Oct. 30, 1928. 1,689,566

N. TRBOJEVICH

HOB

Filed Jan. 28, 1924 4 Sheets-Sheet 1

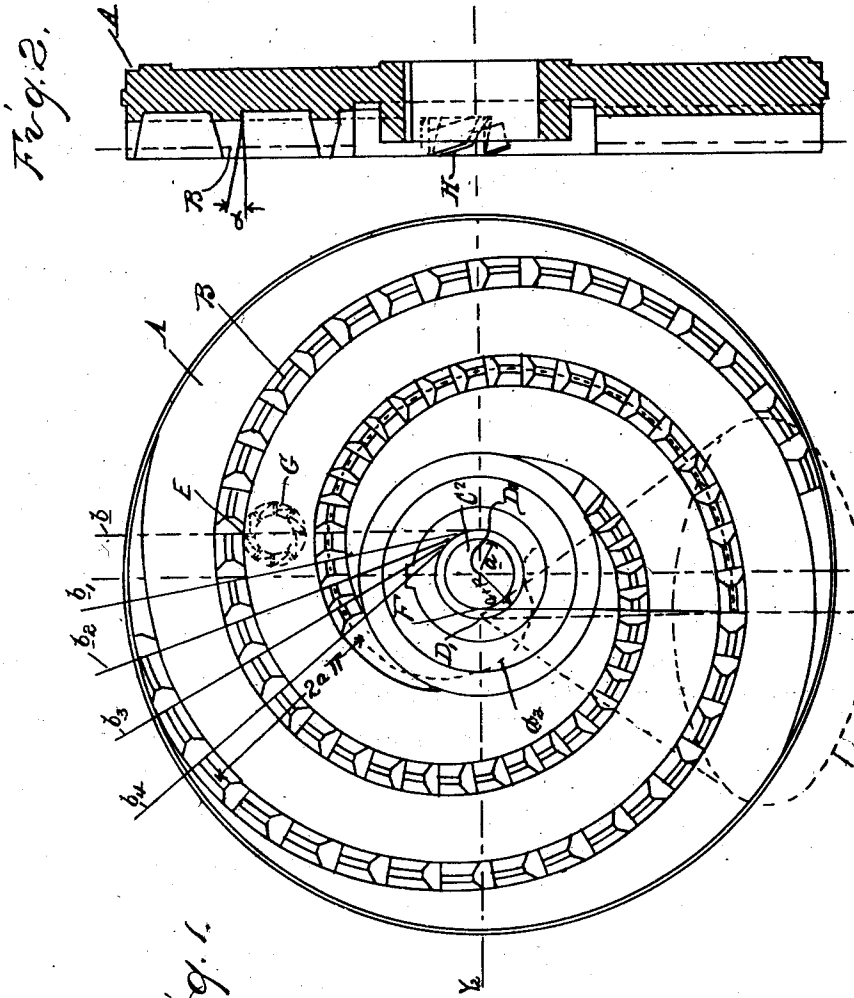


Fig. 2.

Fig. 1.

Inventor
Nikola Trbojevich

By Whittemore, Hulbert & Whittemore Belknap

Attorneys

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N. TRBOJEVICH

HOB

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4 Sheets-Sheet 2

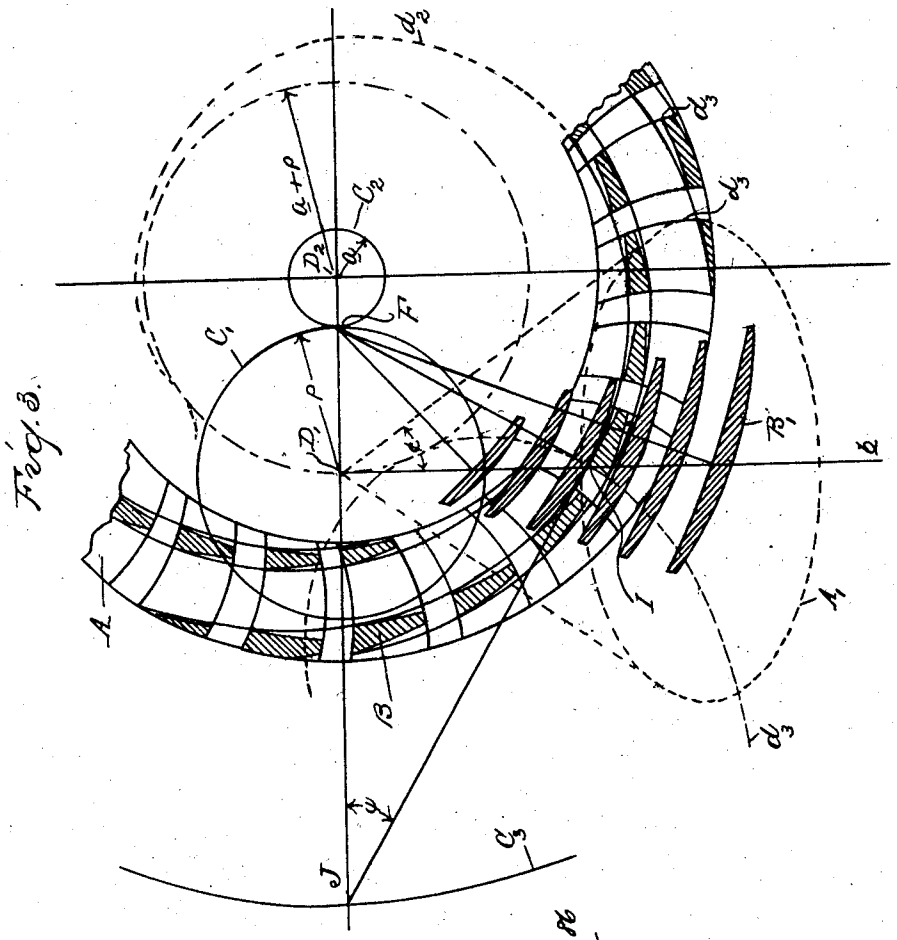


Fig. 3.

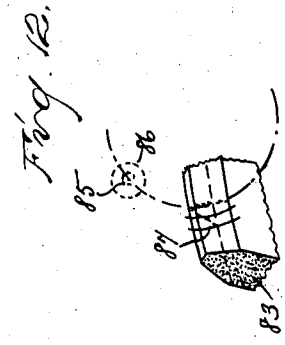


Fig. 12.

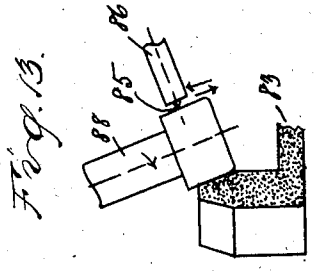


Fig. 13.

Inventor
Nikola Trbojevich

By Whittemore Hulbert & Whittemore & Belknap

Attorneys

Oct. 30, 1928. 1,689,566

N. TRBOJEVICH

HOB

Filed Jan. 28, 1924 4 Sheets-Sheet 3

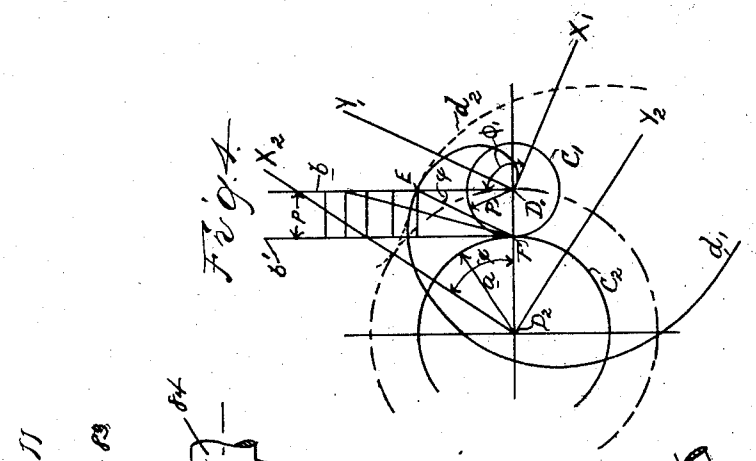


Fig. 4.

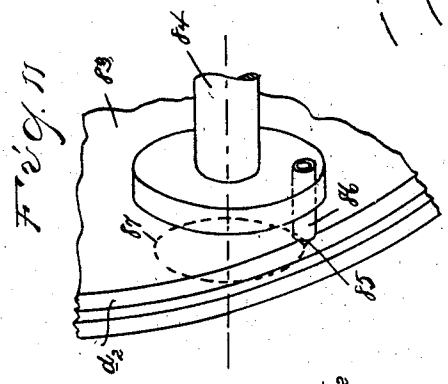


Fig. 11.

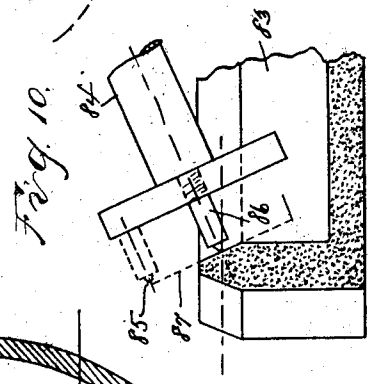


Fig. 10.

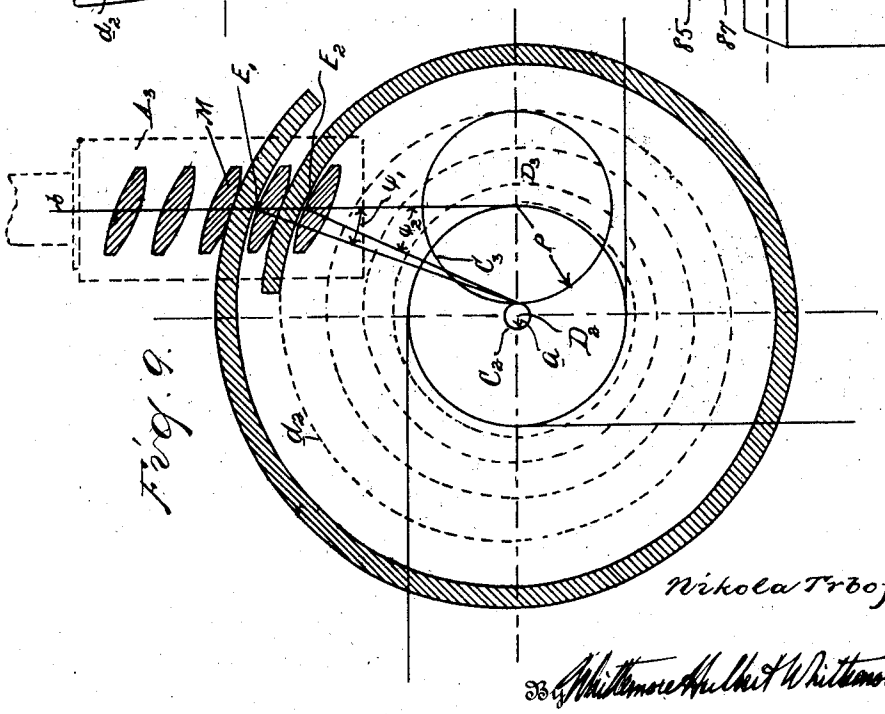


Fig. 9.

Inventor
Nikola Trbojevich

By Whittemore, Hulbert & Whittemore Belknap.

Attorneys

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N. TRBOJEVICH

HOB

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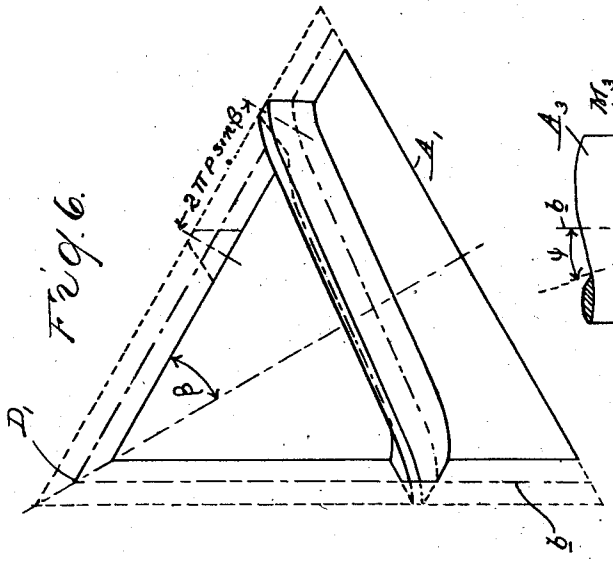


Fig. 6.

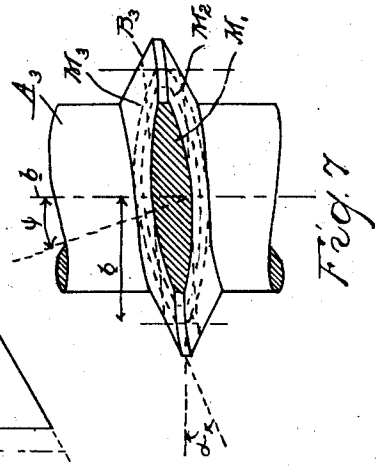


Fig. 7

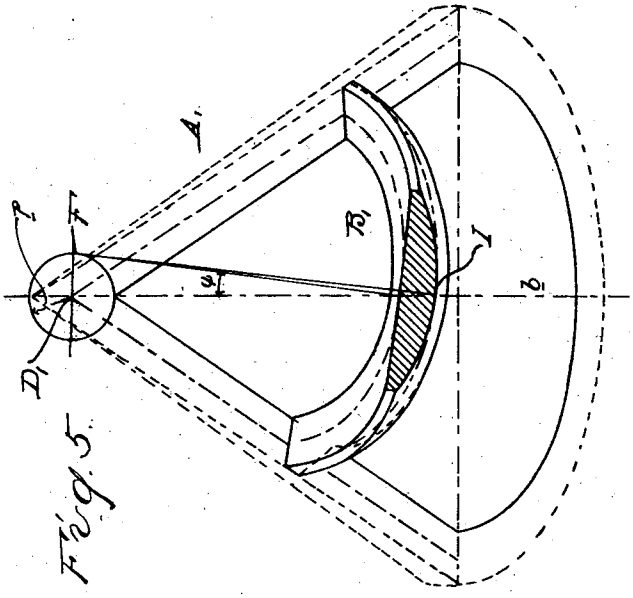


Fig. 5.

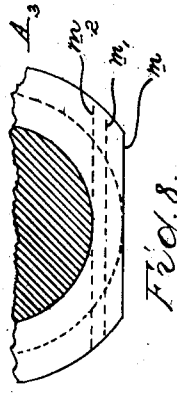


Fig. 8.

Inventor
Nikola Trbojevich

By Whittemore, Hulbert & Whittemore Belknap.

Attorneys

Patented Oct. 30, 1928. 1,689,566

UNITED STATES PATENT OFFICE.

NIKOLA TRBOJEVICH, OF DETROIT, MICHIGAN, ASSIGNOR TO GLEASON WORKS, OF ROCHESTER, NEW YORK, A CORPORATION OF NEW YORK.

HOB.

Application filed January 28, 1924. Serial No. 689,131.

The invention relates to a novel form of hob or gear cutter and particularly to a novel form of hob or gear cutter of the spiral crown wheel type. The new hobs are used principally for the generation of tapered worms of constant pitch, such as are, for instance, the blanks from which the tapered hobs used in my spiral bevel gear hobbing process (U. S. Pat. 1,465,150) are made, or the worms which run in mesh with the new spiral hyperboloidal gears described in my copending application Serial Number 684,862, filed January 7, 1924. Another object of the invention is to provide a cutting tool capable of generating the common or spur worms and screws. Further objects will be apparent hereinafter from the description and the appended claims. The method according to which, and the apparatus in which, the new hobs may be employed in practice, are fully described in another copending application, and the present application is devoted solely to the description of the cutting tool or hob. The new hob has two modifications, both of a similar geometrical form, but different as to their corresponding physical characteristics, viz the steel hob which is made usually of high speed steel and provided with a definite number of permanent cutting teeth, and the grinder hob, composed of emery or some other abrasive material, and possessing practically an indefinite number of cutting particles. In the following description it will be disclosed first how the new hobs may be calculated and designed with reference to the work to be performed, second, how they can be accurately manufactured, and third, how they are sharpened or dressed and kept in proper working condition when in actual use. Thus, in the case of grinder hobs we shall show how such grinders may accurately and comparatively easily be dressed to the proper spiral contour by mechanical means and as often as it may be required.

In the drawings:—

Figure 1 is a plan view of a preferred form of my invention;

Figure 2 is a transverse section thereof;

Figures 4, 5, 6, 7, and 8 are diagrams explanatory of the theory of the process;

Figures 3 and 9 are the pitch plane sections illustrating the generation of the tapered and spur worms respectively;

Figures 10 to 13 are diagrams illustrating the method of trimming the contour of the new grinder hob.

These hobs are used principally, as stated, in the production of worms. In order to understand the principle upon which the new hobs operate, it is necessary to become acquainted with the mathematical peculiarities forming the foundation of this system of worm cutting.

Figure 1 and Figure 2 show two views of the new hob of the modified involute crown wheel type. Said hob consists primarily of a circular flat disk A upon the plane face of which one or more convolutions of cutting teeth B are spirally arranged, said spirals d_2 having the mathematical equation.

$$x=(a+p)\cos\phi_2+a\phi_2\sin\phi_2$$
$$y=(a+p)\sin\phi_2-a\phi_2\cos\phi_2 \qquad (1)$$

The pair of equations (1) refer to the X_2 Y_2 coordinate system shown in Figure 1, and determine a spiral which I termed a modified involute of a circle. A superficial analysis of said two equations will disclose the fact that besides the two variable coordinates x_1 y and the variable parametric angle ϕ_2 the equations also contain two constants a and p, respectively designated as the base radius and the modification of the spiral.

In manufacturing the new hobs, a circular disk A is first turned and bored. Next, the blank is mounted in a universal milling machine and the convolutions B are milled by gearing up said milling machine to a lead equal to $2a\pi$, the circumference of the circle C_2 of the hob, and by placing a rotary end mill G in the line b, said line being offset from the center of the hob to an exact distance equal to $(a+p)$, the algebraic sum of the base radius and the modification of the hob. It can be shown mathematically that if the hob is translated along the line b (which line coincides with the rack element of the hob) and also rotated in a timed relation in the proper direction any fixed point E in the line b will describe a modified involute defined by the equations (1) upon the face of the hob. These modified involutes will be of the extended type if the value of p is positive, that is, if the amount of offsetting $(a+p)$ is greater than the base radius of hob, and they will be abridged involutes for all negative values of p. It is of interest to note that the modified

involute may degenerate into a common involute for the value of $p=o$, and also into an Archimedean spiral for $a+p=o$. We shall show, however, that for the purposes of producing the hob or worm specifically described in the above mentioned applications both p and $a+p$ must always be different from zero and finite.

After the required number of convolutions B have been milled, and their sides have been beveled off to the required pressure angle α (Figure 2) so that the cross section of the hob thread along the line b presents a rack of constant pitch, said convolutions are gashed crosswise by a number of equi-spaced flutes b_1 b_2 etc., and the remaining portions of the thread are relieved by means of a suitable relieving tool in a direction perpendicular to the plane of the hob as shown at H, Figure 2. In Figure 1 the flutes are all straight and are tangent to the $(a+p)$ circle, which arrangement is preferable providing the distance p is small in comparison with the diameter of the hob. However, if the distance p is considerable, the flutes are preferably curved in order that the cutting faces of teeth may be more nearly perpendicular to the thread spirals. In Figure 3 such an arrangement is diagrammatically shown. There the spirals are extended involutes d_2 while the flutes are abridged involutes d_3 so selected that they are perpendicular to the hob spirals d_2 at the point I, said point lying substantially in the middle of the cutting face of the hob. Regarding the selection and general arrangement of flutes in the new hobs it may be stated that theoretically, any kind of flutes may be employed, straight or spiral, equally or unequally spaced. In practice, however, the flutes are usually so selected that first they are equally spaced, second they intersect the thread convolutions at approximately right angles, third the hobs may be relieved mechanically, that is by means of a relieving tool reciprocating in a direction perpendicular to the plane of the hob at a constant ratio, fourth, the finished hobs may be accurately sharpened after they become dull through use, and fifth, the number of flutes is a relative prime number with respect to the total number of convolutions or leads in the hob. Thus it may be seen that in providing the new hobs with suitable flutes, preferably the same precautions are applied as in the case of common or spur hobs.

The dimensions of the abridged involutes d_3 forming the flutes of the crown hob of the extended involute type shown in Figure 3, are so selected that the relieving tool may reciprocate or jump in a timed relation with the rotation of the hob during the relieving or what is sometimes termed, the "backing-off" operation in the manufacture of such hobs, and may be determined from the triangle FIJ. The modification p' of said involute is equal to the distance D_1J while the base radius $a'=D_2J=a+p+p'$. The lead of those spirals along the line b is constant and equal to $2a'\pi$.

Thus the new hobs may be manufactured with an extreme accuracy, as the cutting teeth may be milled, gashed, relieved, and also ground after hardening by means of rotations and translations at a constant ratio only. The cutting action of such hobs is also very favorable as the cutting edges travel in the tangent plane, and in an opposite direction, with respect to the rotation of the work.

In Figure 4 the mathematical principle forming the foundation of this invention is illustrated. When the pitch cone of the tapered worm A, Figure 1 and Figure 3 is developed in a plane, the longitudinal tooth curves become spirals of constant lead (Archimedean spirals) d_1 the mathematical equation of which in the X_1Y_1 system of coordinates is obviously:

$$D_1E=r={}_p\phi_1 \quad (2)$$

where p is the base radius or the so called polar subnormal of the worm spiral.

It is now desired to construct a spiral that will correctly mesh with said Archimedian spiral at a constant ratio. The new spiral must be a modified involute as defined by the equations (1), and I have proved that fact mathematically in my former patents and publications. Said fact is also fairly obvious from purely kinematical considerations. Because when the line b' to which the rack generator b is rigidly attached is rolled without slipping on the circumference of the C_1 circle, the point E on the line b will describe the Archimedean spiral d_1. However, when the parallelogram b b' is rolled on the circle C_2 the curve described by the point E is the extended involute d_2, according to the definition of that spiral. Hence, the two spirals d_1 and d_2 are what might be termed "odontically conjugate" to each other (being generated by the same lines rolling on two tangent circles) and their common normals in any position must pass through the pitch point F of the system, while the locus of points of tangency (the line of action is the line b. Therefore, when the two base circles C_1 and C_2 roll together like the pitch circles of two spur gears, the point E will be translated along the line b with a constant velocity and the spiral d_2 will generate the spiral d_1 (or vice versa) in its full length. It is also evident that in order to insure the continuity of engagement for any number of revolutions, the spirals d_2 must be equally spaced with respect to the center D_2, and said spacing (in the arc measure of the base circle C_2) must be exactly equal to the pitch of the worm to be generated. Thus, in order to insure the continuous and correct meshing between the tapered worm A, and the crown hob A the

following two relations determining the values of a and p, and therefore, the spiral itself, must necessarily exist:

$$p=\frac{n_1 p_0}{2\pi \sin \beta} \quad (3)$$

and

$$a=\frac{n_2 p_0}{2\pi} \quad (4)$$

where n_1 and n_2 are the number of threads or convolutions in the tapered worm and crown hob respectively, β is the pitch cone angle of the worm and p_0 is the pitch of the rack generator b. Hence, the hob spiral is partially determined from the dimensions of the worm to be generated, and becomes fully determined when the number of convolutions in hob n_2 is selected. In selecting the number n_2 it is advisable to select it so that it be relatively prime to n_1, in order to obtain the smoothest finish of the tooth surfaces obtainable with a given (limited) number of flutes or gashes.

Referring now again to the example illustrated in Figure 1 and Figure 2, there the worm, A_1 has a cone angle of 30 degrees and is single threaded, 6 diametral pitch. Therefore, from the equation (3) the distance p, becomes one sixth of an inch. The hob has six threads (of which four were milled away to facilitate the manufacture) and has a base radius (calculated from the equation (4), $a=\frac{1}{2}$ inch. The hob is provided with 35 flutes, said number being relatively prime to six, and six again a prime with respect to one, the number of threads in the worm. The above numerical data serves merely to demonstrate one of the many practical applications of the kinematical laws which I have discovered, and in no way limits the scope of this invention.

In Figure 3 the worm to be generated is multiple threaded, having a considerable angle $FID_1=\psi$, and the hob is spirally fluted. It is interesting to note the shaded areas which represent the cross sections of the two elements with their common tangent plane, or the pitch plane. The teeth B of the hob are relieved thereby forming suitable cutting edges along the spiral flutes d_3, along which the hob also may be sharpened without affecting the correct spacing or form of the cutting teeth when it becomes dull. The crescent shaped cross sections B_1 of the worm thread are concave and comparatively flat on their sides facing the apex D_1 and are pronouncedly convex on the other side. This geometrical peculiarity insures the correct action of the new hob, as the contact between the two elements is thereby localized along the line b (as required by the theory), and the mutilation of the worm threads is avoided by the fact that the hob threads may pass through the series of equi-spaced crescents without touching them at any other points except those lying in the line b.

A graphical method of determining the exact shape of any crescent B_1 (such as are shown in Figure 3) is shown in Figure 5 and Figure 6. It is seen that the curvature of said segment is materially influenced by the pressure angle α of the worm. Thus, in order to avoid interference and multilation of the worm threads, a pressure angle sufficiently great, ranging from 15 to 30 degrees is preferably employed.

The process of generating tapered worms of constant lead by means of new hobs may now be mapped out. The hob spiral is first calculated and made up as already discussed. The tapered worm blank is superposed upon the hob so that its rack generator coincides with the rack element b and its apex with the point D_1, Figure 3. Next the two elements are rotated in a timed relation and the blank is also given a relative movement of translation or feed in a line perpendicular to the face of the hob.

The process of generating cylindrical or spur worms will best be understood from the Figures 7, 8 and 9. The intersections of the worm thread B_3 with a system of planes m, m_1, m_2, all parallel to the axis of the worm, are the elliptical contours M, M_1, M_2. Those contours are more fully shown in Figure 9 where also their engagement with an extended involute convolution d_2 is illustrated. It is seen that if the crown hob possesses a sufficiently large radius of curvature (greater than the radius of the elliptic contours M) a condition may be established in which the contact between the two elements always falls in the line b, and the thread of the hob is very nearly tangent to the helixes of the worm to be generated. Now, when the hob is rotated with a uniform velocity, its imaginary rack element moves also with a uniform velocity along the line b, as this is the definition of the modified involute. On the other hand, the rotary worm blank A_3 possesses a similar characteristic, according to the well known definition of the circular helix. Thus the two elements will correctly mesh providing the discrepancy between the initial and final acute angles ψ_2 and ψ_1, respectively (Figure 9) is not too great. As shown in Figure 9 only one thread convolution d_2 is employed in the hob for the purpose of minimizing said discrepancy, and in consequence, only a short length of the blank A_3 is being machined (the section extending from E_2 to E_1) at a time. However, worms of considerable length may be produced if a slow tangential feed movement is imparted to the blank A_3 along the line b during the process of generation. This may be done without departing from the principle of the uniformly timed movements, as according to the theory, the velocity of the rack element is constant along the line b, and

any uniform translation of the whole blank along said line is convertible into and compensable by, a suitable increment of rotation imparted to the hob.

The abrasive crown hobs.

In the practical application of this process of worm generating, the worms are often made of steel and are hardened or heat treated prior to their commercial use. As it is well known, in that operation the article usually swells up, or shrinks, in an irregular fashion, and also the surfaces which might have been machined in "green" to an accurate and smooth finish, become rough due to scaling and pitting caused by the intense heat. It is therefore often necessary to grind the worms after hardening, and this is best effected by means of the new grinder hobs. Said hobs are made of some suitable abrasive material such as emery, carborundum, etc., and are first roughly molded into a spiral shape of the modified involute type. After the grinder is mounted upon its arbor and properly balanced, it is dressed to the exact shape by means of a rapidly rotating diamond trimmer.

The method of dressing the spiral grinder herein described is based upon a new principle of wheel dressing fully described in my copending application for Patent Serial Number 647,670, filed June 25, 1923. According to that principle the grinding wheel 83 (Figures 10, 11, 12, and 13) while being dressed is rotated very slowly, and the trimmer diamond 84 very rapidly. In this manner it is possible to produce helical and spiral convolutions upon the cutting surface of the wheel with a great precision, and in a reasonable length of time, as the wheel while being slowly rotated may also be translated along a certain fixed line (such as the line *b* Figure 11) in a timed relation, and exact spirals, helixes and other mathematical curves and surfaces thus may be generated.

Figure 10 is the cross section of the arrangement shown in Figure 11 through the line *b*. The diamond 85 is held in the end of the stud 86 in the trimmer spindle 84 and capable of rapidly describing the circles 87. Said circle is so selected that it approaches the true contour of the modified involute convolution d_2 as closely as possible. When the grinder 83 is slowly rotated and also translated in a timed relation along the line *b*, the diamond 85 will describe a series of circles 87 (shown in detail in Figure 12) and thereby dress the surface of the entire convolution d_2. A modification of the above dressing process is diagrammatically shown in Figure 13. There the grinder 83 is not directly in contact with the diamond 85, as first an intermediate small cylindrical wheel 88 made of a harder substance than the main grinder 83, is dressed first by reciprocating the diamond 85 as shown by the arrows, and then the main wheel 83 is trimmed by means of said auxiliary or intermediate wheel 88. It is to be noted that the wheel 88 rotates very rapidly, and the wheel 83 comparatively slowly, and preferably in an opposite direction.

Thus the grinding operation in this system of worm manufacturing is kinematically similar to the milling operation in all respects except that first the generating machine is run at a much higher rate of speed, second, the generating cutter or hob possesses a practically indefinite number of easily destroyed cutting edges or particles, and third, an auxiliary device is provided by means of which the grinder may be accurately dressed to the proper contour, and its cutting qualities thus periodically restored. For the purpose of facilitating the dressing of the wheel it is desirable that the grinders be provided with not more than one full convolution of the thread spiral, as in that case a trimmer diamond 84 of a considerable size may be employed without the danger of interference with the adjacent threads of the wheel.

As illustrated and described, the invention may be employed in either milling or grinding and it is to be understbod, therefore, that the terms "hob", "cutting", "cutting edge", "cutter", etc. as used in the appended claims, are intended to describe and apply to either a milling or a grinding tool and to its use in either a milling or grinding operation.

What I claim as my invention is:—

1. A rotary gear cutting tool having a plurality of axially disposed teeth projecting from a plane face and arranged to form an effective operating portion which is of rack section of constant pitch, each tooth being provided with a top cutting edge and opposite side cutting edges, the top cutting edges all lying in a plane perpendicular to the axis of the tool and the corresponding side cutting edges of the teeth being equally inclined to said plane, said teeth being of equal width, in a plane perpendicular to the axis of the tool.

2. A gear cutting tool having a plurality of side cutting edges projecting from a plane face and arranged in a spiral which is of constant pitch along a straight line offset from the axis of the tool.

3. A gear cutting tool provided with a plurality of cutting teeth projecting from a plane face and arranged to form an effective operating portion of rack section of constant pitch along a straight line offset from its axis, each tooth being provided with opposite side cutting edges, corresponding side cutting edges being equally inclined to a plane perpendicular to the axis of the tool and said teeth being of equal width in a plane perpendicular to the axis of the tool.

4. A rotary gear cutting tool having a plurality of axially disposed teeth arranged to

form an effective operating portion which is of rack section of constant pitch along a straight line offset from the axis of the tool, each tooth being provided with opposite side cutting edges, the corresponding side cutting edges of the teeth being equally inclined to a plane perpendicular to the axis of the tool, said teeth being of equal width and of equal height and having their outermost points all lying in a single plane perpendicular to the axis of the tool.

5. A gear cutting tool having a plurality of side cutting edges arranged in a spiral the perpendiculars to which at the pitch surface along a straight line offset from its axis intersect in a single point, each of said cutting edges being arranged to finish cut a side face of a gear tooth.

6. A gear cutting tool having a plurality of side cutting edges arranged in a spiral the perpendiculars to which at the pitch surface along a straight line offset from its axis intersect in a single point which lies in a line at right angles to the axis of the tool, each of said cutting edges being arranged to finish cut a side face of a gear tooth.

7. A rotary gear cutting tool having a plurality of teeth arranged in a spiral of the general involute type each tooth being provided with a pair of side cutting edges said teeth being of equal width in a plane perpendicular to the axis of the tool, corresponding side cutting edges being equally inclined to said plane.

8. A rotary gear cutting tool having a plurality of teeth arranged in a spiral of the general involute type, each tooth being provided with a top cutting edge and a pair of side cutting edges, the top cutting edges all lying in a plane perpendicular to the axis of the tool and corresponding side cutting edges being equally inclined to said plane, said teeth being of equal width and equal height.

9. A gear cutting tool having a plurality of teeth arranged in a spiral, each tooth being provided with a pair of side cutting edges, said teeth being of equal width in a plane perpendicular to the axis of the tool and the corresponding side cutting edges of the teeth being equally inclined to said plane.

10. A gear cutting tool having a plurality of teeth arranged in a spiral, each tooth being provided with a top cutting edge and a pair of side cutting edges, the top cutting edges all lying in a plane perpendicular to the axis of the tool and corresponding side cutting edges being equally inclined to said plane, said teeth being of equal width.

11. A gear cutting tool having a plurality of teeth arranged in a spiral, each tooth being provided with a top cutting edge and a pair of side cutting edges, said top cutting edges all lying in a plane perpendicular to the axis of the tool and corresponding side cutting edges being equally inclined to said plane, said teeth being of equal width and equal height.

12. A gear cutting tool having a plurality of teeth arranged in a spiral of the modified involute type, each tooth being provided with a top cutting edge and a pair of side cutting edges, the top cutting edges all lying in a plane perpendicular to the axis of the tool and corresponding side cutting edges of the teeth being equally inclined to said plane, said teeth being of equal width.

13. A gear cutting tool having a plurality of teeth arranged in a spiral of the modified involute type, each tooth being provided with a top cutting edge and a pair of side cutting edges, said top cutting edges all lying in a plane perpendicular to the axis of the tool and corresponding side cutting edges being equally inclined to said plane, said teeth being of equal width and equal height.

14. A hob comprising a body having a series of teeth projecting laterally from one face thereof, said hob being of the crown wheel type having the teeth spirally arranged about the center to form a plurality of convolutions of the modified involute type.

15. A crown hob consisting of a disk shaped body and a plurality of spirally aligned cutting edges, in which the alignment of cutters is along a modified involute of circle, the spacing of spirals is uniform along a straight line offset from the center of hob, and the angle of intersection of the cutting spirals with said straight line is acute, each of said cutting edges being arranged to finish cut a side face of a gear tooth.

16. A crown hob of the extended involute crown type having a disk shaped body and spirally wound cutting teeth, having a base radius selected with reference to the pitch, and a modification selected with reference to the helix angle of the worms to be generated.

17. A crown hob for generation of worms having its cutting edges arranged in a spiral resulting from a uniform translation along a straight line situated at a fixed distance from the center of the hob, and a uniform rotation about said center, said fixed distance being the algebraic sum of a base radius, and a modification, and the relation between the two components being such that the circumference of the base circle is exactly equal to a multiple of the pitch of the worms, and the modification depends upon the helix angle of the worms to be generated.

18. A gear cutting tool having its cutting edges projecting from a plane face and arranged in the form of a plurality of convolutions the pitch of which is uniform along a straight line offset from the axis of the tool and which intersects said line at an ever increasing acute angle, each of said cutting edges being arranged to finish cut a side face of a gear tooth.

19. A rotary gear cutting tool having a plu-

rality of cutting teeth extending in a direction generally parallel to the axis of the tool and arranged in a spiral of constant pitch along a straight line offset from said axis, the outermost points of the cutting teeth lying in a plane perpendicular to said axis.

20. A rotary gear cutting tool having a plurality of cutting teeth extending in a direction generally parallel to the axis of the tool and arranged in a spiral of constant pitch along a straight line offset from said axis, said teeth being of equal height and having their outermost points all lying in a single plane perpendicular to the axis of the tool.

21. A rotary gear cutting tool having a plurality of teeth extending in the general direction of its axis and arranged in a spiral of constant pitch, along a straight line offset from said axis, each tooth being provided with a pair of side cutting edges, the teeth being of equal width in a plane perpendicular to the axis of the tool and corresponding side cutting edges of the teeth being equally inclined to the axis of the tool.

22. A rotary gear cutting tool having a plurality of teeth extending in the general direction of its axis and arranged in a spiral of constant pitch along a straight line offset from said axis, each tooth being provided with a pair of side cutting edges, the teeth being of equal height and of equal width, corresponding side cutting edges of the teeth being equally inclined to said axis.

23. A rotary tool, having an operating portion extending in the general direction of its axis, the opposite side cutting edges of which are arranged along spirals which are of constant pitch along a straight line offset from the axis of the tool, said spirals being equally spaced from each other throughout their length in a plane perpendicular to the axis of the tool.

24. A rotary tool, having an operating portion extending in the general direction of its axis, the opposite side cutting edges of which are arranged along spirals, said spirals being equally spaced from each other throughout their length in a plane perpendicular to the axis of the tool.

25. A cutter having its cutting teeth arranged in a row which extends around the axis of the cutter in a spiral curve which has a uniform lead along a line tangent to a circle which has its center at the axis of the cutter.

In testimony whereof I affix my signature.

NIKOLA TRBOJEVICH.