March 5, 1940. E. WILDHABER 2,192,370

APPARATUS FOR RELIEVING CUTTERS

Filed June 2, 1938 4 Sheets-Sheet 1

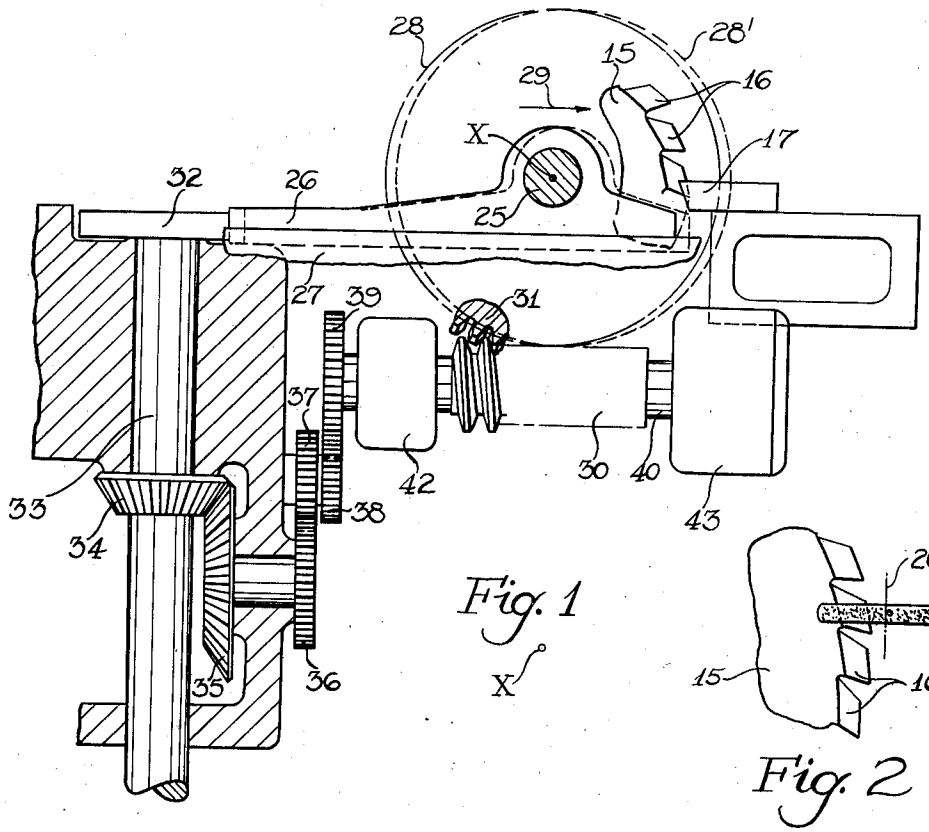


Fig. 1

Fig. 2

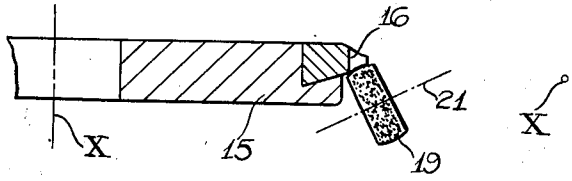


Fig. 3

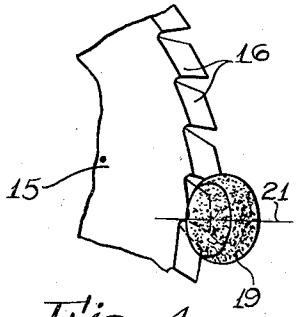


Fig. 4

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APPARATUS FOR RELIEVING CUTTERS

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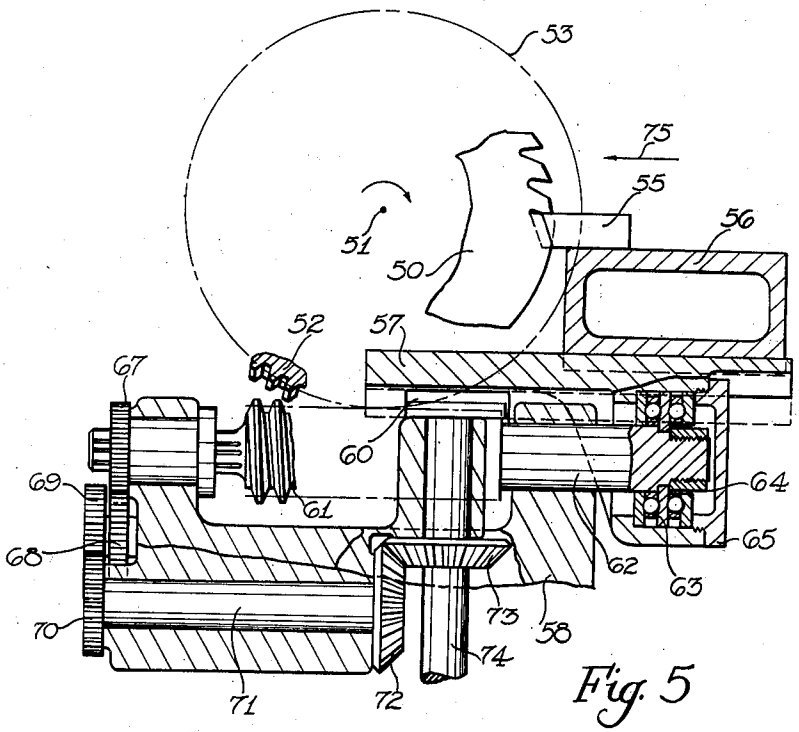


Fig. 5

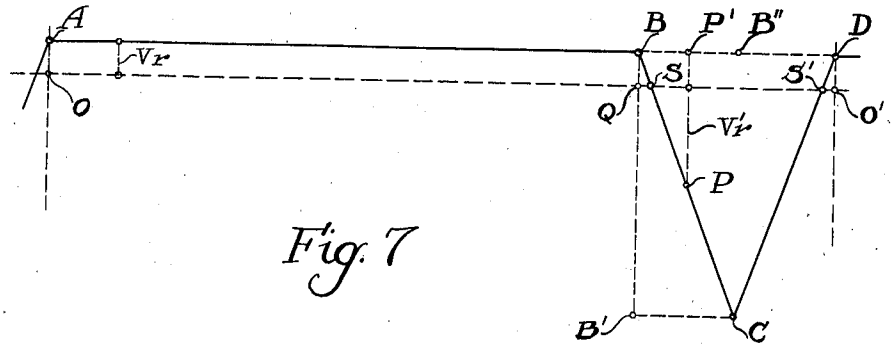


Fig. 7

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APPARATUS FOR RELIEVING CUTTERS

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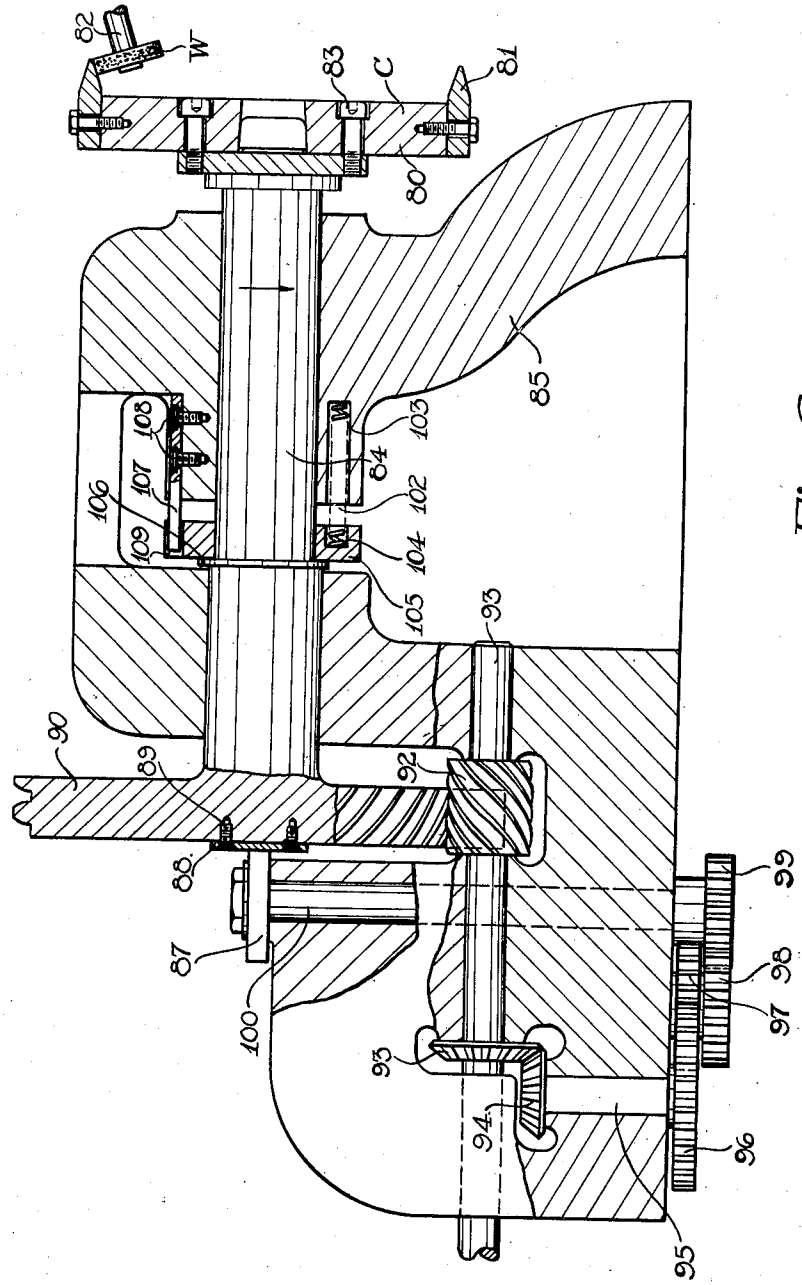


Fig. 6

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APPARATUS FOR RELIEVING CUTTERS

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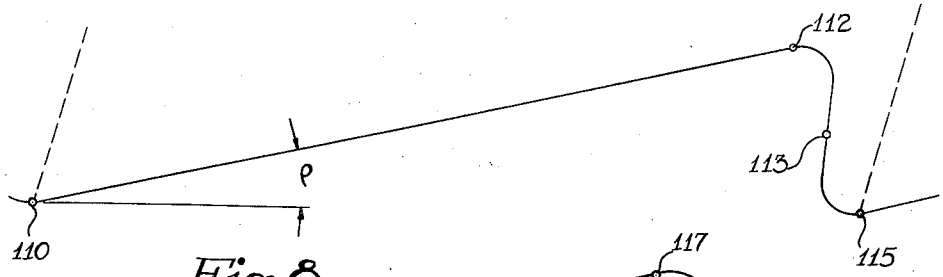


Fig. 8

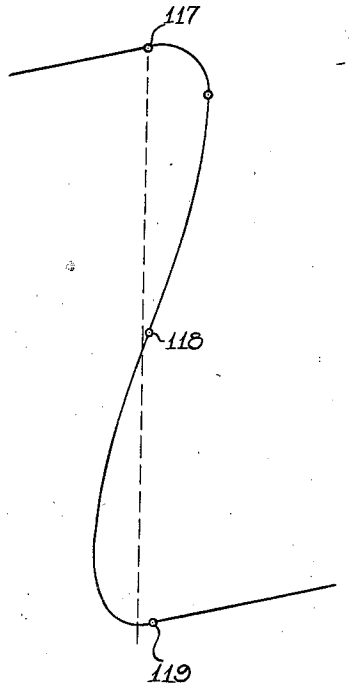


Fig. 10

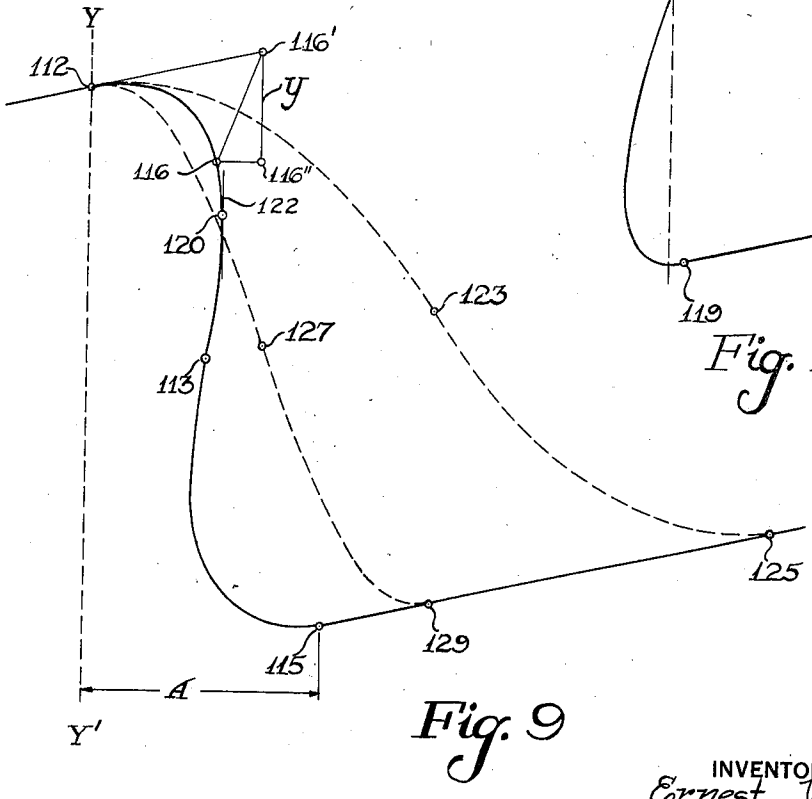


Fig. 9

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Patented Mar. 5, 1940 2,192,370

UNITED STATES PATENT OFFICE

2,192,370

APPARATUS FOR RELIEVING CUTTERS

Ernest Wildhaber, Irondequoit, N. Y., assignor to Gleason Works, Rochester, N. Y., a corporation of New York

Application June 2, 1938, Serial No. 211,448

10 Claims. (Cl. 82—19)

The present invention relates to the relieving of all kinds of cutting tools that have a plurality of successive cutting edges, and more particularly it relates to the relieving of face-mill gear cutters, disc type gear cutters, and hobs.

Ordinarily the relieving of a multi-bladed cutter is effected by rotating the cutter on its axis at a uniform rate while providing a cam-controlled relieving motion between the relieving tool and the cutter at the rate of one relieving cycle for each blade of the cutter. In the relieving of hobs, a lateral motion is added to correspond to the lead of successive teeth of the hob.

With the ordinary relieving process, the length of the portion of the blade which can be relieved is limited inasmuch as the relieving tool must be drawn back to starting position, after relieving one blade of the cutter, in order to be in position to start the relieving of the next blade of the cutter and inasmuch as in this withdrawal movement, the relieving tool must be kept clear of the blade on which it is next to operate. To obtain the maximum length of relieved surface in the ordinary relieving process, then, a very fast return or withdrawal motion must be provided. This means that only a small part of the track of the relieving cam can be devoted to the return motion. To avoid undue accelerations, inaccuracies and shocks in the relieving machine, however, such a cam must be run at relatively slow speed, thus slowing up the whole relieving operation.

The purpose of the present invention is to provide the effect of a very fast return movement in a relieving operation without having any of the drawbacks or disadvantages of a fast-return cam.

The object of the invention is attained by imparting an algebraically added rotational movement to the cutter in addition to the rotary movement ordinarily employed. This added movement is imparted in such way that the cutter becomes practically or even actually stationary at the time of withdrawal of the relieving tool. The result is that the relieving tool can be withdrawn clear of the cutter while the cutter is rotating through a very short distance and yet can be withdrawn at a speed which will avoid undue shock or vibration.

The invention may be embodied in various forms. If a worm and worm wheel are used to impart rotary motion to the cutter during the relieving operation, a relative reciprocatory rolling movement may be imparted to the worm wheel as the worm wheel rotates on its axis. This rolling movement may be controlled from the relieving cam. If the cutter is driven through helical gears, the relieving cam may be employed to reciprocate one of the gears axially of the other as the gears rotate in mesh. Other means may be employed, also, to obtain the desired results, as will be obvious to those skilled in the art. With the method and apparatus of the present invention, the relieving action is smooth and accurate without any sacrifice in the speed of the relieving operation. Moreover, these results are obtained with very simple means.

Several different embodiments of the invention are illustrated in the accompanying drawings, in which:

Fig. 1 is a more or less diagrammatic view with parts broken away of apparatus constructed according to this invention for relieving a disc milling cutter where the relieving motion is imparted to the milling cutter;

Figs. 2, 3 and 4 show that the invention is usable with the various known types of relieving tools, Fig. 3 being a sectional view of the cutter and grinding wheel shown in Fig. 4;

Fig. 5 is a more or less diagrammatic view with parts broken away, showing a modified form of apparatus for relieving a disc milling cutter according to the invention, where the relieving motion is imparted to the relieving tool;

Fig. 6 is a more or less diagrammatic view of apparatus built according to one embodiment of the invention for relieving a face-mill type of gear cutter;

Fig. 7 is a diagrammatic view illustrating the variation in the relieving velocity at various points in the relieving operation;

Fig. 8 is a diagrammatic view showing the path followed by the relieving tool in the relieving of blades of a cutter according to the present invention;

Fig. 9 is an enlarged diagrammatic view illustrating the path of movement of the relieving tool during withdrawal and showing for comparison the paths of the tools during withdrawal in the prior known relieving operations; and

Fig. 10 is a diagrammatic view illustrating a modified path of movement of the tool during withdrawal where the process of the present invention is employed.

Reference will now be had to the drawings for a more detailed description of the invention. In Figs. 1 to 4 inclusive, 15 denotes the cutter which is to be relieved, which is here shown fragmentarily and comprises a disc milling cutter hav-

ing a plurality of cutting blades 16 arranged around its periphery.

For the relieving operation, any of the usual types of relieving tools may be employed. In Fig. 1, the relieving tool is a lathe tool 17.

The relieving motion itself may be imparted either to the relieving tool or to the cutter which is to be relieved. In Fig. 1, the relieving motion is shown imparted to the cutter. The cutter 15 is secured to the work spindle 25 that is journaled in a slide 26. This slide reciprocates on the bed or base 27 of the machine.

There is a worm wheel, indicated partly in section at 31 and partly by its pitch line 28, which is secured to the work spindle 25. A worm 30 meshes with the worm wheel 28 to impart rotary motion to the spindle 25 so that successive blades of the cutter are presented to the relieving tool 17.

As each blade of the cutter moves past the relieving tool, the cutter is moved in the direction of the arrow 29 toward the relieving tool to effect the relieving operation and is then withdrawn away from the relieving tool again to return the cutter to initial position ready for the relieving of the next blade.

The relieving and return movements of the cutter are controlled by the cam 32 which directly actuates the slide 26. This cam may be of the same general shape as the relieving cams employed in the known relieving processes.

The relieving cam 32 is secured to a shaft 33 which is journaled in the base 27 of the machine. The worm wheel 28 and the relieving cam 32 are driven in timed relation with one another through the bevel gears 34 and 35, and the spur change gears 36, 37, 38 and 39. The gear 39 is secured to the shaft 40 upon which the worm 30 is mounted. This shaft is journaled in anti-friction bearings 42 and 43. Power is applied to the shaft 33. Through the gearing described, the relieving cam 32 and the worm 30 are driven in timed relation at uniform velocities. These motions are the same as those employed in the known relieving processes.

The novel step of the present invention resides in the relative movement of the worm 30 and the worm wheel 31 along the axis of the worm which is parallel to the direction 29 of the relieving motion. This is effected by mounting the cutter upon a slide 26 which is movable relative to the worm 30, which is here retained in relatively fixed axial position, the bearings 42 and 43 being secured to the base 27. As a result of the movement of the slide 26, the worm wheel 28 rolls on the worm 30 as the slide 26 is reciprocated. As a consequence, the worm wheel has an additional rotational movement imparted to it which is of an algebraic nature, being first in one direction and then in the other.

On the relieving stroke, the rotational movement produced by the rolling movement of the worm wheel is added to the uniform rotational movement produced by rotation of the worm. On the return stroke, the direction of the rolling movement is reversed and the rotational movement produced by the rolling movement is subtracted from the constant rotational movement produced by the worm. On the return stroke of the slide 26, then, the resultant rotational velocity of the cutter is slowed up and the relieving tool 17 has ample time to clear one blade of the cutter before the next blade rotates into position. As a result, the blades of the cutter may be relieved for a greater length from front to rear than by the relieving methods heretofore practiced and time enough can be taken for moving the cutter clear of the relieving tool to avoid objectionable shocks or accelerations.

Often, the rotational movement due to rolling of the worm wheel along the worm is sufficient to stip the rotation of the worm wheel entirely on the return stroke and even in some cases to reverse the direction of the worm wheel during withdrawal. In such cases, the blades of the cutter can be relieved for practically their whole length by tool 17. In Fig. 1, 28 and 28' denote, respectively, two different positions of the worm wheel in its rolling movement.

The process of the invention is the same when the relieving motion is imparted to the relieving tool. In Fig. 5, there is illustrated apparatus for effecting the relieving of a cutter by imparting the relieving motion to the relieving tool. Here the cutter to be relieved is again shown fragmentarily. It is designated at 50. It is mounted to rotate on the axis 51 and is driven by the worm wheel 52 whose pitch circle is denoted at 53.

The relieving tool is shown at 55. It is secured to a block 56 that is in turn secured to a slide 57. The slide 57 is mounted to reciprocate upon the base or frame 58 of the machine. The slide is actuated by the relieving cam 60 which may be of the usual construction.

The worm wheel 52 is rotated by the worm 61. This form is integral with a shaft 62 that is mounted to reciprocate with the slide 57. The shaft 62 is connected to the slide 57 through the antifriction bearings 63 and the nuts 64 and 65. The worm shaft 62 has a splined connection at one end with the hub of a spur gear 67 and slides in the hub of this gear. This gear is journaled by means of its hub in the frame 58. The worm shaft 62 slides at its opposite ends in a plain bearing formed in the frame 58.

The shaft 62 and the cam 60 are connected to rotate in timed relation through the spur gears 67, 68, 69 and 70, the shaft 71, the bevel gears 72 and 73 and the shaft 74. The cam 60 is secured to the shaft 74 and power may be applied to this shaft.

As the relieving tool 55 moves inwardly in the direction of the arrow 75, on the relieving stroke, through operation of the cam 60, the shaft 62 and worm 61 are carried inwardly with it, causing the worm 61 to roll axially over the teeth of the worm wheel 52. Thus, a uniform rotational movement is imparted to the worm wheel which is added to the uniform rotational movement produced by the rotation of the worm 61. On the return stroke of the tool 55, however, the rotational movement due to roll is subtracted from the constant rotational movement due to the rotation of the worm and hence the resultant rotation of the cutter 50 is slowed up. It may be stopped entirely or may even be reversed. Thus, in this embodiment of the invention, as in the previously described modification of the invention, it is possible to relieve the blade of a cutter for a greater part of its length than in previous practice without danger of the relieving tool striking a succeeding blade of the cutter on the return stroke of the tool.

In the apparatus of both Figs. 1 and 5, springs or other suitable means will in practice be employed to hold the slides against the cams but have been omitted for the sake of clearness in illustration.

As already stated, the process of the present

invention may be applied with any of the usual forms of relieving tools. Fig. 2 illustrates the relief grinding of blades of curved profile with a grinding wheel 18 whose axis is at 20. Here the relieving tool 18 is set above the cutter center or axis X. Fig. 4 shows another way of relief grinding the curved profile side surfaces of the blades 16 of the cutter 15. Here a grinding wheel 19 is used which is set below the center or axis X of the cutter. The axis 21 of the grinding wheel is inclined to the axis X of the cutter.

The relieving motions which may be employed with the grinding wheels 18 and 19 are the same as may be employed with the lathe tools 17 and 55. In fact, the grinding wheels can be substituted for the lathe tools and mounted directly on the tool block of the apparatus shown in Fig. 1 or Fig. 5.

In Fig. 6, I have shown an application of the invention to the relieving of face-mill gear cutters. The cutter to be relieved is denoted at C. It comprises a rotary head 80 and a plurality of cutting blades 81 which project beyond one side face of the head in the general direction of the axis of the head. The relieving tool is here shown as a cylindrical grinding wheel W which is mounted to rotate about the axis of a shaft 82.

To relieve the blades of the cutter C, the cutter head is secured by bolts 83 to the spindle 84 of the relieving machine. This spindle 84 is mounted to rotate and reciprocate axially in the work head 85 of the machine.

The reciprocating movement of the spindle 84 is produced by the relieving cam 87 which may be usual or suitable construction. This cam engages a hardened nose or follower 88 that is secured by screws 89 to an end face of the spindle. The rotary motion of the spindle 84 is produced by rotation of the helical gear 90 which is here shown as formed integral with the spindle.

This helical gear 90 is driven by a long-faced helical pinion 92 which is secured to a shaft 93 that is journaled in the head 85 parallel to the spindle 84.

The relieving cam 87 is driven in timed relation with the pinion 92 by the bevel gears 93 and 94, the shaft 95, the spur gears 96, 97, 98 and 99 and the shaft 100. The cam 87 is secured to the shaft 100. Power may be applied to the shaft 93.

The plate or follower 88 is held against the cam 87 by operation of coil springs 102 of which a plurality are provided although one only is shown in the sectional view of Fig. 6. These coil springs are spaced around the spindle 84 and each seats at one end in a recess 103 formed in the head 85 and at its opposite end in a recess 104 formed in a collar 105. The collar 105 seats against a flange or shoulder 106 formed on the spindle 84 and it is held against rotation by one or more lugs or keys 107. The key or keys 107 is or are secured by screws 108 to the head 85 and engage in a slot or slots 109 formed in the collar 105.

In the relieving of the blades of a face-mill gear cutter by the processes ordinarily used heretofore, the cutter head is rotated on its axis at a uniform velocity and simultaneously a relative relieving movement is produced axially of the cutter. These two motions are still employed in principle in the present invention, but by making the helical gear 90 slidable relative to the helical pinion 92, an additional rotational movement is imparted to the cutter spindle 84 during the axial movement of the spindle 84 under actuation of the cam 87. This movement is separate from the rotational movement imparted to the spindle 84 by rotation of the helical pinion 92 itself and it is added to this last named rotational movement during the relieving stroke of the spindle 84 while it is subtracted from this last named rotational movement on the return stroke of the spindle 84. Thus with the mechanism of the present invention, it is possible again to slow up, stop entirely, or even reverse the direction of rotation of the cutter head during the return stroke of the relieving tool. As a result it is possible to grind the blades of a face-mill gear cutter for a greater length from front to rear with the present invention than has been possible with the processes previously used.

Let us now further analyze the relative path of the relieving tool particularly with reference to the illustrated embodiments of the invention. Let ω denote the angular velocity of the relieving cam and N the number of teeth or blades in the complete circumference of the cutter which is to be relieved. Let r denote the mean radius of the cutter and R the pitch radius of the worm wheel 31 or 52 (Figs. 1 and 5). Then the turning velocity of rotation v_1 of the cutter at radius r, due to the worm rotation alone, is for a single-threaded worm:

$$v_1 = r \cdot \frac{\omega}{N}$$

The velocity of the relieving motion v_r in direction 29 (Fig. 1) is $v_r = c.\omega$ where $2\pi c$ is equal to the throw of the relieving cam per revolution of the cam.

The rotation of the cutter due to its rolling motion is

$$\frac{v_r}{R}$$

and the velocity v_2 of the cutter at the radius r is therefore:

$$v_2 = r \cdot \frac{v_r}{R} = \frac{r.c.\omega}{R}$$

The resultant rotational velocity v of the cutter is equal to $v_1 + v_2$, or

$$v = r.\omega\left(\frac{1}{N} + \frac{c}{R}\right)$$

It is well known that the tangent of the top relief angle ρ of a cutter blade, when the relieving tool moves in a radial path, is

$$\tan \rho = \frac{v_r}{v}$$

or

$$\tan \rho = \frac{c}{r\left(\frac{1}{N} + \frac{c}{R}\right)} \qquad (1)$$

Through transformation:

$$\tan \rho\left(\frac{1}{N} + \frac{c}{R}\right) = \frac{c}{r}$$

and

$$c\left(\frac{1}{r} - \frac{\tan \rho}{R}\right) = \frac{\tan \rho}{N}$$

and

$$c = \frac{r \tan \rho}{N} \div \left(1 - \frac{r}{R} \tan \rho\right) \qquad (1A)$$

Formulas 1 and 1A give the top relief angle ρ obtainable with a given cam characterized by a

rate of throw c and the cam characteristic c for a given top relief ρ, respectively.

Let us now consider the return stroke. Fig. 7 is a diagram using the angle of rotation of the cam as an abscissa and the velocity of the relieving motion v_r as the ordinate. Instead of v_r, the quantity

$$\frac{v_r}{\omega}$$

might be plotted if desired. Distance OO' denotes the complete circumference of the relieving cam, that is 360°.

During the relieving stroke from A to B, the relieving velocity v_r is constant. At the end of the relieving stroke, the velocity drops to zero and reverses rapidly. At C, the maximum return velocity has been reached. The straight lines BC and CD indicate constant accelerations. When the cam is constructed in this way, the acceleration may be kept at a minimum with the result of a minimum of shock or vibration in the operation of the relieving machine. The way of designing cams to obtain constant acceleration is known and needs no explanation. A cam with constant acceleration curves on the return stroke is preferred, but this construction is not essential to the invention. Other curves may be used if desired.

In determining the return stroke and the constant accelerations desired, it must be kept in mind that obviously the return stroke must cover the same distance as the relieving stroke. The distance covered is the product of the velocity and the time and the latter is proportional to the rotation of the cam. The distance travelled in the relieving stroke OQ is therefore proportional to the area of the rectangle OQBA. The relieving distance per revolution of the cam is proportional to the area OO'DA.

The total forward motion, as expressed by the areas OQBA+QSB+S'O' D must be equal to the total return motion expressed by the area SCS'. Add area SS'DB to both items and we get:

$$\text{Area } OO'DA = \text{area } BCD = \tfrac{1}{2}\ BB'.BD$$

and

$$BB' = 2\frac{OO'.v_r}{BD}$$

The acceleration is such as to give a change in velocity of 2 BB' during the time corresponding to rotation of the cam through the angle BD.

The return velocity v'_r at any point P is given by its ordinate. From Fig. 6, then, we have:

$$PP' = v'_r + v_r = BB' \cdot \frac{BP'}{BB''}$$

B'' is a point midway between B and D.

Let θ denote the angle of rotation of the cam between B and P' and θ' the angle of rotation of the cam during travel of the distance BD. Then:

$$v'_r + v_r = 2v_r \frac{OO'}{BD} \cdot \frac{\theta}{\frac{1}{2}\theta'} = 4v_r\left(\frac{2\pi}{\theta'}\right)\cdot\frac{\theta}{\theta}$$

where the angles θ and θ' are measured in radians.

The distance Y travelled back by the cutter on the return stroke at any point P' between the points B and B' as measured from the continuation of the relieving stroke is given by the area of the triangle BPP' and is equal to the product:

$$y = \tfrac{1}{2}T(v'_r + v_r)$$

where T is the time measured by

$$BP'.\theta = \omega.T, \text{ and } T = \frac{\theta}{\omega}$$

Then

$$y = \tfrac{1}{2}\frac{\theta}{\omega}(v'_r + v_r) = \tfrac{1}{2}\theta.4c\left(\frac{2\pi}{\theta'}\right)\frac{\theta}{\theta'}$$

and

$$y = 4\pi c\left(\frac{\theta}{\theta'}\right)^2$$

In Fig. 8, the relative path of the point of a relieving tool during the relieving of the tip surfaces of successive blades of a cutter is illustrated. A cutter of large diameter has been assumed so that the cutter periphery may be considered as straight for the purposes of the present analysis. A smaller cutter would be shown in devlopment.

The uniform relieving motion during the rotation of a blade under the relieving tool gives a relief line 110—112 for the top of the blade. This line is inclined at the top relief angle ρ to the cutter periphery. The uniform inward relieving motion ceases at the point 112. At this point deceleration begins. Then the return stroke of the relieving tool commences and the tool begins to be accelerated outwardly. At point 113, the relieving tool is halfway withdrawn and at point 115, the uniform relieving motion starts again for the relieving of the next blade of the cutter.

The relative path 112—113—115 is shown on a larger scale in Fig. 9. It is to be noted that the relieving tool moves almost straight out relative to the cutter. This is so even though in the instance illustrated the return stroke 112—115 occupies a full quarter of the track of the relieving cam and of the time of a complete relieving cycle.

Any point such as 116 in the return stroke of the relieving tool may be obtained by plotting distance y from any assumed point 116', which is the same as point P' in Fig. 7, and first obtaining a point 116''. Point 116 is on a peripheral line 116—116'' at a distance proportional to y and to the ratio

$$\frac{r}{R}$$

In other words, distance 116—116''$=y\frac{r}{R}$

In the example P shown in Figs. 9 and 10,

$$\frac{r}{R}$$

has been assumed as equal to two-thirds and ρ as equal to 12°. Full line 112—113—115 (Fig. 9) corresponds to a turning angle $\theta'=90°$. In Fig. 10, the relative path 117—118—119 has been plotted for the return movement of a relieving tool where the turning angle $\theta'=60°$.

At point 120 (Fig. 9), where the tangent 122 to the path of the relieving tool is parallel to Y—Y', the rotation of the cutter comes to a stop and in the instances illustrated performs a slight reverse rotation at mean point 113 or 118. The advance A of point 115 from line Y—Y is seen to be quite small and if desired may even be

made a negative quantity by suitably assuming the turning angle θ', and the ratio

$$\frac{r}{R}$$

The point 115 or 119 will then be to the left of the line Y—Y'. For the sake of comparison, I have shown in Fig. 9 the relative path 112—123—125 of the return stroke of the relieving tool in the conventional relieving process for the same time and same cam angle $\theta'=90°$ as the path 112—113—115. The path 112—127—129 is such as would be produced in the conventional relieving process if a cam having a faster return movement were employed. The path 112—127—129 corresponds to a cam having a return angle, $\theta'=45°$. As will be clear from Fig. 9, even with such a cam, there is a considerable lost time as compared with the relieving process of the present invention. Moreover, for a return angle of $\theta'=45°$, if the cam is operated at the same rotational speed, accelerations and inertia forces will be four times as large as where the return path is 112—123—125. The advantage of the relieving method of the present invention is plainly evident from the diagrams of Figs. 8 to 10 inclusive which show that the relieving tool receded nearly radially with very little overlap while nevertheless it has ample time to recede. Excessive stresses, vibrations and inaccuracies are thereby avoided while a maximum efficiency in the relieving process is attained.

While the invention has been illustrated and described in connection with several different embodiments thereof, it will be understood that it is capable of further modification. This application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth and as fall within the scope of the invention or the limits of the appended claims.

Having thus described my invention, what I claim is:

1. Apparatus for relieving the blades of a rotary multi-bladed cutter comprising a rotary work support, a relieving tool, a slide on which one of said members is mounted, means for rotating the work support, means for reciprocating said slide in time with the rotation of the work support once for each blade of the cutter to be relieved, and means whereby the movements of the slide vary the rate of rotation of the work support.

2. Apparatus for relieving the blades of a multi-bladed cutter comprising a rotary work support, a relieving tool, a slide on which one of said members is mounted, a pair of gears for rotating the work support which are rotatable and reciprocable relative to one another, one of said gears being mounted to move with said slide, means for rotating said gears to effect rotation of the work support, and means for reciprocating said slide in time with the rotation of said gears once for each blade of the cutter to be relieved, one of said gears being so connected to said slide that the reciprocatory movement of the slide simultaneously imparts an added rotational movement to the driven member of said pair of gears which is in opposite directions, respectively, for opposite directions of movement of the slide.

3. Apparatus for relieving the blades of a multi-bladed rotary cutter comprising a rotary work support, a relieving tool, a slide upon which one of said members is mounted, a worm and worm wheel for rotating said work support, means for reciprocating the slide once for each blade of the cutter to be relieved, means for rotating the worm and worm wheel continuously in one direction in time with the slide reciprocation, and means for effecting relative movement between the worm and worm wheel axially of the worm on reciprocation of the slide.

4. Apparatus for relieving the blades of a rotary multi-bladed cutter comprising a rotary work support, a relieving tool, a slide upon which one of said members is mounted, a worm and worm wheel for rotating the work support, one of which parts is mounted to rotate on a relatively fixed axis and the other of which is mounted to move with the slide in the direction of the worm axis, means for rotating the worm and worm wheel, and means for reciprocating the slide in time with said rotating means.

5. Apparatus for relieving the blades of a rotary multi-bladed cutter comprising a rotary work support, a relieving tool, a slide upon which one of said members is mounted, a worm and worm wheel for rotating the work support, one of which is mounted to rotate on a relatively fixed axis and the other of which is mounted to move with the slide in the direction of the worm axis, a rotary cam for reciprocating the slide, means for rotating the worm and worm wheel, and means for rotating the cam in timed relation therewith once for each blade of the cutter to be relieved.

6. Apparatus for relieving the blades of a rotary multi-bladed cutter comprising a rotary work support, a relieving tool, means for reciprocating the work support relative to the relieving tool, a pair of gears for rotating the work support, one of which is rotatable and reciprocable relative to the other and is connected to said reciprocating means to reciprocate on actuation of said reciprocating means, and means for rotating the gears in time with the reciprocating means.

7. Apparatus for relieving the blades of a rotary face-mill gear cutter comprising a rotary work support, a relieving tool, means for reciprocating the work support relative to the relieving tool axially of the work support, a pair of helical gears for rotating the work support, one of which is rotatable and reciprocable relative to the other axially of the work support, means connecting said gear to said reciprocating means to reciprocate on actuation of said reciprocating means, and means for rotating the gears in time with the reciprocating means.

8. Apparatus for relieving cutter blades comprising a tool support, a work support, means for rotating the work support continuously at a uniform velocity, means for producing a relative reciprocating movement between the tool and work supports in time with said rotary movement once for each blade of the cutter to be relieved, and means whereby said reciprocating movement itself produces an additional rotary movement of the work support.

9. Apparatus for relieving cutter blades comprising a rotary and axially reciprocable work support, means for rotating the work support at a uniform velocity, means for reciprocating the work support in time with its rotary movement once for each blade of the cutter to be relieved,

and means whereby the reciprocating movement imparts an added rotary movement to the work support which is in opposite directions for opposite directions of the reciprocating movement.

10. In a machine for relieving cutter blades, a frame, a slide reciprocable on the frame, a work spindle journaled in the slide with its axis perpendicular to the direction of reciprocation of the slide, means for rotating the work spindle comprising a worm wheel secured to the spindle and a worm which meshes therewith and which is journaled in the frame, said worm being mounted so that its axis extends in the direction of movement of the slide, means for rotating the worm, and means driven in time with the last-named means for reciprocating the slide once for each blade to be relieved.

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