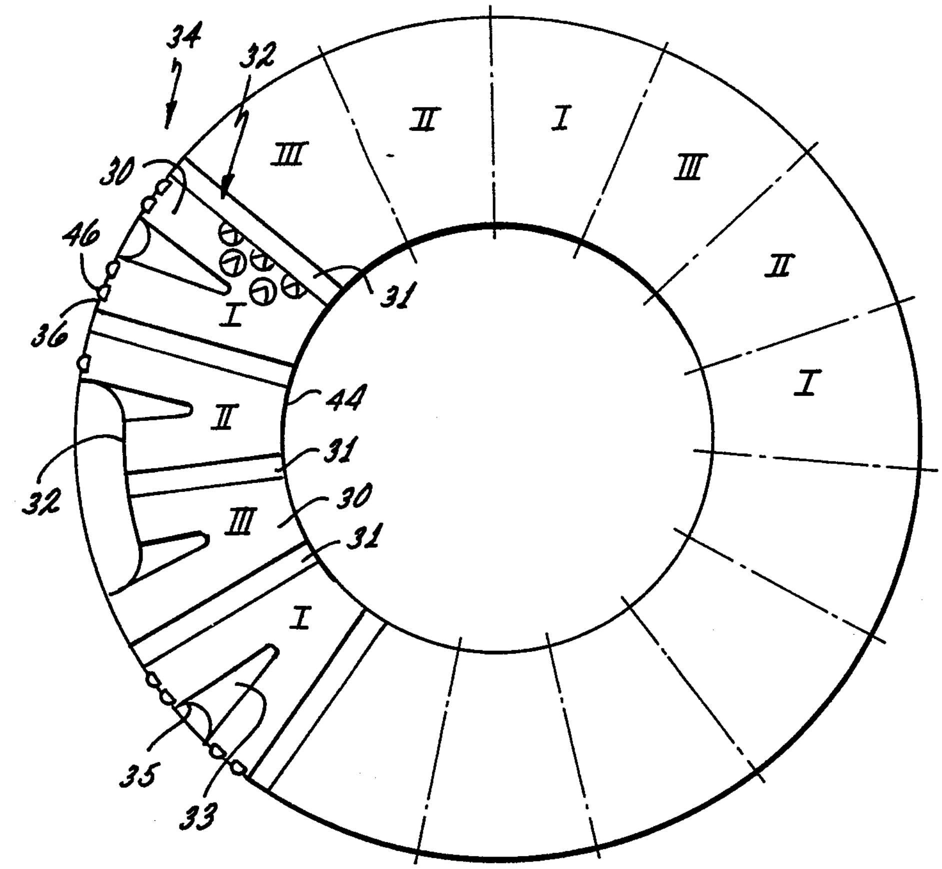
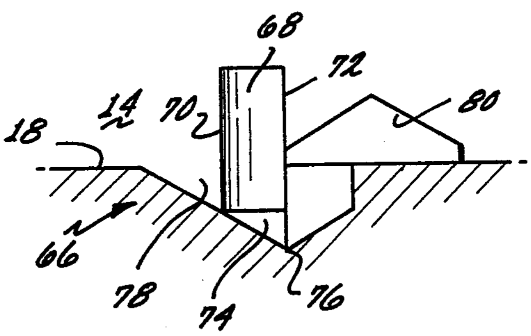


Fig.4

Fig.7



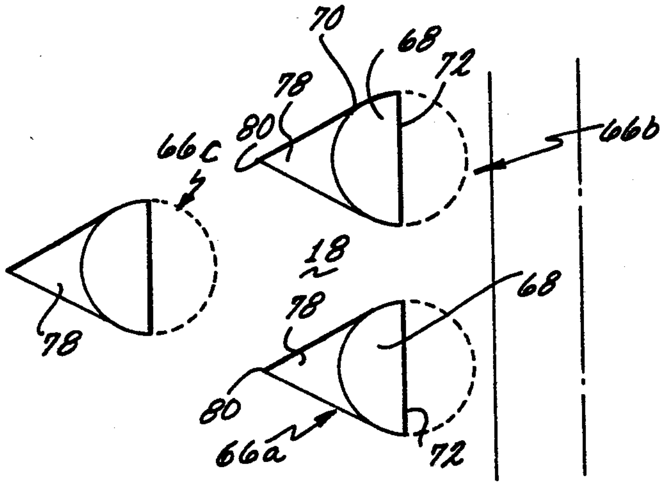


Fig.8