Aug. 9, 1966 E. L. HADEN ET AL 3,265,139

ROLLER CONE DRILL BIT

Filed Dec. 9, 1963 5 Sheets-Sheet 1

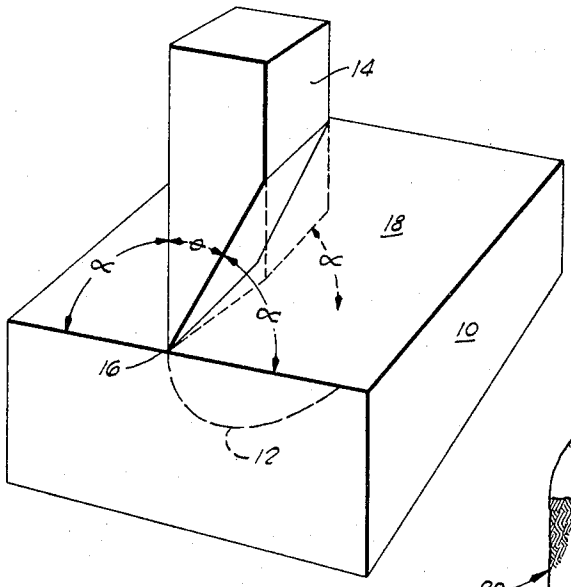


FIG. 1

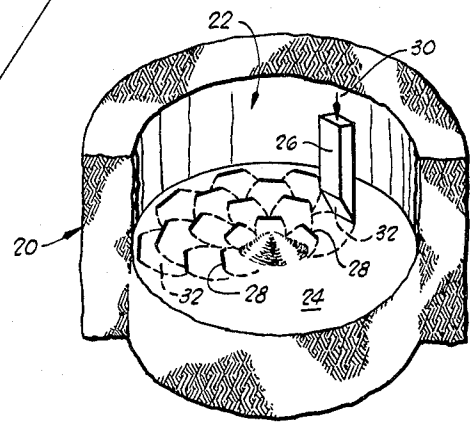


FIG. 2

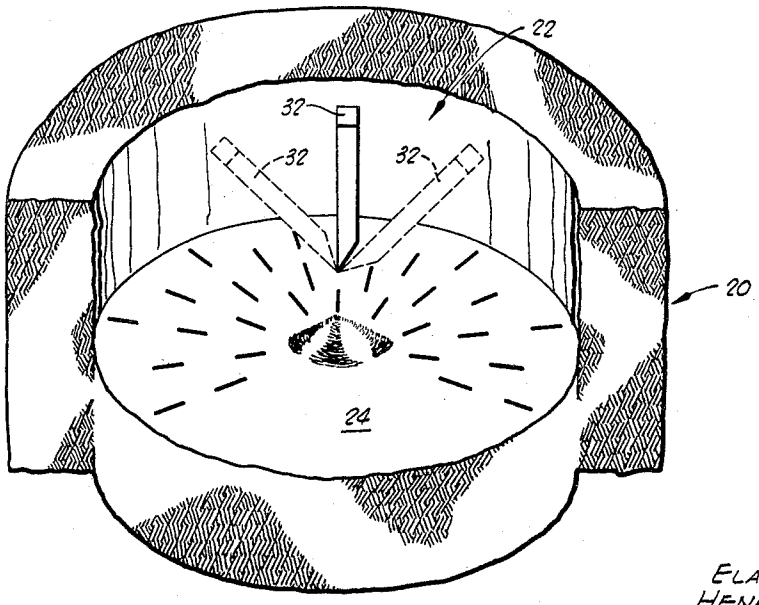


FIG. 3

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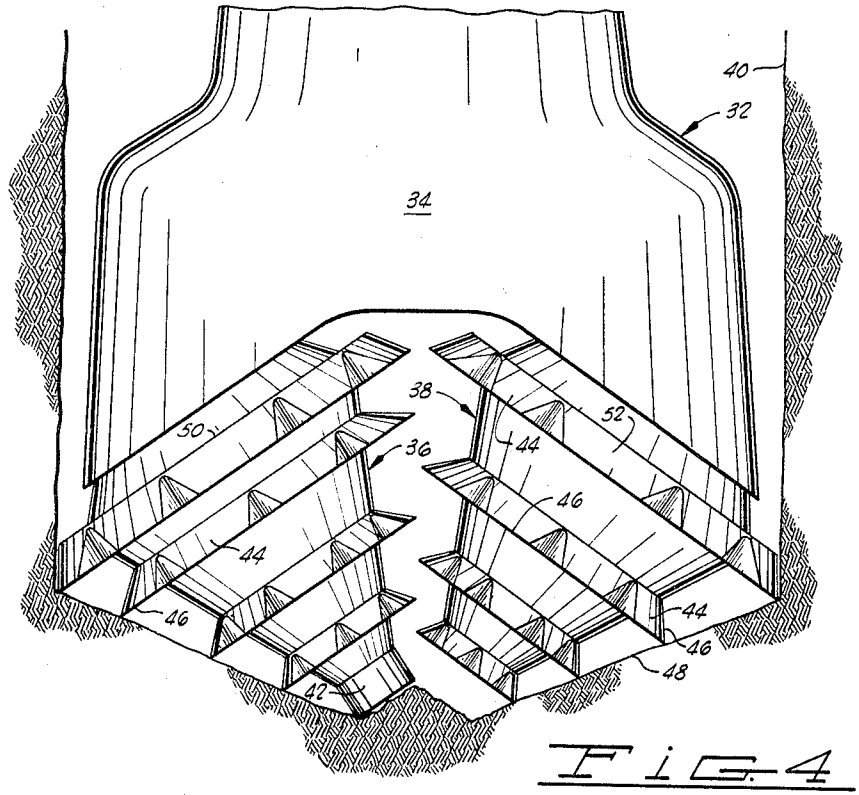


Fig. 4

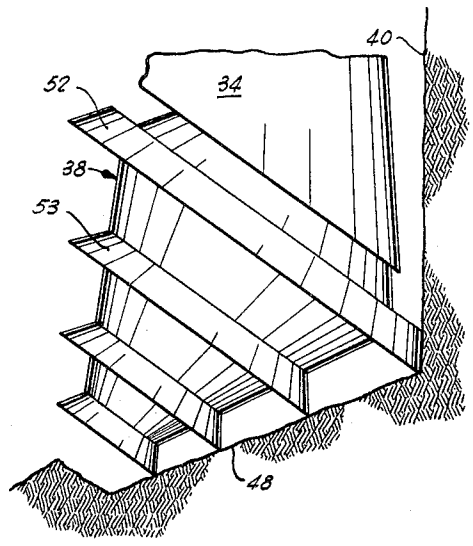


Fig. 5

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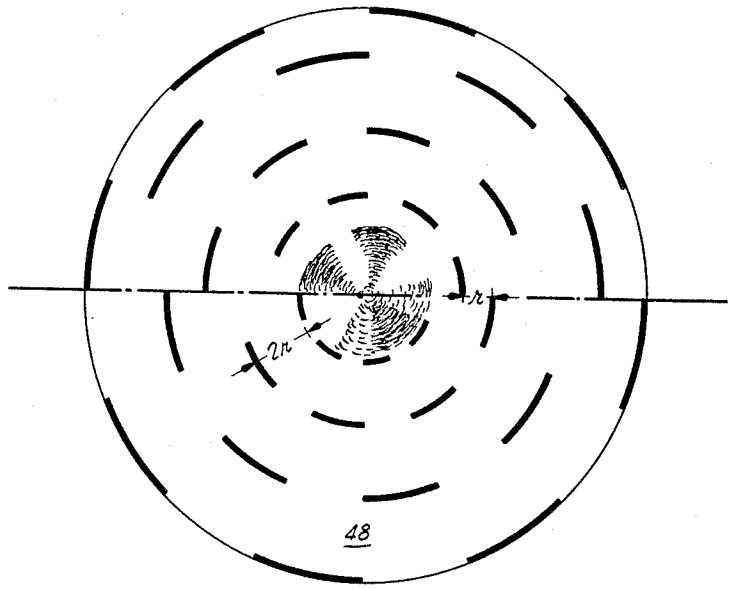


Fig. 6

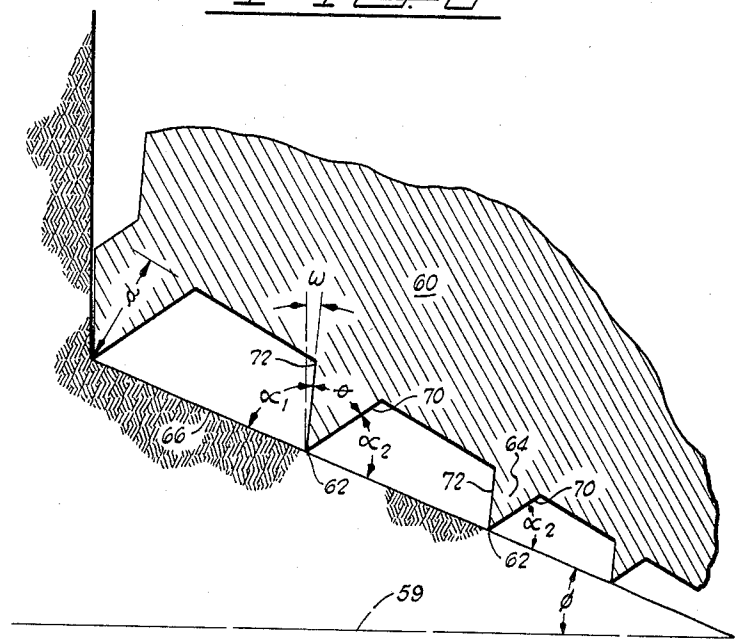


Fig. 7

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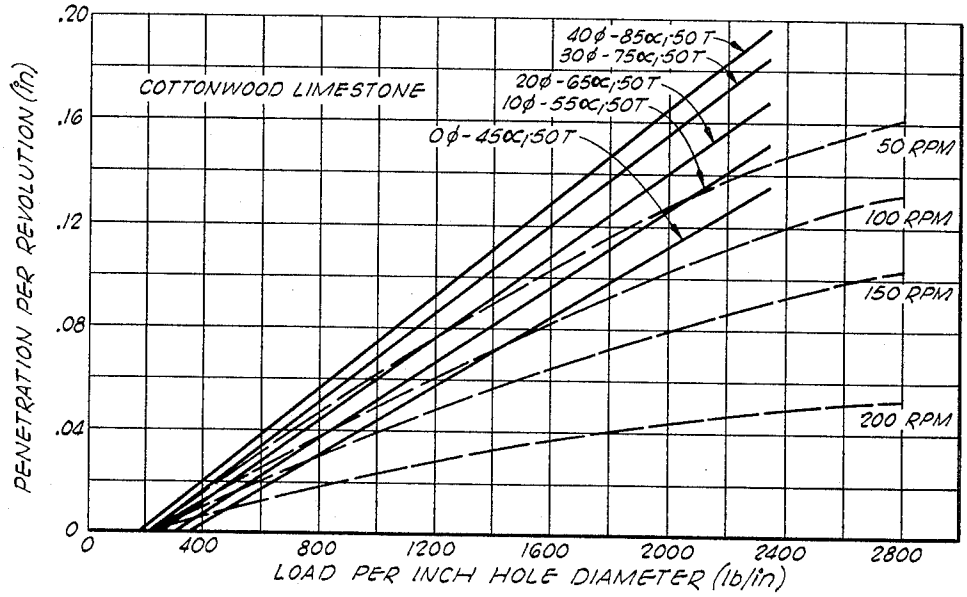


Fig. 8

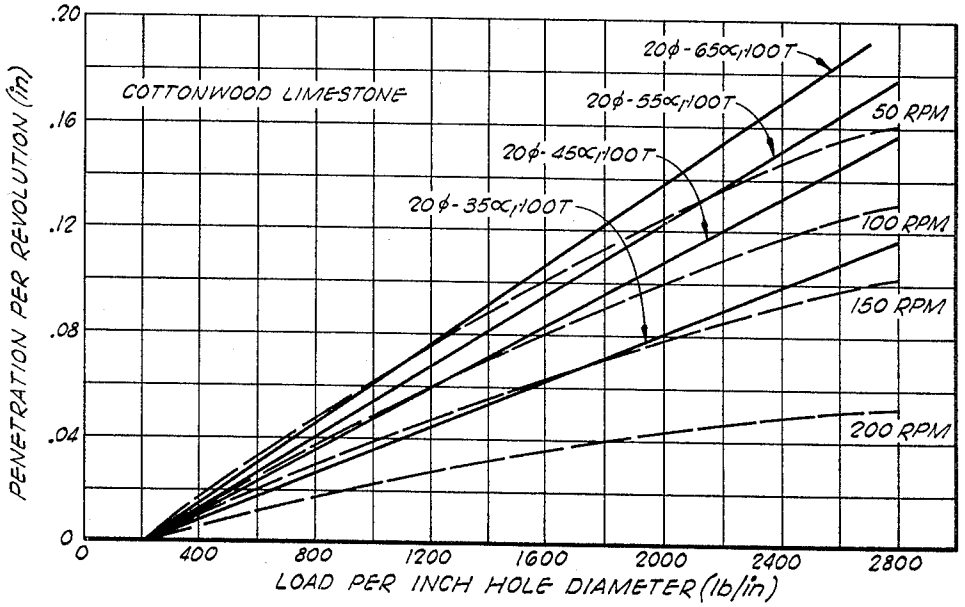


Fig. 9

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ROLLER CONE DRILL BIT

Filed Dec. 9, 1963 5 Sheets-Sheet 5

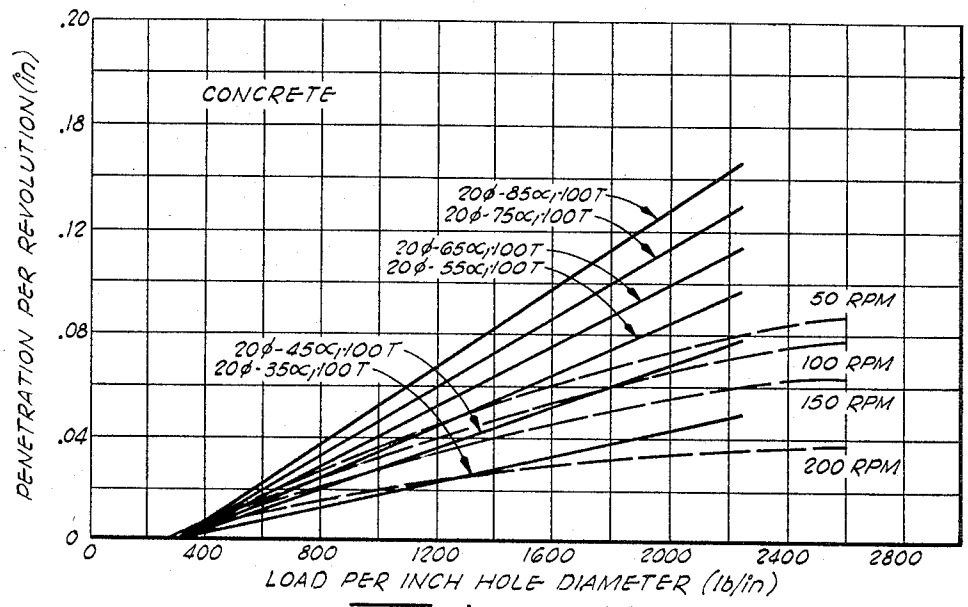


Fig. 11

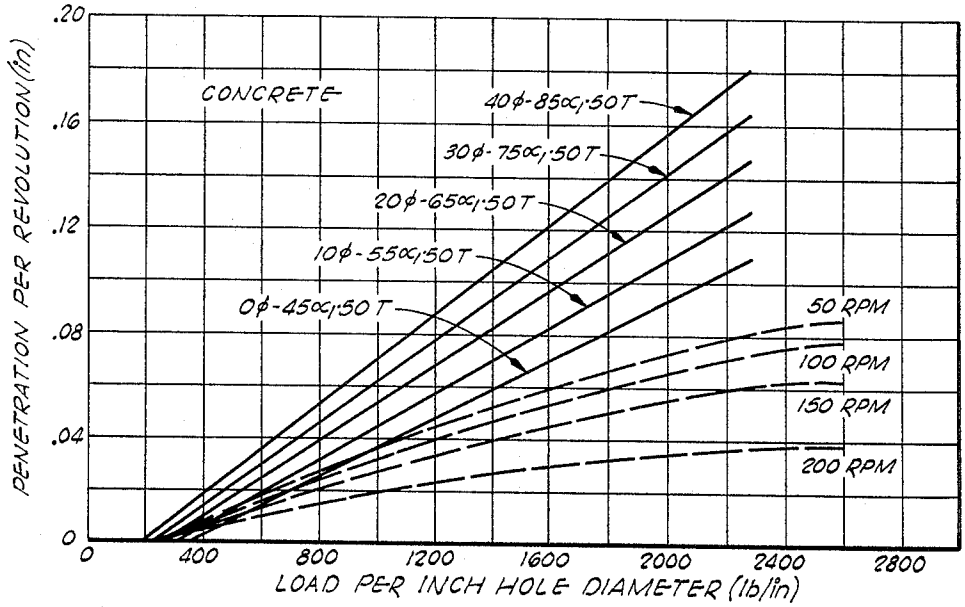


Fig. 10

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United States Patent Office 3,265,139 Patented August 9, 1966

3,265,139

ROLLER CONE DRILL BIT

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Filed Dec. 9, 1963, Ser. No. 329,130
10 Claims. (Cl. 175—356)

This application is a continuation-in-part of co-pending application for United States Letters Patent Serial No. 232,558 filed October 23, 1962, now abandoned.

The present invention relates to earth boring, and more particularly, but not by way of limitation, relates to an improved apparatus for drilling a well bore.

Rotary drilling bits were developed over fifty years ago and have since become the standard drilling tool of the oil industry. Today there are half a dozen or so companies engaged in the manufacture of three-cone rolling cutter type rock bits. In general, however, for a particular drilling job, about the only difference in the bits offered by the various companies is in the materials and metallurgy. There is virtually no difference in the bit geometry of the cutter cones of the several brands of bits, and almost all three-cone rock bits are patterned after the basic designs of Hughes Tool Company. Most of these bits have rows of teeth which are sequentially brought to bear against the bottom of the hole as the individual cones upon which the teeth are mounted rotate about their several axes and roll on the bottom of the well bore as the entire bit is rotated by the drill stem. The teeth of these bits are generally chisel-shaped in configuration and are oriented parallel to the axes of the individual rolling cones which carry them. Therefore, the individual teeth contact the bottom of the well bore along generally radial lines extending from the center of the hole. This type of bit is used almost exclusively when drilling hard formations in order to reduce abrasion of the teeth. When drilling in softer formations, such as shale, where abrasion is less of a consideration, the axes of the various cones are skewed slightly so as not to intersect in a common point, and a twisting action of the individual teeth on the bottom of the well bore is achieved which aids drilling. Such twisting action, however, shortens the effective service life of the teeth, and an examination of the surface which has been contacted by the teeth during drilling reveals that small bits of metal are abraded or worn from the teeth rather rapidly during the drilling operation.

A number of other rotary drill bit designs have also been proposed and patented. In general, these other designs employ the principles of either abrading or slicing the formation. The abrading type bits employ a scraping action and are known in the art as drag bits. In practice, this type of bit is generally unsuitable for cutting through hard rock formations, and, with the exception of diamond bits, is not used for this purpose. Another general type of bit which has been proposed utilizes a plurality of individual rotary discs having beveled cutting edges. These rotary discs are disposed in any one of a large number of patterns around the body of the drill bit and both roll and scrape in order to slice into the formation and thereby cut a well bore. These types of bits have, however, generally proven very impractical for several reasons. For example, the discs are relatively small and are easily stuck or frozen in which case they are quickly worn away by abrasion on the side in contact with the formation. Because of the small size, high capacity load bearings are not available to rotatably mount the individual discs and heavy loading necessary to penetrate the formation rock cannot be applied without damaging the bearings.

It is contemplated by the present invention to provide an improved rotary type drilling apparatus which utilizes a different principle for penetrating and making a well bore through hard rock formations. In general, the present invention utilizes the principle that deeper penetration of a tooth or chisel in rock can be achieved by tapering the faces of the tooth or chisel so as to include a relatively small angle in the point of the tooth. Stated differently, if the angle which is defined between either of the inclined faces of a tooth and the surface into which the tooth is being driven is termed the attack angle, then the larger the attack angle, the greater is the depth of penetration of the tooth when a load of a given magnitude is imposed thereon.

The bit of the present invention utilizes this principle by constructing the teeth of the bit in a configuration and arrangement to achieve a maximum attack angle with the bottom of the bore hole. The large attack angle which is developed in the use of the bit is in part due to the particular geometric configuration of the individual teeth, and is in part due to the slope or inclination of the surface of the bottom hole relative to a true horizontal plane. This inclination, which will be hereinafter referred to as hole bottom angle, makes possible the attainment of a relatively large attack angle without the concurrent reduction of the included tooth angle to a size so small that the very thin teeth resulting would have a very short service life.

In tapering the bottom of the bore hole to facilitate increasing the attack angle of the drill bit teeth relative to the surface of the hole bottom, another important advantage is achieved with respect to the conventional practice of drilling on a flat, substantially horizontal hole bottom. The over-all configuration of the surface of the hole bottom during drilling conducted in accordance with the present invention is generally conical, with the vertex or apex of the conical hole bottom surface being located on the axis of the hole. Chips or cuttings generated by the bit during drilling thus tend to gravitate or move inwardly toward the center of the hole. This common directional movement of the cuttings and their concentration adjacent the center of the bore hole makes it considerably easier to clean the hole bottom with water jets or other conventional procedures.

In a preferred embodiment of the invention, in order to maintain the same large attack angle of the bit teeth during the entire interval of time that each tooth is in contact with the bottom of the hole, the teeth are oriented on their respective rolling cones so as to contact the hole bottom surface along lines which are tangential or chordal with respect to imaginary circles concentric with the bore hole. The attack angle of each tooth is then measured in a plane extending substantially normal to the respective chordal lines of contact and remains substantially constant during the entire time interval of contact. In the case of radially oriented teeth of the type heretofore in widespread use for drilling bits, even if it were undertaken to develop a maximum attack angle between each of the teeth and the hole bottom surface during one instant of each tooth's contact with such surface, this angle would be diminished both immediately before and immediately after this instant during the rolling movement of the cone carrying the teeth, and could therefore not achieve the rate of penetration which characterizes the chordally oriented teeth of the drill bit of this invention.

Finally, because of the greatly increased drilling rate which has been observed to characterize the bits of the present invention, it is possible to mount the rolling cones carrying the teeth in proper geometric alignment to provide a true rolling movement of the teeth on the surface of the hole bottom. In other words, the bit of the present

invention does not require, and preferably does not make use of the skewing, slicing and scraping motions which have, by proper offset or non-alignment of the roller cones, been imparted to the teeth of many previous types of bits in order to increase the drilling rate. By virtue of such true rolling movement of the teeth, their effective service life is greatly prolonged.

In summary then, the drill bit of the present invention, in one of its broader aspects, comprises a body, such as a drill stem, having a longitudinal axis of rotation and rotatably carrying at least one cutter member, such as a rolling cone, with said cutter member mounted on said body for rotation about an axis inclined to the horizontal and said cutter member having a plurality of teeth mounted thereon and projecting radially outwardly from the axis of rotation of the cutter member and aligned for commonly contacting a surface preferably inclined to the horizontal during the rotation of said body, said teeth each having sides converging to form an elongated, wedge-shaped tip with each of said sides forming an angle of at least 40° with said surface during the contact of said teeth therewith.

In a preferred embodiment of the invention, the teeth are chordally (or tangentially) arranged as hereinbefore described, and are mounted on a plurality of rolling cones, the axes of which converge to a common point located on the longitudinal axis of rotation of the drill string so that there is obtained a true rolling motion of the teeth on the bottom of the bore hole.

From the foregoing description of the invention, it will have become apparent that it is an important object of the present invention to provide an improved drilling apparatus for drilling a bore hole through a rock formation at a greater rate for the same level of energy input as used in bits of previously devised types having relatively slower drilling rates.

A further object of the present invention is to provide an improved rotary cutting cone of the type described which will drill a well bore at a faster rate with less weight on the bit and at a slower rotational speed of the bit.

A still further object of the present invention is to provide a rolling cutter cone bit construction which may be operated under reduced weight loads and will thereby have an extended service life.

Another object of the present invention is to provide an improved drilling bit which is characterized by a rate of penetration which increases linearly with increases in rotational speeds.

Yet another object of the present invention is to provide an improved bit design of the type described which will cut a greater depth of bore hole before the bit is worn beyond use because of reduced wear of the teeth, and wear of the anti-friction load bearings used to connect the cutting cones of the bit to the bit body.

An additional object of the invention is to provide a drill bit which requires only about one half the horsepower input of conventional bits to attain the same drilling rates as conventional bits.

Another object of the present invention is to provide an improved drilling bit which achieves a high rate of formation penetration using a true rolling movement of the bit teeth on the formation surface, and thus attaining a longer service life than bits which operate by moving the teeth of the bit into the formation with a slicing or abrading motion.

Another object of the invention in one of its preferred forms is to generate and maintain a bore hole bottom surface which is of inverted conical configuration so that chips and cuttings generated during drilling are moved toward the center of the bore hole and may be more easily removed therefrom.

Many additional objects and advantages of the present invention will be evident to those skilled in the art from the following detailed description and from the accompanying drawings which illustrate the invention.

In the drawings:

FIGURE 1 is a schematic perspective view which serves to illustrate the fundamental principle underlying the present invention.

FIGURE 2 is a schematic perspective view which further illustrates by analogy the principle utilized in the present invention.

FIGURE 3 is a schematic perspective view illustrating by analogy the action of a bit having radially oriented teeth as contrasted with the chordally oriented teeth employed in a preferred embodiment of the present invention.

FIGURE 4 is a vertical sectional view of the bottom of a well bore, showing, in side elevation, a drill bit constructed in accordance with the present invention.

FIGURE 5 is a view similar to FIGURE 4, but illustrating only one of the rolling cones of the bit used in a modified embodiment of the present invention.

FIGURE 6 is a schematic tracking diagram of the teeth of the bit illustrated in FIGURE 4.

FIGURE 7 is a view in section taken on a plane passing through the axis of rotation or geometric axis of the roller cone illustrated in FIGURE 4.

FIGURES 8 through 11 are graphs presenting comparative data exemplifying the superiority of the bit of the present invention over a conventional rotary drilling bit currently in use and illustrating the importance of the attack angle between the teeth and the bottom of the bore hole.

The present invention can best be understood by first discussing the basic principle upon which the invention is founded. Referring to FIGURE 1, a generally rectangular block of stone **10** may be used for illustration purposes to demonstrate the basic concept. When it is undertaken to remove a chip **12** from the block **10** by striking the block with a pointed chisel **14**, it is found that the depth of penetration of the cutting edge **16** of the chisel **14**, and the efficiency with which chips **12** are removed from the block **10** are dependent upon the angles which are defined between the converging faces of the chisel and the surface **18** of the block **10**. The ease with which the chip **12** may be removed from the block **10** and the depth to which the chisel **14** penetrates the block **10** are found to be proportional to the size of the angle α (hereinafter termed attack angle) which exists between the surface **18** of the block **10** and the faces of the chisel which converge to the chisel edge **16**. Thus when α is less than 40°, such as the situation depicted in dashed lines in FIGURE 1, a relatively hard blow must be applied to the chisel **14** in order to remove a chip from the block. This is because the component of force exerted downwardly on the surface of the block by the face of the chisel which is inclined at less than about 40° to the surface **18** of the block tends to compress the stone inwardly toward the chisel point, resulting in greater resistance to the penetration of the chisel into the block, and also tending to reduce the wedging action of the chisel tending to pry the chip loose from the remaining portion of the block. On the other hand, as the attack angle α continues to increase, at values of α greater than about 40°, the depth of penetration of the chisel **14** into the block **10** and the ease with which a chip **12** may be removed from the block both increase rapidly. In summary then, for the most efficient penetration of the block **10** by a chisel **14** of the type having a generally wedge-shaped point, as shown in FIGURE 1, it is desirable to have the attack angle made by the defining faces of the chisel **14** with the block **10** as large as possible. Stated differently, maximum penetration of the block **10** by the chisel **14** is obtained when the angle theta (θ), hereinafter termed the included angle, is made as small as possible. It will be readily apparent, of course, that reduction in the size of the included angle theta is limited by the require-

ments of a certain minimum mechanical strength and durability in the point of the chisel and thus by present metallurgical technology.

The present invention makes use of the principal enunciated in the foregoing discussion that maximum penetration of a wedge-shaped member into a block for a given applied force may be obtained by shaping the wedge-shaped member so as to provide a maximum attack angle between the sides of the member which converge to its cutting edge, and the surface of the block which is to be struck with the wedge-shaped member. The manner in which the described principle is employed in extending the bore hole of a well by a drilling operation is schematically illustrated by analogy in FIGURE 2. Here the earth being drilled is represented by a block of stone 20 which has formed therein a large hole 22 representing the bore hole which is being drilled using the present invention. The bottom of the bore hole is represented by the surface 24. It is proposed by the present invention to extend the bore hole 22 by bringing to bear on the bottom surface 24 thereof, a series of chisel-shaped teeth, which in the schematic perspective diagram of FIGURE 2 may be represented by the chisel 26 and by lines 28 which represent the lines along which the cutting edges of a plurality of other chisel-shaped teeth are brought into contact with the bottom surface 28. When a force is applied downwardly in the direction of the arrow 30 to the chisel 26 and to each of the other teeth not shown, but implicitly acting downwardly to apply force at the lines 28, chips 32 will be severed from the bottom of the hole with an ease which is largely dependent upon the attack angle defined between the converging faces of the chisel and the bottom surface 24. Stated differently, the rate of penetration of the chisel-shaped teeth into the block 20 will depend upon the magnitude of the attack angles which are defined between the converging faces of the several teeth with the bottom surface 24. In using a plurality of chisel-shaped teeth in the manner shown in FIGURE 2, the teeth are preferably arranged so that the lines of contact of the teeth with the surface of the bottom 24 of the bore hole 22 are staggered or overlapped as shown in FIGURE 2 in order to assure a more complete coverage of the area of the bottom, and greater ease in removal of the chips.

It will be noted in referring to FIGURE 2 that the lines of contact 28 of the edges of the teeth with the bottom surface 24 are located on chords or tangents of imaginary circles drawn concentrically with respect to the axis of the bore hole 22. This arrangement of the chisel-shaped teeth constitutes a departure from the arrangement which has been previously employed in roller cone type drilling bits in that, in the latter devices, the teeth of the bits are usually arranged along lines extending radially from the axis of the bore hole. In other words, the line of contact of the cutting edges of the teeth on the majority of roller cone bits previously employed extends substantially normal to the lines of contact of the chordally oriented teeth used in a preferred embodiment of the present invention, and represented by the lines of contact 28 illustrated in FIGURE 2.

An advantage of the chordal tooth arrangement over the less preferred radial tooth arrangement may be perceived from a concurrent consideration of FIGURES 2 and 3 wherein like reference numerals are used to designate similar elements. Let it be assumed that the chisels shown in each of these figures are rotated about an axis which extends through the body of the chisel in a roughly horizontal direction and through the axis of the well bore, a movement which simulates the movement of the teeth carried by a rotating roller cone and drilling on a relatively flat bottom surface. It will be percieved that the attack angle which is formed between the surface and the converging faces of the chisel 26 shown in FIGURE 2 will remain constant throughout the entire time that the chisel point is in contact with the bottom surface 24 of the bore hole 22. On the other hand, in the case of radially oriented teeth represented by the chisel 32 shown in FIGURE 3, the attack angle defined between the converging faces of each tooth and the bottom surfaces 24 of the bore hole 22 varies from the initial instant of contact with the surface through the last instant of contact. These latter positions of the chisel 32 are portrayed in dashed lines. Thus, the initial and final attack angles are smaller than the attack angle which exists at approximately the midpoint in the period over which the teeth are in contact with the surface. It may thus be perceived that with the chordally oriented teeth, a maximum attack angle achieved by properly configuring each of the individual teeth can be maintained throughout the entire time period when the teeth are in contact with the surface to be drilled, whereas it is impossible to maintain maximum attack angle for more than one increment of the total time that the individual teeth are in contact with the surface to be drilled when the teeth are radially oriented. The preferred construction of the bits of the present invention thus contemplates the positioning of the teeth of the bit on rolling cones so that the cutting edges of the teeth impinge on the surface to be drilled along chordally oriented lines of contact of the type described.

In FIGURE 4, one embodiment of a drill bit constructed in accordance with the present invention and useful for drilling a new bore hole is indicated generally by reference character 32. The bit comprises the usual bit body 34 upon which two or more cone-shaped roller cutters indicated generally by reference numerals 36 and 38, respectively, are journaled on suitable conventional axles and load bearings (not illustrated). The rotational axes of the cones 36 and 38 are inclined to the horizontal at an angle dictated in part by the necessity of avoiding overloading of the load bearings and axles, and of providing sufficient space for the accommodation of the load bearings. The inclination of the axes is also dictated in part by the desirability of attaining a large attack angle between the sides of the bit teeth and the surface being drilled as will be hereinafter more fully explained. Also it is preferred to orient the rotational axes of the roller cones so that these axes converge in a common point which lies in the common vertical or longitudinal axes of the body 34 and a well bore 40 in which the drill bit is located. This arrangement imparts a true rolling action to the cutter cones 36 and 38, and in thus eliminating scraping or abrading contact of the teeth with the surface to be drilled, extends the effective service life of the bit.

The cone 36 has, at the lower end thereof, a generally cylindrically shaped point 42 which acts as the lowermost tooth on the cone and is preferably formed of a hard metal. As the cones 36 and 38 rotate, the point 42 cuts a groove in the bottom of the bore hole which circumscribes a small conical knub. After a plurality of revolutions of the bit, this knub is broken off by the action of the point 42. Rings of wedge-shaped teeth 44 are secured around the body of the cones 36 and 38 in planes extending normal to the rotational axis of the cones and are spaced from each other in an axial direction along the respective cone bodies. The cutting edges of the wedge-shaped teeth 44 thus become coincident with chords of imaginary circles concentric with respect to the rotational axis of the bit body 34 during the rotation of the cones 36 and 38. The teeth are thus hereinafter sometimes referred to as "chordal" teeth. Stated differently, the cutting edges of the wedge-shaped teeth 44 extend normal to the lines extending radially outwardly from the rotational axis of the bit body 34 at the time when the respective cutting edges contact the bottom of the bore hole. Preferably, the wedge-shaped teeth 44 are formed integrally with the cone body and extend radially outwardly therefrom. The rows of teeth are preferably spaced from each other by from about 0.25 inch to about 0.5 inch. This axial spacing of the rows of teeth 44 has been found to be pre-

ferred in that a closer spacing of the rows of teeth permits the space between the teeth to become packed with cuttings and material removed by the drill so that the cutting efficiency of the teeth is substantially reduced. On the other hand, if the spacing between the rows of teeth 44 exceeds 0.5 inch, the areal coverage which can be obtained with the teeth is reduced, as is the efficiency of the drilling operation.

In referring to the embodiment of the invention illustrated in FIGURE 4, it will be perceived that as the cutter cones 36 and 38 rotate about their axes and the body 34 rotates about its longitudinal axis, each of the teeth thereon is moved so that in one period of its rotation, its cutting edge 46 passes through a generally conical, imaginary surface which is complementary in configuration to the bottom surface 48 of the well bore 40. Stated differently, during the rotation of the cutter cones 36 and 38, the cutting edges 46 of all of the teeth 44 mounted on the cones 36 and 38 pass through a common conically shaped plane at the instant that they contact the surface to be drilled. It should be noted that but for certain engineering limitations which presently exist, the bottom surface 48 could constitute a substantially monoplanar horizontal surface rather than the generally conical surface illustrated. At the other extreme, the same limitations necessarily limit the steepness or degree of inclination of the conical surface through which the edges 46 of the teeth 44 pass during rotation. In order, however, to permit the teeth 44 to be fabricated in the generally wedge-shaped configuration illustrated, and to be oriented so as to provide a large attack angle with the surface being drilled, it is preferable, even assuming the non-existence of such limitations, to incline the rotational axes of the cones 36 and 38 in the manner hereinbefore described, and to align the cutting edges 46 of the teeth 44 in a conical surface which is coaxial with the conical cutters 36 and 38 so that the teeth 44 constantly act upon a generally conical bottom hole surface 48 in the manner illustrated in FIGURE 4. As will be further described hereinafter, the development of a generally conically shaped bottom hole surface 48 has the further advantage of permitting the cuttings generated by the drilling to be more easily removed from the bole hole.

In referring to FIGURE 4, it will be noted that, except for the aligned gauge rows 50 and 52, the rows of teeth 44 on the cutter cones 36 and 38 are axially staggered or offset from each other so that the teeth do not interfere with each other during rotation of the cones, and so that maximum areal coverage of the hole bottom 48 may be attained. Non-interference of the staggered rows of teeth, of course, permits the plurality of roller cones ordinarily used to occupy less space and to be individually enlarged so that the problem of bearing accommodation can be more easily overcome. As has been previously indicated, the axial spacing between adjacent rows of teeth 44 on either of the cones 36 or 38 preferably is from about 0.25 inch to about 1.0 inch. It is further preferred that the radial tracking distance between the adjacent annular rings of lines of contact formed by the movement of the teeth of both cones through the imaginary conical surface be not less than about 0.2 inch nor more than about 0.50 inch.

The radial tracking distance to which reference is made is designated by the letter *r* in FIGURE 6 which is a tracking pattern diagram illustrative of the imprints made by the cutting edges 46 of the teeth 44 on the bottom surface 48 of the bore hole 40 during one-half revolution of the drill body 34. The teeth 44 of the cone 36 will track as illustrated in the upper half of FIGURE 6, while the teeth of the cone 38 will track according to the diagram in the lower half of FIGURE 6. Of course, the illustrated tracking pattern for the teeth on each of the cones will be repeated during the other 180° of rotation of the drill body 34 so that the complete tracking pattern would include a repetition of the tracks shown in both the upper and lower halves of FIGURE 6 in the respective opposite halves thereof. It will be noted in referring to FIGURES 4 and 6 that the teeth on each of the cones 36 and 38 are radially offset or staggered so that a major portion of the weight on each cone will be concentrated on a single tooth at any one time. Of course, in arrangements of the teeth 44 wherein a greater circumferential spacing is provided between individual teeth in each of the rows, a greater amount of radial offset or staggering can be effected and the weight thus more effectively concentrated on a single tooth during the time when it is in contact with the formation being drilled.

A slightly different embodiment of the invention is illustrated in FIGURE 5. Whereas the several wedge-shaped teeth 44 which are formed on the conical cutters 36 and 38 in FIGURE 4 are circumferentially spaced from each other around the body of the conical cutters, the teeth in each of the rows in the embodiment of the bit illustrated in FIGURE 5 are integrally formed on the cutter bodies as a continuous, single annular wedge-shaped tooth 53 which extends concentrically around the body of the respective cutter and generally occupies a plane which extends normal to the rotational axis of the cutter. Each of the embodiments illustrated in FIGURES 4 and 5 presents advantages over the other, depending upon the conditions prevailing during the use of the two types of bit.

In general, the interrupted tooth type of bit illustrated in FIGURE 4 will be characterized by a faster rate of penetration and generally higher drilling efficiency. The precise rate of penetration of the interrupted tooth type of bit illustrated in FIGURE 4 into a particular formation will be dependent in part upon the circumferential spacing between the wedge-shaped teeth 44 in the several rings around the cutter body. In addition to the arrangement illustrated in FIGURE 4 which may be said to be approximately 75 percent tooth continuity, a 50 percent tooth arrangement may also be used. By a 50 percent tooth arrangement, it is meant that the spacing between adjacent teeth 44 in each ring of teeth is substantially equal to the circumferential width of the cutting edge 46 of each of the teeth. Using the same nomenclature, the arrangement of the teeth 44 in the FIGURE 5 embodiment may be referred to as a 100 percent tooth arrangement since the teeth extend continuously around the cutter body without interruption or discontinuity. The advantage of employing the annular continous tooth arrangement of this embodiment over the interrupted tooth arrangement shown in FIGURE 4 is that the continuous or 100 percent tooth embodiment is characterized by a substantially longer service life.

Only minor reference has been hereinbefore made to the particular cross-sectional configuration of the teeth carried on the cutter cones 36 and 37 except to refer to these teeth as wedge-shaped. In order to realize the improved drilling rate which may be attained by maximizing the attack angle formed between the converging sides of the wedge-shaped teeth and the surface which is to be drilled, the particular cross-sectional configuration of the teeth which are mounted on the cutter cones is of substantial importance and constitutes one of the salient features of the present invention. In referring to the embodiments of the invention illustrated in FIGURES 4 and 5, it will be perceived that the teeth 44 and 53, respectively, are, in each instance, triangular in cross-section with said cross-section being taken in a plane extending through the teeth and normal to the axis of rotation of the respective cutter cone upon which the teeth are mounted. An enlarged sectional view through the center of a continuous (100 percent) tooth type bit is illustrated in FIGURE 7 to which reference will be made for the purpose of better explaining the construction of the teeth used in bits of the present invention.

In FIGURE 7, a horizontal plane is designated by reference character 59. When the rotational axis of the cutter cone 60 is inclined as shown in the embodiments of the invention illustrated in FIGURES 4 and 5, the cutting edges 62 of teeth 64 will occupy a generally conical surface which is coaxial with the respective roller cone upon which the teeth 64 are mounted. The departure from congruity between the conical exterior surface of the roller cone 60 and the imaginary conical surface occupied by the cutting edges 62 will be dependent upon the differences in the radial dimension d of each of the teeth 64.

As the roller cone 60 carrying the teeth 64 rotates upon its axis, and as the body (not seen) of the drill bit carrying the cone 60 rotates about its longitudinal axis, the cutting edges 62 of the teeth 64 sequentially pass through an imaginary conical surface corresponding to a surface of revolution swept out by the line 66 illustrated in FIGURE 7. In other words, if the line 66 is rotated about the point where it intersects the longitudinal axis of the bore hole and drill bit body, a generally conical surface (inverted) will be generated and may be equated to the hole bottom surface 48 illustrated in FIGURES 4 and 5. Considering then the line 66 as the generatrix of the conical bottom hole surface 48, an angle phi (ϕ) is defined between the generatrix 66 and the horizontal plane 59 and will hereinafter be termed the hole bottom angle. As hereinbefore defined, the attack angle α is that angle which is included between the generatrix 66 and the converging sides 70 and 72 of the wedge-shaped teeth 64. Stated differently, the attack angle α is the angle which is formed between a bottom hole surface and the converging sides 70 and 72 of each of the teeth 64 at the time the tooth is in contact with the hole bottom surface. It should be noted that the attack angle α_1 measured from the generatrix 66 to the upper side 72 of each tooth need not be of the same magnitude as the attack angle α_2 which is measured from the generatrix 66 to the lower side 70 of the respective tooth. The included angle theta (θ) is, as hereinbefore defined, the angle measured across the respective teeth 64 between the converging sides 70 and 72 thereof.

In referring to FIGURE 7, several considerations which are important relative to the structural configuration of the teeth 64 become apparent. First, it will be noted that if, for a given tooth, either or both of the attack angles α_1 and α_2 are increased, the included angle θ of the respective tooth must be decreased. As the included angle θ is decreased, the structural strength of the tooth is also decreased and we have found that a point is reached at an included angle of about 30° where the thickness of the tooth is reduced to the point where the service life of the tooth is unacceptably foreshortened. It is further apparent in referring to FIGURE 7 that the attack angle α_1 formed between the high side 72 of the teeth 64 and the line 66 could be decreased to enlarge the included angle θ of the teeth without exceeding the smaller attack angle α_2 formed between the lower side of the tooth and the generatrix 66. Despite this possible means of increasing the included angle θ of the teeth 64 and thereby increasing their strength, we have found that the inclination of the high side 72 of the teeth at a sligth angle ω with respect to the vertical is desirable since with this tooth configuration, the side 72 of each tooth does not compress the material being drilled in such a way that chip removal occurs less readily. In other words, if the high side 72 of the teeth 64 were inclined to the vertical on the opposite side thereof from that shown in FIGURE 7, the side 72 would tend to force the material being drilled and positioned above each of the teeth 64 upwardly toward the next higher tooth and would interfere with the chipping action of the next higher tooth. It is therefore preferred to retain an angle ω of from about 1° to 5° in the construction of the teeth 64. This angle will hereinafter be referred to as the negative relief angle of the teeth 64.

Since the negative relief angle ω is always measured with respect to the true vertical (since the weight imposed on the drill bit is applied vertically downwardly) and since the minimum included angle θ which it is desirable to use in forming the teeth 64 is about 30°, it becomes apparent that the attack angles α_1 and α_2 which are defined between the two sides of the teeth 64 and the generatrix 66 will depend, when the tooth is made with a minimum included angle of 30°, solely upon the magnitude of the hole bottom angle ϕ. As φ is made larger, the attack angle α_2 between the lower side of the teeth and the contacted hole bottom surface is also made larger, provided that a fixed negative relief single ω and a fixed included angle θ is employed. At the same time, the attack angle α_1 which is included between the hole bottom surface or generatrix 66 and the high side 72 of the teeth 64 is decreased.

With the foregoing general considerations relative to the geometry of FIGURE 7 in mind, several observations and conclusions derived from bit tests hereinafter described will be discussed. In initial tests of the preferred, chordally oriented tooth embodiment of the present invention, it was noted that as the hole bottom angle ϕ of the surface contacted by the teeth of the bit was increased, the rate of penetration for a given load and rotational speed of the bit also increased. The same wedgeshaped tooth configuration was used in these tests, and it was supposed from the results of the tests that the main factor contributing to an increased drilling efficiency of the bit was the use of relatively steeply inclined bottom hole surfaces. In other words, the results of these tests were interpreted to mean that the larger the hole bottom angle ϕ, the greater the efficiency of the bit.

It was then noted, however, that in changing the hole bottom angle ϕ without changing the tooth configuration, the effect was to change the attack angles α_1 and α_2 made by the converging sides of each tooth with the hole bottom. To determine whether the attack angle or hole bottom angle was the parameter which was responsible for the improved drilling efficiency, a number of drilling runs were conducted in which the hole bottom angle was retained constant, and the attack angles of the bits were varied by changing the included angles θ of the bit teeth, and by changing the inclination of the sides of the teeth relative to the contacted hole bottom surface. The results of these drilling runs indicated that the attack angle α was actually the critical parameter. It was further confirmed that the greater the attack angle α, the greater the rate of penetration of the bit for a given bit load and rotational speed.

In subsequent endeavors to fabricate bits having chordal teeth configured to provide a large attack angle, it was noted that the hole bottom angle ϕ reassumes importance by virtue of present engineering limitations on rotary, roller cone type bit construction. Thus, if the roller cones and teeth are constructed to permit the cutting edges to impinge upon a flat bottom hole at large attack angles α, the teeth become undesirably thin, and the rotational axis of each roller cone tends to be supported in the nature of a generally horizontal cantilever from the bit body. This arrangement requires very heavy duty bearings and also limits the space available for cutter cone mounting. At the other extreme, when the axes of the roller cones are only slightly inclined with respect to the vertical so as to orient the teeth for contacting a conically shaped bottom hole surface of large hole bottom angle ϕ, space limitations severely limit the space available for the bearings used to rotatably support the cones. It was noted, however, that except for the latter consideration which, at the present time, imposes a practical limitation on the upper limit of the hole bottom angle ϕ, the teeth of the bits could be more easily configured to contact conical hole bottom surfaces of large hole bottom angles ϕ than those of relatively small hole bottom angles.

In summary then, the tests indicated that the teeth should be configured to afford maximum attack angle, and that

because of present practical engineering limitations as related to tooth, bearing and roller cone construction, optimum attack angles can be more easily achieved when the bit is designed to drill on a hole bottom which is of inverted conical configuration, and the generatrix of which forms with a horizontal plane an angle ϕ of between about 10° and about 40° and is preferably between about 20° and 30°. In line with the initial discussion of the basic principle underlying the invention, the attack angle of the teeth relative to the drilled surface preferably exceeds 40°, and can be as high as 85° in the case of α_2 (the angle defined between the lower side of each tooth and a conical bottom hole surface). Preferably, the included angle θ of the tooth is not less than 30° nor more than 100°, and it is further preferred that in all instances of drilling upon an inverted conical surface, the back or higher side of each tooth be inclined to the vertical with a negative relief angle of from 1° to 5°. The latter consideration does not, of course, apply to teeth in the gauge rows of teeth on the cutter cones, since the higher sides of these teeth actually establish and maintain the constant diameter of the bore hole as it is drilled and should be formed in a vertical plane for this reason.

As previously indicated herein, a number of tests were conducted to determine the effectiveness of bits embodying the several features of the present invention. In one series of the tests, the attack angles α formed between each of the two converging sides of the teeth and the surface being drilled with the bit, were varied by changing the included angle θ between the two converging sides of the bit. In other words, the slope or inclination of the hole bottom was maintained constant (and therefore the hole bottom angle ϕ was also maintained constant) and the attack angles α_1 and α_2 were increased by decreasing the included angle θ.

In another series of tests, the included angle θ was maintained constant, that is, the tooth configuration per se was not changed. The attack angles α_1 and α_2 were made to vary by changing the inclination of the hole bottom, or, stated differently, changing the value of the hole bottom angle ϕ.

Tests of the foregoing described types were carried out using bits having a 100 percent or uninterrupted tooth configuration, and bits having a 50 percent tooth configuration. The tests were also carried out using both types of tooth configurations in two different types of material—Cottonwood limestone and concrete simulating natural limey sandstone. During these tests in which all of the foregoing described variables were altered, the speed of rotation of the drill bit body, and therefore of the several cutter cones was varied with tests being run at 50 r.p.m., 100 r.p.m., 150 r.p.m. and 200 r.p.m. Finally, bits constructed in accordance with the present invention and having the various tooth arrangements hereinbefore described were also tested with varying loads being imposed on the drill body, and thus transmitted to the teeth of the bit through the cutter cones.

For purposes of comparison, a conventional three-cone rock bit of a type heretofore commercially available and in use was used to drill holes of comparable size in both the Cottonwood limestone blocks and in the cement blocks. The rates of revolution of the bit body, and the loads imposed upon the bit were substantially identical to those used in the tests of the bits of the present invention.

The data obtained from the several tests was composited and are graphically portrayed in FIGURES 8 through 11. In each of the graphs, the data obtained utilizing two-cone chordal toothed bits constructed in accordance with the present invention are represented by unbroken curves or lines. The data obtained for the conventional three-cone rock bit are represented by dashed lines. In each of the graphs, the effectiveness of the bit for a given load is portrayed in terms of inches of penetration per revolution of the bit. The load which was imposed upon the bits is plotted on the ordinate axis of the graph and is expressed in terms of pounds per inch of hole diameter. In this way, slight variataions in hole diameter during the tests are taken into consideration.

In the case of the solid lines reresenting the composite data obtained for test runs using the bits of the present invention, certain symbols are utilized on the graphs to indicate the conditions obtaining in the run, and the particular type of tooth structure utilized. Thus, ϕ is used to designate the particular hole bottom angle which was employed during the runs, α_1 is used to designate the attack angle which obtained during each run between the lower side of the teeth of the bit and the hole bottom, and t is used to designate the tooth configuration, i.e., 50 percent, 100 percent (continuous), etc. For Example, the uppermost continuous or uninterrupted line in FIGURE 8 is derived from a series of tests which were carried out using a hole bottom angle ϕ of 40°, an attack angle α_1 of 85° and a 50 percent tooth configuration. The data utilized to derive this line on the graph were obtained by running tests at a number of different bit loadings and measuring the penetration obtained per revolution of the bit at such loadings.

It should be pointed out that in the case of the bits of the present invention as contrasted with the conventional bit tested, the rate of penetration of the bits of the invention did not appear to be affected (in terms of inches of penetration per revolution) by the rotational speed at which the bits were driven. Tests were carried out on the bits of the present invention at differing rotational speeds of 25, 50, 100, 150 and 200 r.p.m. and it was found that, in each case, the penetration per revolution of the bit appeared to be substantially the same. On the other hand, as indicated by the dashed lines which are representative of tests made with the conventional three-cone rock bit the penetration per revolution in the case of the conventional bit fell off as the rotational speed of the bit was increased. Thus, in referring to FIGURE 8, it will be perceived that in the tests conducted in Cottonwood limestone, only at a rotational speed of 50 r.p.m. did the conventional bit compare at all favorably with the bits of the present invention. Even at this low rotational speed, the conventional bit was comparable in drilling efficiency with only those bits of the present invention employing relatively small attack angles of 45° and 55°.

In referring to FIGURE 9, a comparison may be made of the drilling effectiveness of the conventional bit with 100 percent or continuous tooth bits constructed in accordance with the present invention. The 100 percent tooth bit of the invention was operated with a constant hole bottom angle ϕ of 20° C., and an attack angle α_1 varying from 35° to 65° obtained by varying the size of the included angle θ of the teeth of the bit. Here it will be perceived that at a relatively low rotational rate of 50 r.p.m., the conventional bit compared well with 100 percent tooth bits of the present invention only when the latter had an attack angle α_2 or 55° or less. It should be recalled, more over, that the 100 percent tooth configuration of this embodiment of the present invention has the marked advantage over the interrupted tooth arrangement of both the 50 percent tooth bit of this invention and the conventional two-cone rock bit employed in the tests of having a much greater service life, since there is a much greater extent of tooth surface which must be worn away before the bit becomes useless. It must be concluded then that even assuming some low attack angle versions of the 100 percent tooth type bits of the present invention to be comparable in drilling efficiency to a conventional bit operated at low speeds, the 100 percent tooth embodiment of the present invention is substantially superior to the conventional bit in the length of service life which may be expected and also demonstrates a much higher drilling rate in footage of bore hole drilled per unit of time when it is operated at higher speeds in the vicinity of 200 r.p.m.

In referring to FIGURES 10 and 11, it will be noted that the bits of the present invention, in drilling a bore hole in concrete (simulating the limey sandstone frequently encountered in actual drilling operations), are again substantially superior in drilling efficiency to the conventional two-cone rock bit. The superiority is particularly manifest in the case of the 50 percent tooth configuration bits as represented by the data presented in FIGURE 10. In all of the graphs, it will become apparent that as the load imposed upon the bit increases and as the rate of revolution of the bit increases, the superiority of the bits of the present invention over the conventional bit becomes more pronounced. Within the range of tests which were conducted, the bits of the present invention did not evidence any tendency to taper off in drilling effectiveness as the load imposed upon the bit was increased, or as the rate of revolution was increased.

From the foregoing description of the present invention, it will have become apparent that an improved bit for drilling a bore hole in the earth or similar material has been provided. The bits of the invention are generally characterized by a longer service life than has usually been characteristic of the bits heretofore in use, this feature of the invention being a result in large degree of the possibility of imparting a true rolling action to the cutter cones of the bit during a drilling operation. The true rolling action of the cutter cones on a formation surface is in turn made possible by the more efficient penetration of the teeth of the bit into the hole bottom in the course of drilling. Because of the particular configuration of the preferred embodiment of the drill bit of the invention and the manner in which the teeth are brought to bear against a hole bottom surface of generally conical configuration, the invention has the further advantage of permitting cuttings generated during the drilling operation to be more easily removed from the bore hole.

Having thus described several embodiments of the present invention in detail, it is to be understood that various changes, substitutions and alterations can be made therein without departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A rotary drilling bit for boring a hole into the surface of relatively hard material comprising:

a body having a vertically extending, longitudinal axis of rotation;

converging axles extending downwardly from said body toward each other;

roller cones mounted on said axles for rotation about downward extending, converging axes of rotation which converge in a point in said vertically extending, longitudinal axis of rotation;

cutter means mounted on each of said cones and positioned to bear upon and roll against the material to be bored during rotation of said body, said cutter means including a plurality of teeth positioned in concentric, annular array about the axis of rotation of the respective roller cones for contacting the surface of the material to be bored during the rotation of said roller cones, said teeth each having a wedge-shaped tip defined by two converging sides, and each mounted so that the lines of intersection of the two converging sides of all of said teeth pass through a common plane during rotation of each of said roller cones about its respective axis of rotation, said lines of intersection each forming a portion of a chord of a circle concentrically surrounding the longitudinal axis of rotation of said body at such time as the respective lines of intersection pass through said common plane, and wherein each of the two converging sides of each tooth defines an angle of at least 40° with said common plane as measured from the respective converging side directly to said common plane.

2. A rotary drilling bit as claimed in claim 1 wherein said common plane extends at an angle of from about 10° to about 40° to a horizontal plane extending normal to the longitudinal axis of said body whereby said bit may more suitably drill upon a surface inclined with respect to the horizontal.

3. A rotary drilling bit as claimed in claim 1 wherein each of the converging sides of each of said teeth defines an angle of between 40° and 85° with said common plane.

4. A rotary drilling bit as claimed in claim 1 wherein each of said teeth is annular and extends continuously and concentrically around the respective roller cone upon which it is mounted.

5. A rotary drilling bit as claimed in claim 1 wherein the teeth on each of said roller cones are arranged in a plurality of concentric rows around the periphery of the respective roller cone with the teeth in each of said rows being circumferentially spaced from each other in the respective row.

6. An improved rotary drilling bit for boring a hole in the earth comprising:

a body having a vertically extending, longitudinal axis of rotation;

at least one generally conical cutting member rotatably journaled on the body for rotation about a downwardly extending axis of rotation which passes through said vertically extending longitudinal axis of rotation whereby said generally conical cutting member is positioned for engaging and rolling on the earth as the body is rotated about its vertically extending longitudinal axis of rotation;

a plurality of wedge-shaped teeth secured around said conical cutting member in rings concentric with the rotational axis of said cutting member with said rings being axially spaced from each other on said cutting member, and each positioned in a plane extending normal to the axis of rotation of said cutting member, said teeth each being triangularly shaped in cross-section with the apex of said triangular cross-section forming the cutting edge of the respective tooth, the cutting edge of each tooth becoming, during the rotation of said cutter body, coincident with a chord of a circle concentrically surrounding said axis of rotation, and the converging sides of each of said teeth including an angle at said apex not exceeding 100° whereby a flat surface may be contacted by each of said teeth at an attack angle of at least 40°, said attack angle being defined as the angle measured between the flat surface and the converging sides of each of said teeth.

7. An improved rotary drilling bit as claimed in claim 6 wherein the angle included by said converging sides at said apex is at least 30°.

8. An improved rotary drilling bit as claimed in claim 6 wherein each of said teeth is annular and extends continuously around said generally conical cutting member to form one of said rings.

9. An improved rotary drilling bit as claimed in claim 6 wherein each of said rings contains a plurality of circumferentially spaced teeth.

10. A rotary drilling bit for boring a substantially vertical hole in the earth comprising:

a bit body having a vertically extending, longitudinal axis of rotation;

a plurality of axles secured to said bit body and horizontally spaced from each other thereon, said axles extending downwardly from said bit body and converging toward each other at their lower ends;

a roller cone mounted on each of said axles for rotation about an axis, the rotational axes of said roller cones converging in a point located in the projected longitudinal axis of rotation of said bit body and located below said bit body;

wedge-shaped teeth on each of said roller cones, the

teeth being disposed in rings around the respective cone, said rings each being concentric to the rotational axis of the respective cone, and the several rings on each cone being axially spaced from each other therealong, each of said wedge-shaped teeth having two sides converging in a cutting edge with the angle included between said sides being at least 30° and less than 100°, and the cutting edge of each tooth occupying a plane extending normal to the rotational axis of the roller cone upon which the respective tooth is mounted, the cutting edges of the teeth of each roller cone lying in a conical surface coaxially related to the outer, tooth-bearing surface of the respective roller cone, the rotational axes of said roller cones all being inclined to the horizontal by an amount such that all of the cutting edges of said teeth pass through a common, inverted conical surface at one time during the revolution of each of said roller cones, and in passing through said common, inverted conical surface, extend normal to lines radiating from the vertically extending, longitudinal axis of rotation of the bit body, the generatrix of said inverted conical surface extending at an angle of from about 10° to about 40° with a horizontal plane.

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