May 22, 1945. E. WILDHABER 2,376,465

METHOD AND MACHINE FOR PRODUCING GEARS

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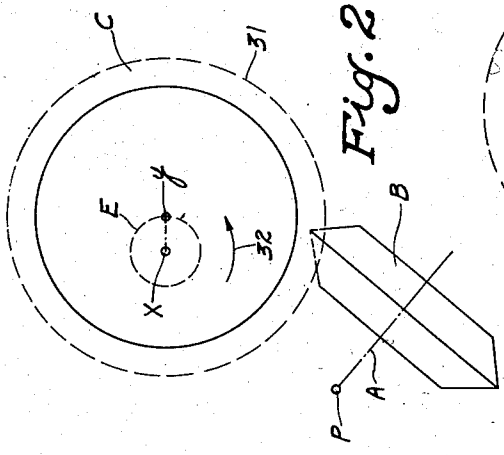


Fig. 2

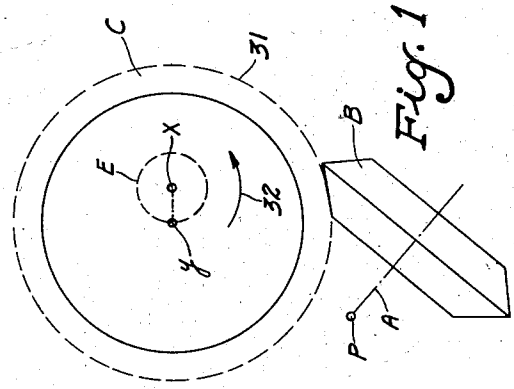


Fig. 1

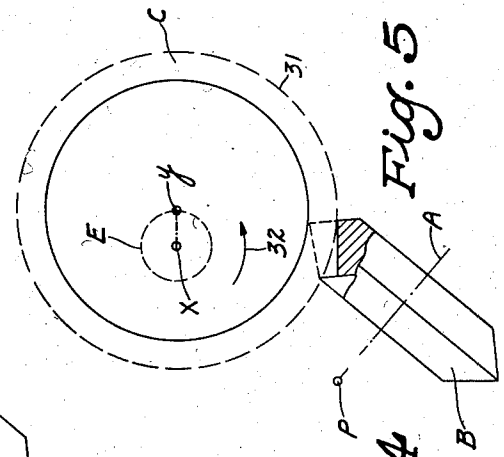


Fig. 5

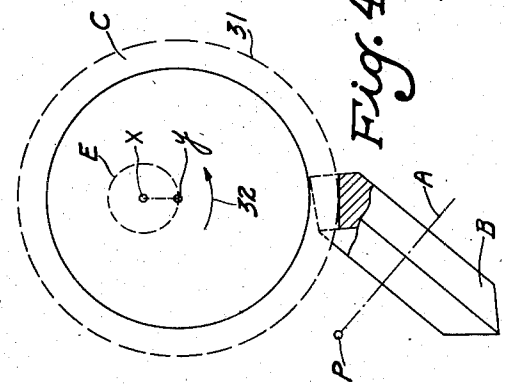


Fig. 4

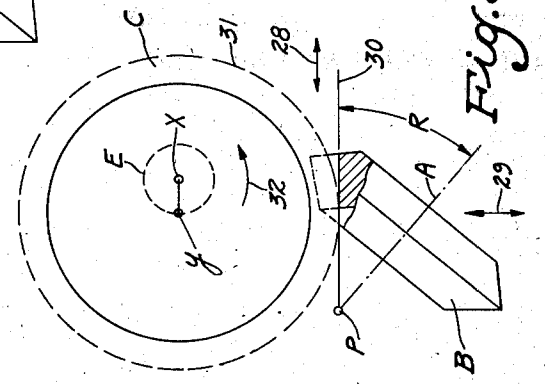


Fig. 3

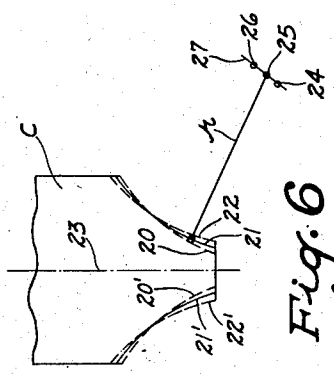


Fig. 6

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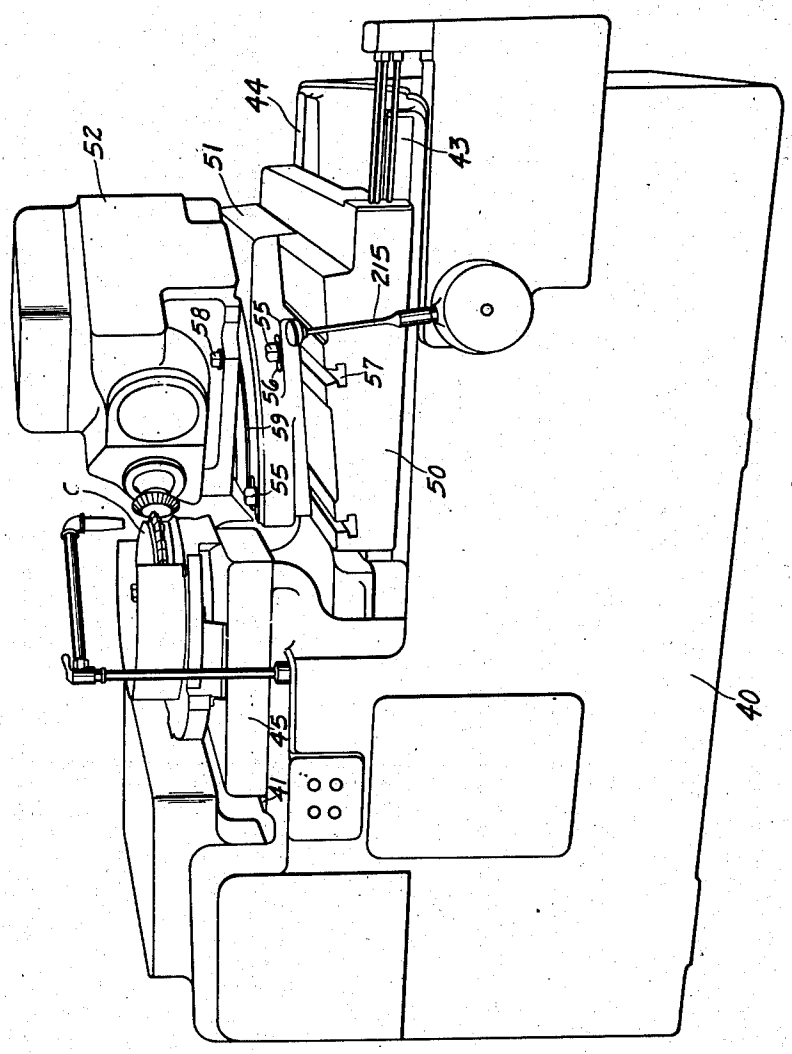


Fig. 7

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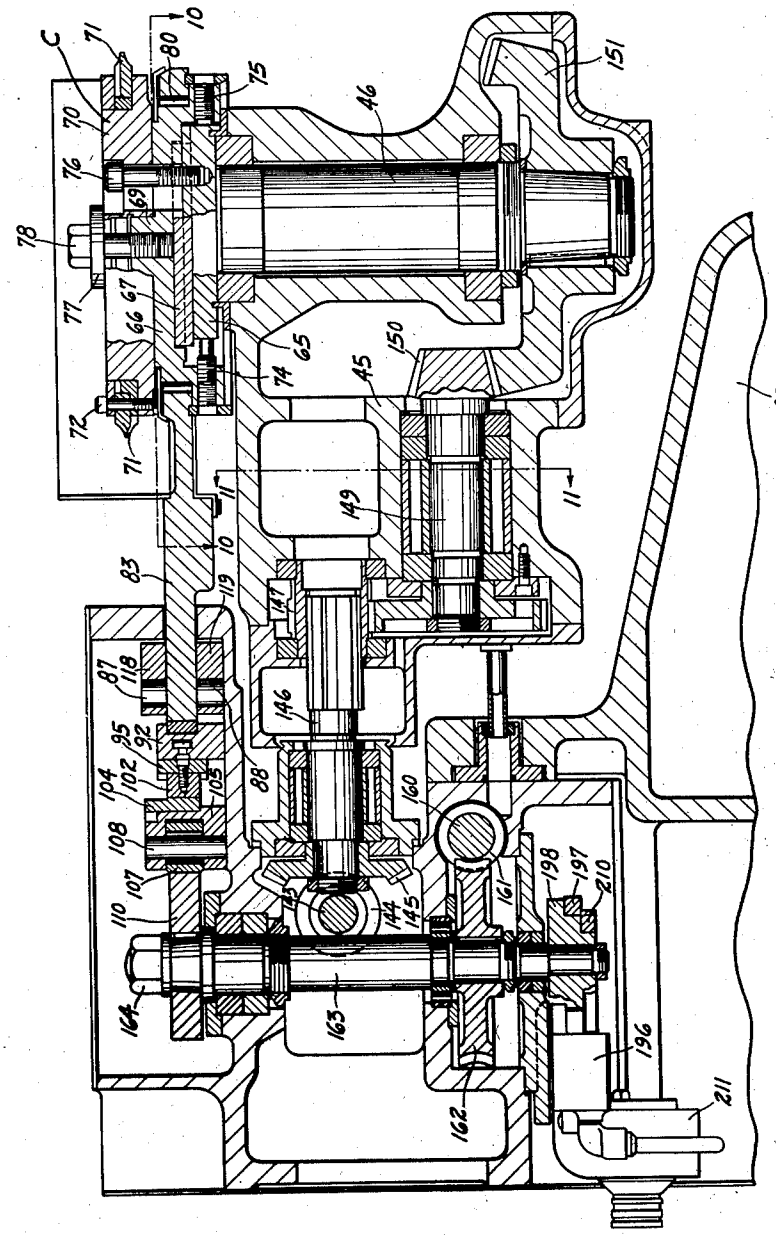


Fig. 8

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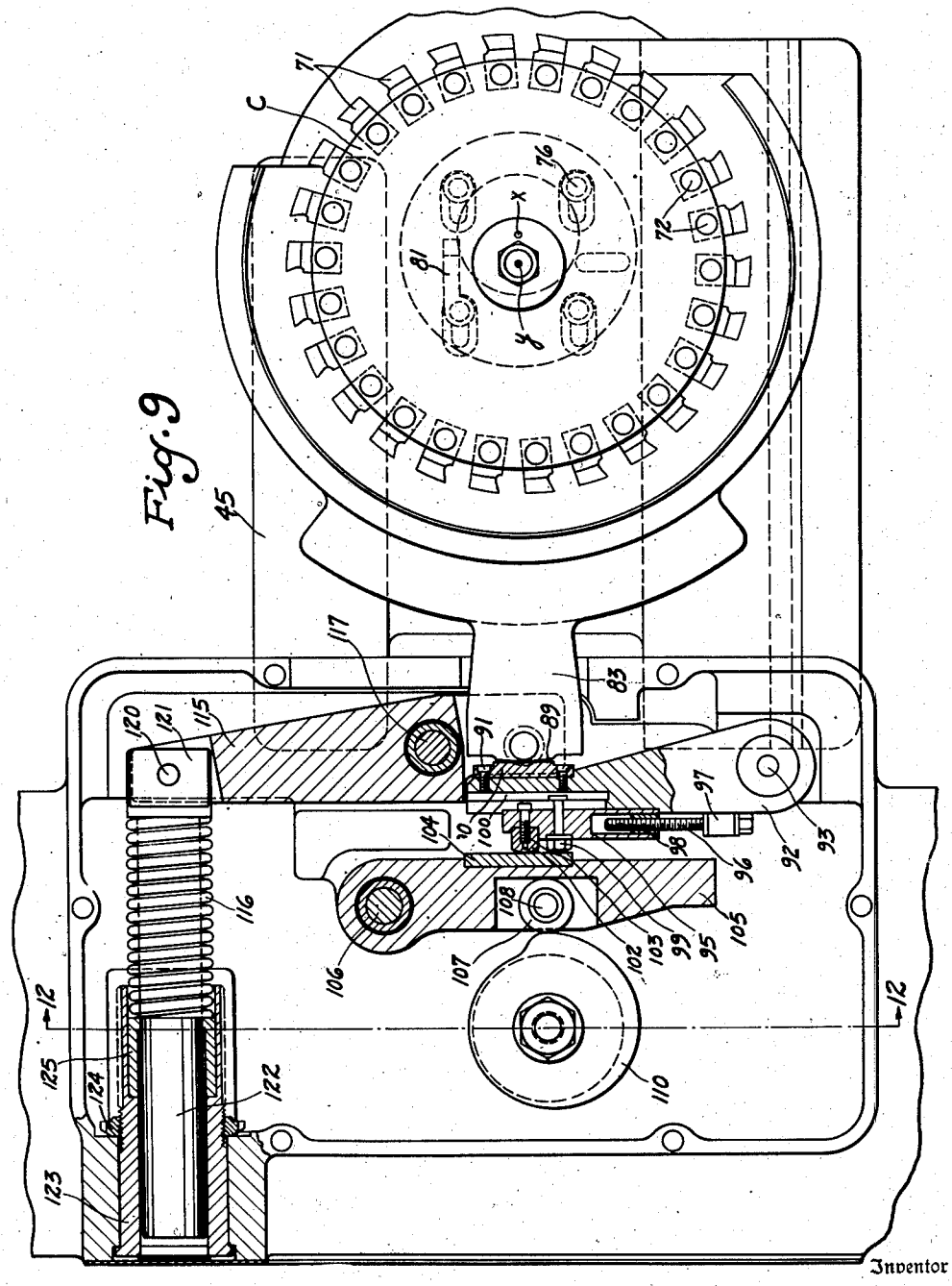
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Fig. 9



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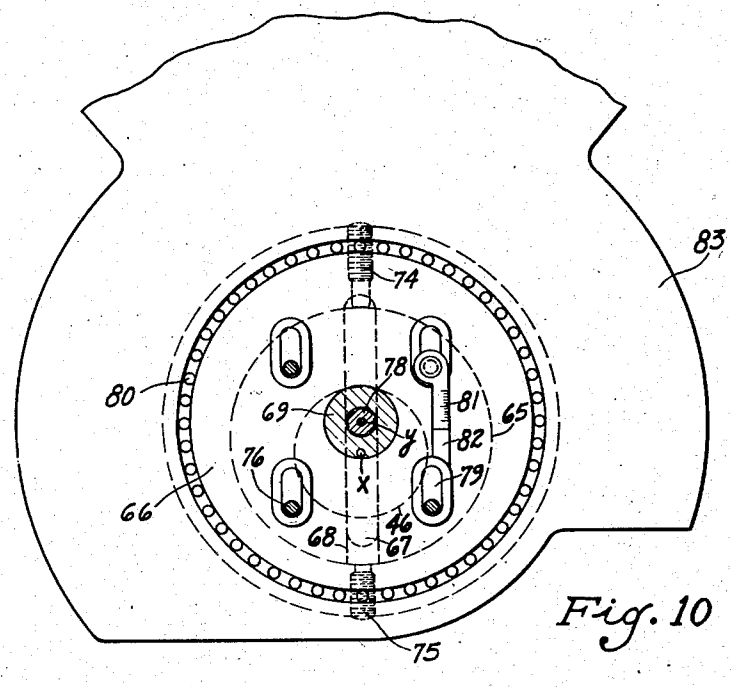


Fig. 10

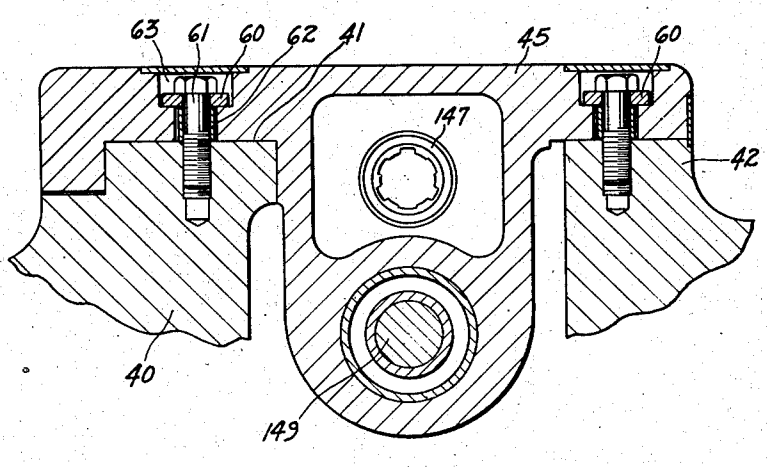


Fig. 11

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METHOD AND MACHINE FOR PRODUCING GEARS

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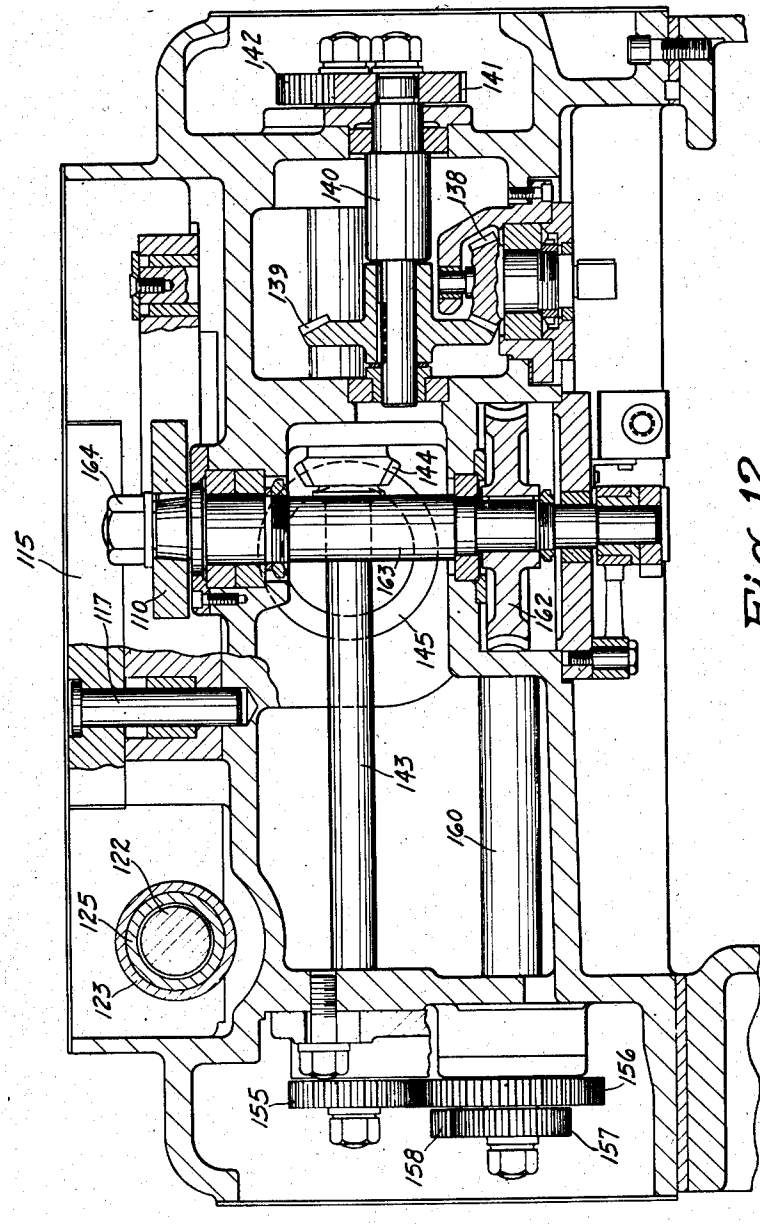


Fig. 12

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METHOD AND MACHINE FOR PRODUCING GEARS

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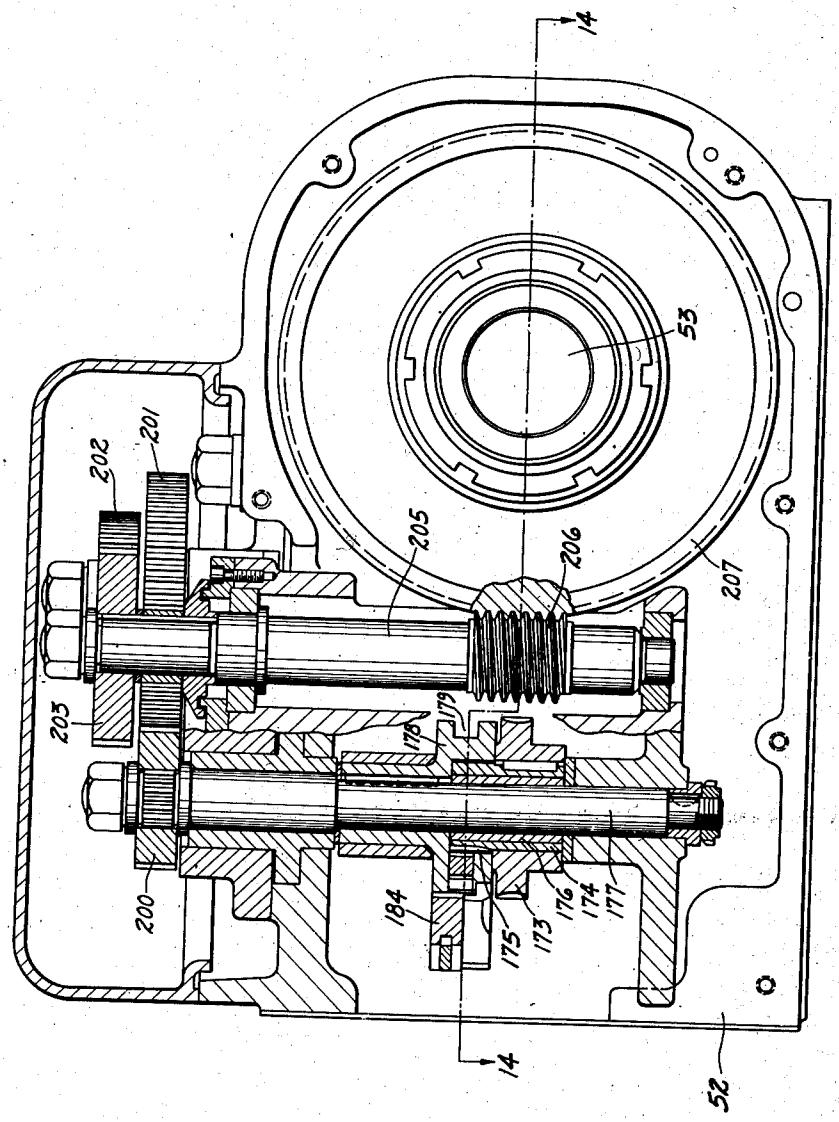


Fig. 13

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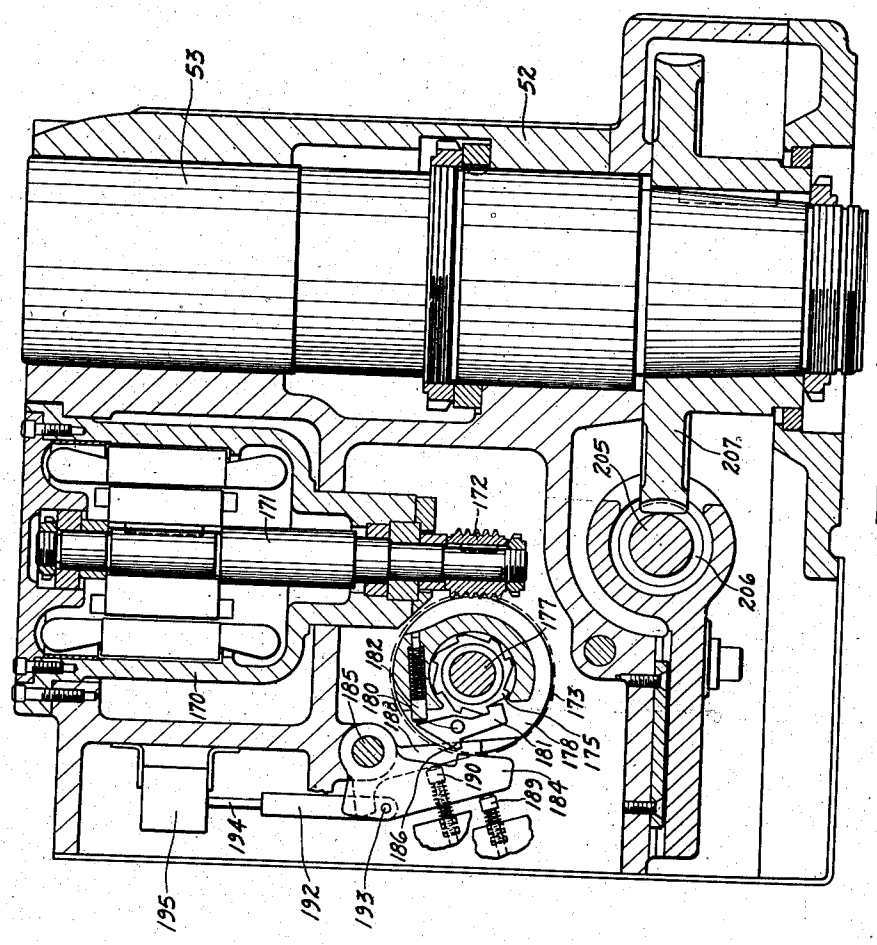


Fig. 14

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METHOD AND MACHINE FOR PRODUCING GEARS

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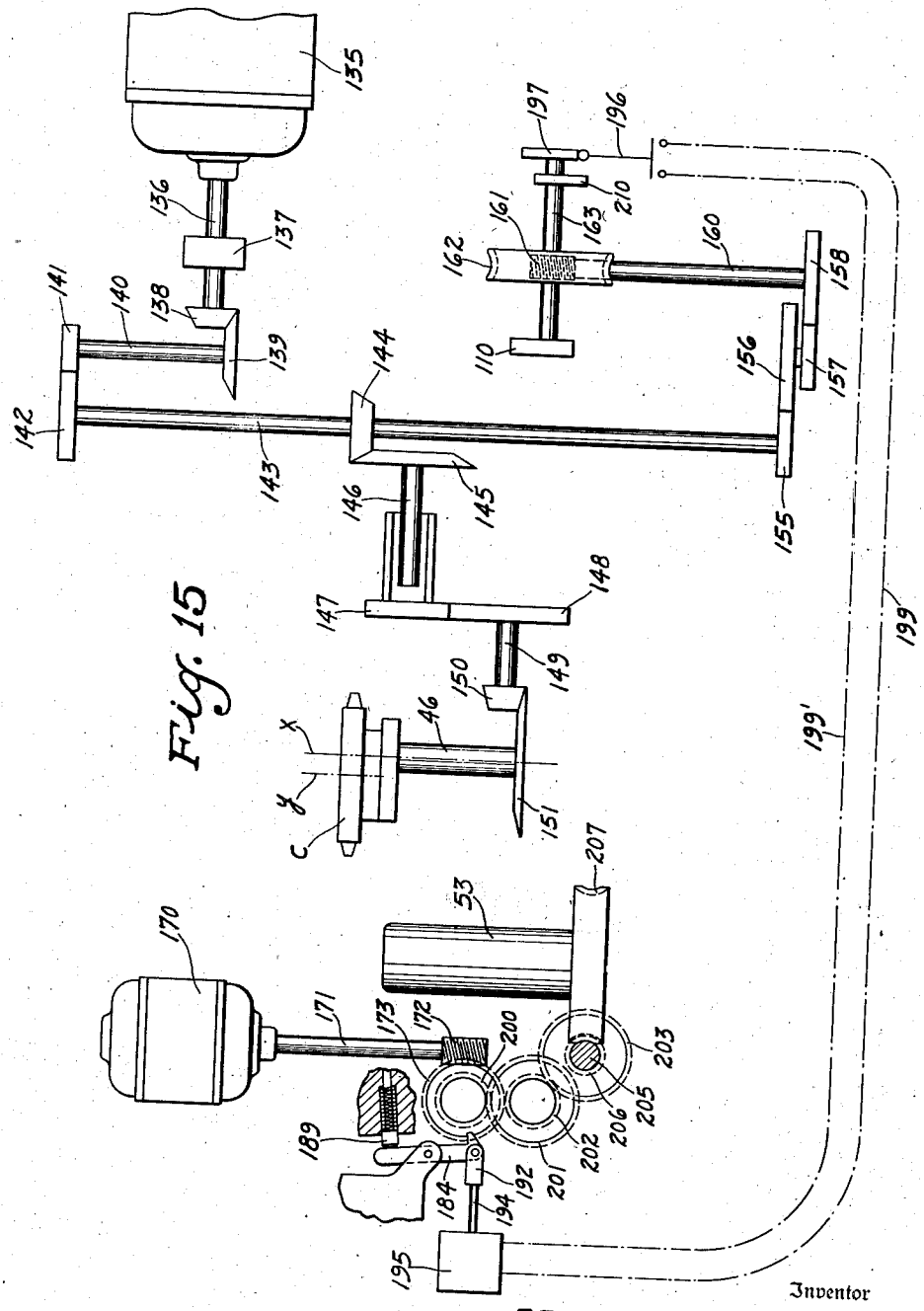


Fig. 15

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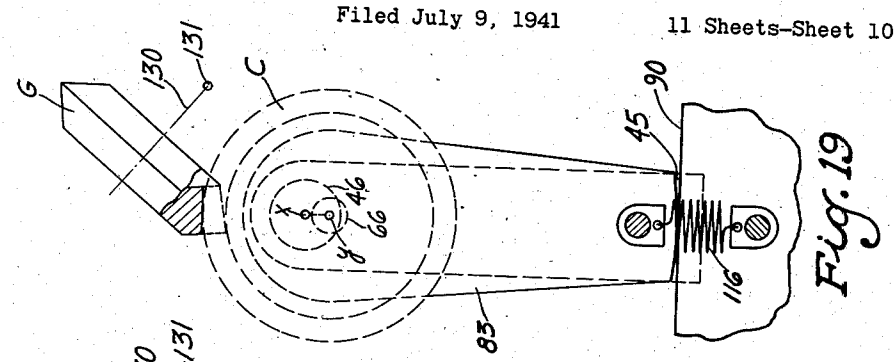


Fig. 19

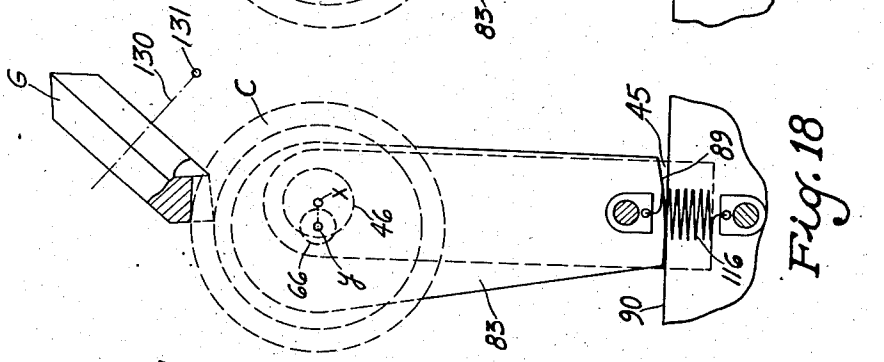


Fig. 18

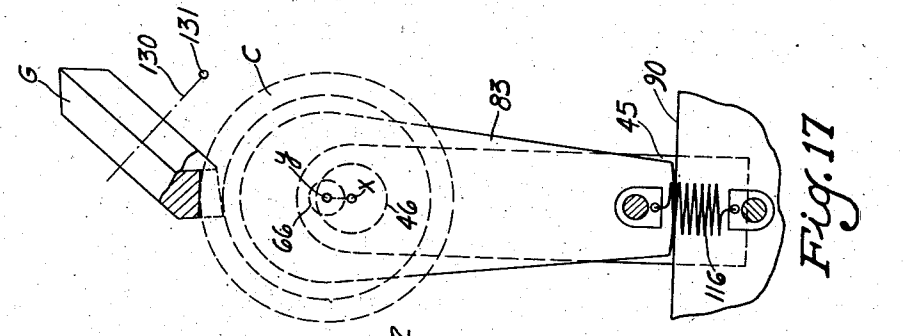


Fig. 17

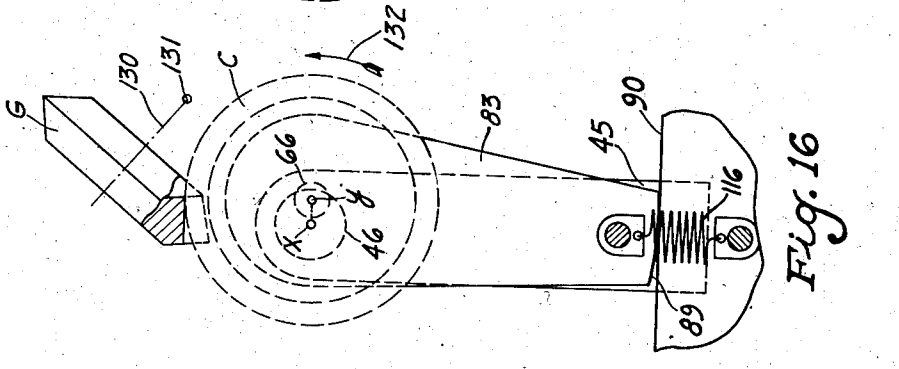


Fig. 16

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METHOD AND MACHINE FOR PRODUCING GEARS

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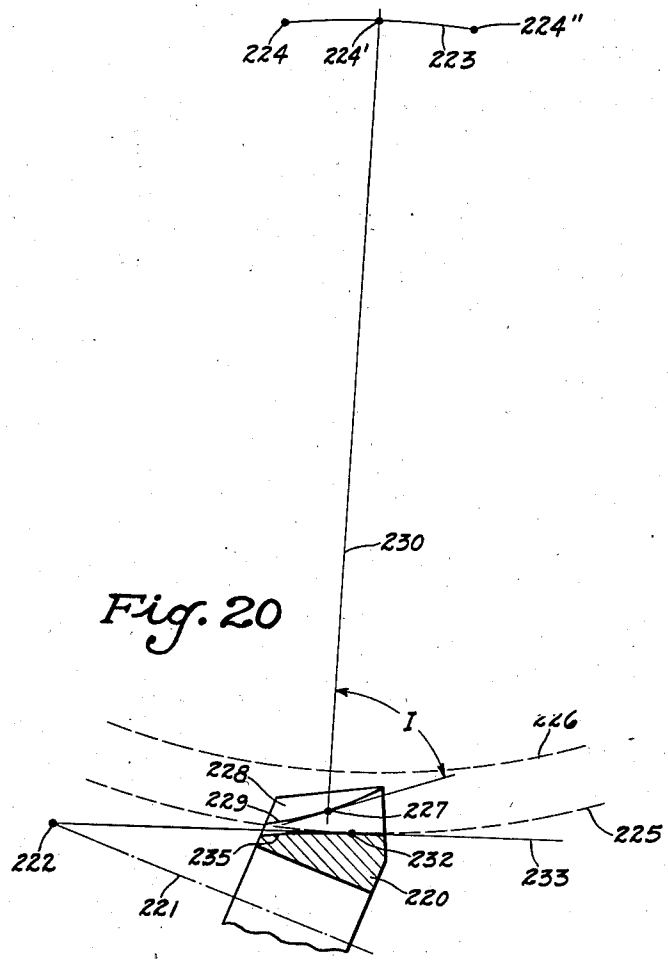


Fig. 20

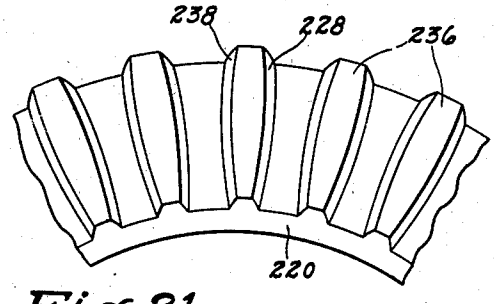


Fig. 21

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Patented May 22, 1945 2,376,465

UNITED STATES PATENT OFFICE

2,376,465

METHOD AND MACHINE FOR PRODUCING GEARS

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

Application July 9, 1941, Serial No. 401,631

25 Claims. (Cl. 90—9)

The present invention relates to a method and machine for producing gears and particularly to a method and machine for rough-cutting straight bevel gears.

Various processes have been employed heretofore for roughing straight bevel gears.

For manufacturing work, it has been customary to use a disc milling cutter of large diameter, and to rough each tooth slot simply by rotating this cutter in engagement with the blank while holding the blank stationary on its axis and while effecting a relative depthwise feed movement between the cutter and blank until the tooth space has been roughed to the proper depth. Corresponding side-cutting edges of the blades of such a cutter have been made of the same profile shape, the shape being such as would cut as close as possible to the desired profile shape all along the tooth space without cutting the profile away too far at any point along the length of the tooth space. This process is fast but it cuts tooth slots with concave bottoms and these tooth spaces do not taper in width from end to end, as is required in bevel gears. Moreover, at any point along the length of the tooth space, the tooth profiles only approximate the required finished tooth shape. There is, therefore, a considerable amount of stock left on the roughed tooth spaces to be removed in the finishing operation.

For jobbing work, it is common to employ a smaller size disc milling cutter and to rough the tooth slots by rotating the cutter in engagement with the gear blank while moving the cutter lengthwise of the tooth space from one end of the space to the other. A depthwise feed movement between cutter and blank may or may not be effected, in addition, depending upon the size and pitch of the gear to be roughed. This process produces tooth slots having straight bottoms but it is slow and the tooth slot produced is of uniform width from end to end instead of tapering width. Moreover, the tooth profiles produced only approximate the finished profile shape at any point along the length of the tooth space.

For jobbing work, it is also common to rough straight bevel gears with reciprocating planing tools. The tools are reciprocated across the face of the gear blank in straight paths which converge at an angle corresponding to the angle of longitudinal convergence of the sides of the tooth surfaces being cut. The tools cut in adjacent tooth spaces of the blank and by indexing the blank from tooth to tooth, tooth spaces may be roughed out which taper properly in width from end to end and which have straight bottoms, but unless a generating roll is employed, the tooth profiles produced are only approximate. Moreover, the process is slow.

In my pending application, Serial No. 181,177, filed December 22, 1937, now Patent No. 2,267,181, issued December 23, 1941, I have described a method for cutting straight bevel gears with tooth spaces that taper properly in width and depth from end to end and that have straight tooth bottoms and correct tooth profile shapes, and in the pending joint application of Clarence T. Galloway and myself, Serial No. 215,188, filed June 22, 1938, now Patent No. 2,288,058, issued June 30, 1942, there is described a machine for practicing this process. In this process, a disc milling cutter of large diameter is used which has a plurality of cutting blades arranged part way only around its periphery with a gap between the first and last blades. The blades are made with side-cutting edges of uniform circular arcuate profile shape, but the centers of curvature of corresponding successive side-cutting edges are displaced from one another so that the cutter has, in effect, a progressively varying effective profile shape. Cutting of a tooth space is effected by rotating the cutter in engagement with the gear blank while moving the cutter lengthwise of a tooth space of the blank from one end of the tooth space to the other in such timed relation with the cutter rotation that different blades of the cutter cut at different points along the length of the tooth space during a revolution of the cutter. A tooth space is completed when the cutter has made one revolution, and the blank is indexed when the gap in the cutter is abreast of the blank. The process may be used for roughing, but is intended primarily for cutting a blank complete from the solid, and the cutter is therefore ordinarily provided with both roughing and finishing blades. A tooth space is then roughed during movement of the cutter from one end of the space to the other in one direction and is finished on the return movement of the cutter. The process is very fast but it is suited only to large production jobs where the number of gears to be cut is such as to justify the use of the highly specal and costly cutter required.

A primary object of the present invention is to provide a method and machine for roughing straight bevel gears, with tooth spaces tapering in depth and width from end to end and having straight bottoms and profiles very closely approaching the finished tooth shapes required, which will be fast and at the same time relatively flexible.

A further object of the invention is to provide a method for rough-cutting straight bevel gears in which both sides of a tooth space may be cut simultaneously with a single disc milling cutter and with tooth shapes very closely approximating the finished tooth shapes required.

A further object of the invention is to provide a process for cutting straight bevel gears wherein the principles underlying the method of my prior application No. 181,177 may be used but in which a cheaper cutter may be employed and the method used will have greater flexibility so that a single cutter may be employed economically in the cutting of various sizes and types of straight bevel gears.

A further object of the invention is to provide a very simple form of machine for cutting straight bevel gears with a milling cutter in which a single rotary motion may be employed both to revolve the cutter and feed it lengthwise of the tooth slot being cut so as to produce a tooth slot having a straight bottom.

Other objects of the invention will be apparent hereinafter from the specification and from the recital of the appended claims.

With the present invention, a disc milling cutter is used that has a plurality of radially disposed cutting blades arranged completely around its periphery. These blades are preferably of circular arcuate profile shape and corresponding side-cutting edges of the blades are preferably made of the same curvature but the centers of curvature of successive corresponding side-cutting edges are displaced from one another so that successive corresponding side-cutting edges have progressively different inclinations to a plane of rotation perpendicular to the axis of the cutter and the cutter has a progressively varying effective cutting contour. In the cutting of a tooth space of a gear, the cutter is rotated in engagement with the gear blank while being fed back and forth across the face of the blank from one end of the tooth space to the other and while being simultaneously fed into depth. The rotation of the cutter is so timed to the lengthwise feed movement that during a revolution of the cutter each blade cuts at one specific point only, lengthwise of the tooth. In the preferred embodiment, the cutter makes one revolution for a complete back and forth movement along the length of a tooth space. The cutter, however, makes several passages back and forth across the face of the blank during the cutting of a single tooth space, being fed all the while into depth so that on successive passages it cuts deeper and deeper into the tooth space until full depth is reached. Then the cutter is withdrawn from engagement with the blank and the blank is indexed.

One of the novel features of the invention is the arrangement whereby a single rotary motion is employed to produce both the rotation of the cutter and its feed motion back and forth across the face of the blank. To this end the cutter is mounted on the cutter spindle of the machine, eccentrically of the axis of rotation of that spindle, and the resulting eccentric motion of the cutter causes the cutter to travel back and forth across the face of the blank as the cutter spindle revolves. The eccentricity of the cutter is adjustable to adjust the length of cutter stroke. To cut a tooth space with a straight bottom, the work must be moved relatively toward and from the cutter during the cutter spindle rotation, and this motion must be a harmonic motion in time with the cutter spindle rotation. This harmonic motion may be effected by a relative depthwise movement of the work, but in the preferred form of cutting machine is effected by movement of the cutter itself. It is produced without separate cams by mounting the cutter spindle in a slide and providing means that is connected to the cutter to constrain the slide to move inwardly and outwardly with the rotation of the cutter spindle. Thus as the cutter spindle rotates, the cutter center itself is constrained to move in a straight line parallel to the root line of the tooth space being cut. In the preferred form of machine, the depth of the tooth space is controlled by a feed cam which is driven in time with the cutter spindle so that the cutter spindle makes an integral plural number of revolutions and the cutter makes a plurality of passages back and forth across the face of the blank in one revolution of the feed cam. The feed cam is so constructed as to effect a relatively slow depthwise feed movement of the slide in which the cutter spindle is journaled, during the cutting of a tooth space, and when the tooth space has been cut to full depth, the cam permits withdrawal of the slide and cutter through operation of a spring so that the gear blank may be indexed.

In the drawings:

Figs. 1 to 5 inclusive are diagrammatic views, illustrating the principles underlying the process of the present invention;

Fig. 6 is a diagrammatic view, illustrating the preferred construction of a cutter used for practicing the present invention, and showing three different blades of this cutter superimposed on one another;

Fig. 7 is a perspective view of a machine built according to a present preferred embodiment of the invention;

Fig. 8 is a vertical sectional view through the cutter end of this machine;

Fig. 9 is a part plan, part horizontal sectional view of the parts shown in Fig. 8;

Fig. 10 is a fragmentary sectional view on the line 10—10 of Fig. 8;

Fig. 11 is a fragmentary sectional view on the line 11—11 of Fig. 8;

Fig. 12 is a sectional view on the line 12—12 of Fig. 9;

Fig. 13 is a view looking at the rear end of the work head of the machine, parts being broken away and shown in section;

Fig. 14 is a horizontal sectional view on the line 14—14 of Fig. 13;

Fig. 15 is a diagrammatic view, illustrating the drive to the various parts of the machine;

Figs. 16 to 19 inclusive are diagrammatic views, illustrating the operation of the machine shown;

Fig. 20 is a diagrammatic view, illustrating the cutting action of a tool when cutting a gear according to the present invention, and further showing how a localized tooth bearing may be produced; and

Fig. 21 is a fragmentary plan view of a bevel gear cut according to the present invention with crowned teeth for localization of tooth bearing.

As already stated, the cutter used in the present invention is preferably provided with cutting blades whose side-cutting edges are of concave circular arcuate profile shape but the centers of curvature of the successive corresponding profiles are displaced from one another axially and radially of the cutter axis. This construction is illustrated diagrammatically in Fig. 6. Here the

blades, which are to cut at the small end, the center, and the large end, respectively, of a tooth space, are shown superimposed on one another. The opposite side-cutting edges of the blade, which is intended to operate in the small end of the tooth space, are shown in dotted lines and denoted at **20** and **20'**, respectively. Opposite side cutting edges of the blade, which is intended to operate at a point midway the length of a tooth space, are denoted at **21** and **21'**, respectively, and are shown in full lines. Opposite side cutting edges of the blade, which is intended to operate at the large end of the tooth space, are shown in dotted lines and are denoted at **22** and **22'**, respectively. Ordinarily the cutting surfaces on the two sides are made symmetrical with reference to a median plane **23** perpendicular to the axis of the cutter.

Corresponding side-cutting edges **20**, **21**, **22**, etc. of the blades have the same radii r of curvature, and likewise the corresponding opposite side-cutting edges **20'**, **21'**, **22'**, etc. have the same radii of curvature. The centers of curvature of corresponding side-cutting edges of successive blades are, however, displaced from one another. Thus the center of curvature of the side-cutting edge **20** may be at **24** on the line **27**, the center of curvature of the side-cutting edge **21** may be at **25**, and the center of curvature of the side-cutting edge **22** may be at **26**. The centers of curvature of successive corresponding side-cutting edges may be displaced from one another at a varying rate. The blades are preferably all made of the same height, as shown in Fig. 6, but they may be made of progressively varying height.

In cutting a gear with the process of this invention, the cutter C is mounted so that its center y is offset from the turning center x of the cutter, that is, from the axis of the cutter spindle, and the amount of offset is equal to one half of the desired lengthwise feed movement of the cutter, which amount is, of course, determined by the width of face of the gear to be cut. During cutting, then, the center y of the cutter describes a circle E about the turning center x.

In Figs. 1 to 5 inclusive, the gear blank that is to be roughed, is designated at B. Its axis is denoted at A and its apex at P. The gear blank is, of course, adjusted to its root angle R (Fig. 3), and is also adjusted in the direction of the arrows **28** and **29** in accordance with the mean cone distance of the work and the desired depth of tooth to be cut. In Figs. 1 to 5 inclusive, it is assumed that the depthwise feed movement for producing the depth of tooth space is imparted to the work and that the harmonic motion for producing a straight tooth surface bottom is also imparted to the work.

Fig. 1 shows the start of the roughing cut. Fig. 2 shows a phase of the roughing operation before full depth is reached. Fig. 3 shows the cutter at full depth position with the cut being taken at the small end of the tooth space; Fig. 4 shows the cutter at full depth position with the cut being taken at a point midway the length of the tooth space; and Fig. 5 shows the cutter at full depth position with the cut being taken at the large end of the tooth space. The peripheral cutting surface of the cutter is denoted at **31**. The cutter is assumed to be rotating in the direction of the arrow **32** throughout the whole of the cutting operation.

In Figs. 1 to 5, it will be seen that as the cutter revolves about the axis x from a position such as shown in Fig. 1 to a position such as shown in Fig. 2, its peripheral cutting surface **31** will first be moved inwardly towards the blank and then outwardly away from the blank. Likewise, as the cutter rotates about the axis x from the position shown in Fig. 2 back to the position shown in Fig. 1, its peripheral surface **31** will first move further outwardly away from the blank and will then be moved inwardly again. If the axis x is fixed, then, this means that the work must have a movement away from the axis x as the cutter moves inwardly and towards the axis x as the cutter moves outwardly if a straight tooth space bottom is to be cut in the blank.

The necessity for and character of this relative harmonic motion is illustarted quite clearly in Figs. 3 to 5 which illustrate what takes place when the cutter is cutting at full depth. In the position shown in Fig. 3, the peripheral surface **31** of the cutter is tangent to the root line **30** at the small end of the tooth space. As the cutter revolves about the axis x from the position shown in Fig. 3 to the position shown in Fig. 4, the cutter center y moves through an angle of 90° on the circle E circumscribed about the axis x. This causes the periphery of the cutter to move inwardly toward the blank. To maintain the root line **30** of the tooth space tangent to the peripheral surface **31** of the cutter and cause the cutter to cut further along the length of the tooth space, the work is moved outwardly away from the cutter in the direction of the arrow **29** to the position shown in Fig. 4. In this position, the periphery of the cutter is tangent to the root line of the work at a point midway of the length of the tooth space. As the cutter revolves about the fixed center x from the position shown in Fig. 4 to that shown in Fig. 5, the cutter moves away from the work again and to maintain the root line **30** of the work in tangency with the periphery **31** of the cutter, and cause the cutter to cut further along the length of the tooth space, the work is moved inwardly again to the position shown in Fig. 5 which is the same position that the work occupies in Fig. 3.

Ordinarily after the cutter has made one passage across the face of the blank at full depth position, the work will be withdrawn from engagement with the cutter and indexed. During feed into full depth position, however, the cutter will make several passages back and forth across the face of the blank, revolving continuously in the same direction and cutting on both its forward and return passages across the face of the blank. On each return passage, the cutter climb-cuts.

To understand the complete cycle of operation, then, it will be assumed that the cutter continues to cut as it revolves from the angular position shown in Fig. 5 back to the the angular position shown in Fig. 3. Such a cut might actually be employed were it desired to obtain a fine finish.

During the first 90° of its rotation from the position shown in Fig. 5, the cutter will continue to move away from the work. To maintain the root surface **30** of the tooth space in tangency to the peripheral surface **31** of the cutter and cause the cutter to cut back along the length of the tooth space toward the small end thereof during this part of the cutter rotation, the work must be moved further into the cutter. Finally, as the rotation about the axis x causes the cutter to return to the position shown in Fig. 3, the cutter moves toward the work again. To maintain tangency between the root line of the blank and the periphery of the cutter during this part of the cutter rotation and to cause the cutter to

cut on to the small end of the tooth space, the blank is again fed away from the cutter.

The described motion of first outward and then inward movement of the work relative to the cutter takes place on each revolution of the cutter as the cutter is being fed into full depth position. It is a harmonic motion at the rate of once per revolution of the cutter. This harmonic motion causes the cutter to cut a straight tooth bottom in the blank. The depth feed required to cut the desired depth of the tooth space is added to this harmonic motion until full depth position is reached. This depth feed may also be in the direction of the arrow 29. The depth feed ceases when full depth position is reached, but the harmonic motion goes on until the cutter has swept the full length of the tooth space from the position shown in Fig. 3 to the position shown in Fig. 5. The depth feed may then be reversed and the work be moved clear of the cutter and indexed. This may be done during the half revolution of the cutter which takes place between the position of the cutter shown in Fig. 5 and the position of the cutter shown in Fig. 1. Then the cycle begins anew.

In the machine which is illustrated in the drawings for practicing the invention, the harmonic motion is imparted to the cutter instead of to the work and the cutter spindle is not fixed but is mounted in a slide that is reciprocable toward and from the work. The harmonic motion is imparted to this slide. The depthwise feed movement is also imparted to the cutter and slide. Reference will now be had to Figs. 7 to 19 inclusive for a description of this machine.

40 denotes the base or frame of the machine. The base is formed on its upper face with parallel longitudinal ways 41 and 42 (Figs. 7 and 11) and with parallel longitudinal ways 43 and 44 (Fig. 7). The slide 45 (Figs. 7, 8, 9, and 11) is mounted to reciprocate on the ways 41 and 42. The cutter spindle 46 (Fig. 8) is journaled in this slide. Mounted on the ways 43 and 44 for adjustment toward and away from the cutter is a slide 50 (Fig. 7). Mounted on the slide 50 is a plate 51. Mounted on the plate 51 is the work head 52. The work spindle 53 is journaled in the work head 52.

The slide 50 has an inclined upper face as shown clearly in Fig. 7. This face slants downwardly toward the cutter end of the machine. The plate 51 has a complementarily inclined lower face. The plate 51 is adjustably mounted on the slide 50 for adjustment in two directions at right angles to one another. By adjustment of the plate toward and from the cutter end of the machine, the height of the work spindle can be raised or lowered. This adjustment is provided to permit of control of the tooth profile shapes of the gears being cut and to permit of cutting straight tooth hypoid gears. The adjustment of the plate 51 laterally of the slide 50 is for the purpose of adjusting the work in accordance with the mean cone distance of the gear to be cut. Both adjustments are effected manually, and after adjustment, the plate 51 is secured to the slide 50 by T-bolts 55. These bolts pass through elongated slots 56 in the plate 51 and their heads engage in the transverse T-slots 57 formed in the upper face of the slide 50. The slots 56 extend at right angles to the slots 57.

The work head 52 is mounted on the plate 51 for angular adjustment about an axis that extends at right angles to and intersects the axis of the work spindle. This adjustment is for the purpose of setting the work to its root angle. This adjustment is effected manually, and, after adjustment, the work head is secured to the plate 51 by T-bolts 58 whose heads engage in arcuate T-slots 59 formed in the upper face of the plate 51.

As already stated, the cutter spindle 46 is journaled in the slide 45. This slide is held on the ways 41 and 42 simply by its own weight. It is prevented from lifting off of the ways 41 and 42 by washers 60 (Fig. 11). These washers are mounted on screws 61 that thread into the base 40 of the machine and they are held by spacer sleeves 62 so that their under faces just clear the tops of the recesses 63 in the slide 45 in which the heads of the screws 61 lie.

The cutter spindle 46 is provided at its upper end with an enlarged head 65. The periphery of this head may be concentric of the axis x of the cutter spindle, but in order to get as large a head as possible without having undue overhang of the cutter, the periphery of this head 65 is preferably made eccentric of the axis x of the cutter spindle, as shown. There is a plate 66 keyed to the enlarged head 65 of the spindle 46 by an elongated key 67 that fits in the slot 68 formed in the upper face of the head 65 (Figs. 8 and 10). The plate 66 is formed with a nose portion 69 which is adapted to enter the bore of the cutter C which is to be used on the machine.

The cutter shown is a disc milling cutter of the inserted blade type and has a plurality of radially disposed cutting blades 71 arranged completely around its periphery. Each blade may be formed with two opposite side-cutting edges, but preferably each blade is formed with a single side-cutting edge and alternate blades are provided with opposite side-cutting edges. The blades are relieved on their sides and tips back of their front faces and may be relieved by any suitable relieving process such as, for instance, the process described in the U. S. patent to Leonard O. Carlsen, No. 2,246,503, issued June 24, 1941. The blades are secured to the cutter head 70 by screws 72.

The plate 66 is mounted on the head 65 for lateral adjustment relative thereto to adjust the eccentricity of the cutter. For the purposes of effecting this lateral adjustment, there are two adjusting screws 74 and 75 threaded into the plate 66 to engage the periphery of the head 65 at diametrically opposed points. To permit effecting this adjustment accurately, there is a graduated scale 81 (Fig. 10) secured to one of the screws 76. This scale is adapted to slide in a slot 82 formed therefor in the upper face of the plate 66 and is adapted to be read against a zero mark inscribed on the upper face of the plate 66.

The plate 66 is secured to the head 65, after adjustment, by screws 76 which pass through elongated slots 79 formed in both the plate 66 and the head 70 of the cutter and which thread into the head 65. The cutter is secured to the plate 66 by these screws 76 and by the clamping disc 77 and bolt 78.

The plate 66 is journaled by means of the needle bearings 80 in a yoke-member or arm 83. The rear end of this arm 83 is formed with a convexly curved contact portion or face 89. This contact face 89 engages the front face of a hardened block or abutment 90 (Figs. 8 and 9) that is secured by screws 91 to a lever arm 92. The lever arm 92 is pivotally mounted by means of the pin 93 in the frame of the machine.

Adjustably mounted on the rear face of the lever arm 92 is a block 95. This block is ad-

justed on the lever arm 92 radially of the pivot 93 by means of a screw 96. This screw is journaled in a lug 97 that is integral with the lever arm 92, and it threads into a nut 98 which is secured in any suitable manner in a hole bored in the block 95. The block 95 is secured to the lever arm 92 in any adjusted position by means of a T-bolt 99 whose head engages in a T-slot 100 formed in the rear face of the lever arm 92. There is a contact block 102 secured to the block 95 by means of a screw 103. This block has a convex rear face and engages a hardened plate 104 that is fastened in any suitable manner to lever arm 105. This lever arm is pivotally mounted in the frame of the machine by means of a pin 106.

Journaled on a pin 108, that is mounted in the lever 105, is a rotatable roller 107. This roller is adapted to engage and ride on the periphery of the cam 110. The cam 110 is the feed cam of the machine and controls the depth of the tooth slots which are to be cut in a given gear blank. The cam shown is so formed as to make one revolution for each tooth slot which is to be cut, and, during a revolution, the cam feeds the cutter into the gear blank being cut until full depth position is reached and then permits withdrawal of the cutter from engagement with the blank so as to allow indexing of the blank.

The motion produced by the cam 110 is transmitted to the tool slide 45 and cutter C through the lever 105, plate 104, contact block 102, plate 95, lever 92, contact block 90, arm 83, bearings 80, head 66, screws 74 and 75, head 65, and spindle 46. The roller 108 is held in engagement with the cam 110, the hardened block 102 is held in engagement with the hardened plate 104, and the convex end face 89 of the arm 83 is held in engagement with the hardened plate 90 by a lever 115 and a coil spring 116.

The lever 115 is pivoted by means of the pin 117 in the base or frame of the machine. It is bifurcated at one end and is formed with ears 118 and 119 that engage around pins 87 and 88 that are formed integral with the arm 83. At its opposite end, the lever 115 is pivotally connected by means of the pin 120 with the head 121 of a plunger 122. This plunger is mounted in a sleeve 123 that is secured by means of the nut 124 in the base or frame of the machine. The coil spring 116 is mounted to surround the plunger 122 and is interposed between the head 121 of this plunger and a nipple 125 whch is mounted in a recess in the sleeve 123 and surrounds the plunger 122.

The feed cam 110 rotates on a relatively fixed axis. At any instant in its rotation, then, the point of its contact with the roller 107 is, therefore, fixed. Hence as the cutter spindle 46 revolves, the eccentrically disposed plate 66 causes the slide 45 to move back and forth on the ways 41 and 42. This motion is in addition to and superimposed upon the depthwise displacement of the slide 45 under actuation of the feed cam. The back and forth movement of the slide 45 causes the center y of the cutter to travel back and forth parallel to the root line of the tooth space being cut so that the cutter will cut a straight bottomed tooth space.

This is clearly illustrated in Figs. 16 to 19 inclusive. Here G is the gear to be cut. Its axis is denoted at 130 and its apex at 131. The structure of the cutter end of the machine is only illustrated diagrammatically in these figures. x again denotes the axis of the cutter spindle 46 which is journaled in the slide 45. y again denotes the axis of the cutter itself which is secured to the plate 66 that is rotatably mounted in the yoke-member or arm 83. This arm has, as described, a convex contact surface 89 at its inner end which engages with the front plane face of the hardened block or abutment 90 and the contact surface 89 is held against the block 90 by the coil spring 116.

As already pointed out, at any instant in the operation of the machine, the block 90 is relatively fixed, and for the purpose of analyzing the eccentric motion of the cutter, the block 90 will be considered fixed. Hence, as the cutter spindle 46 revolves, arm 83 is rocked from side to side, and the slide 45 and cutter spindle 46 are moved in and out. As the cutter spindle revolves from the position shown in Fig. 16 to that shown in Fig. 17, the slide 45 and the spindle 46 are moved rearwardly to their extreme rearward positions shown in Fig. 17, and the arm 83 is rocked from a position at the right of center to a central position so that the cutter travels from the small end of the tooth space to a point midway the length thereof. In the further rotation of the cutter spindle from the position shown in Fig. 17 to that shown in Fig. 18, the arm 83 is swung to the left, and the slide 45 and cutter spindle 46 move forwardly again so that the cutter is moved on to cut at the large end of the tooth. In the further rotation of the cutter spindle from the position shown in Fig. 18 to that shown in Fig. 19, the cutter begins to move back across the tooth face again, but the slide 45 continues to move forward to its extreme forward position shown in Fig. 19 and the arm 83 returns to central position again with the cutter again cutting on center at a point midway the length of the tooth space. In the further rotation of the cutter spindle from the position shown in Fig. 19 back to that shown in Fig. 16, the arm 83 is swung on to the right, causing the cutter to cut towards the small end of the tooth space, and the slide 45 moves rearwardly again. Thus it will be seen that in a revolution of the cutter, the arm 83 has a pendular movement, swinging from left to right and back again, and the slide 45 has a harmonic reciprocatary movement moving rearwardly and then forwardly and then rearwardly again. Further, it will be seen that during these movements of the arm 83 and slide 45, the center y of the cutter will travel in a path parallel to the front face of the block 90 and parallel to the root line of the tooth space being cut.

Of course, during the cycle of cutting a tooth space, the block 90 is advanced by the operation of the feed cam 110 through the levers 105 and 92 and their connecting parts. Thus, during its back and forth travel across the face of the blank, the cutter is fed into the tooth space to cut the tooth space to the full depth. When full depth position is reached, the roller 107 moves down off of the high part of the cam 110 on to the lowest part thereof again and the spring 116 operates to withdraw the cutter from engagement with the blank to permit of indexing the blank. In roughing, the cutter is preferably passed only once across the face of the blank at full depth position, simply moving from the small to the large end of the tooth during half a revolution of the cutter spindle. Then the cutter is withdrawn and the blank indexed dur-

ing the other half revolution of the cutter spindle.

The cutter spindle 46 is driven from the motor 135 (Fig. 15). The armature shaft 136 of this motor is coupled through a suitable coupling 137 to a bevel pinion 138 (Figs. 15 and 12). The pinion 138 meshes with a bevel gear 139 which is keyed to a shaft 140. The shaft 140 is suitably journaled in the base of the machine. It has a spur gear 141 fastened to its outer end and this spur gear meshes with a spur gear 142 which is secured to a shaft 143. The shaft 143 is suitably journaled in the base of the machine. It has a bevel pinion 144 mounted on it intermediate its ends. This bevel pinion meshes with a bevel gear 145 (Figs. 8 and 15). The bevel gear 145 is keyed to a shaft 146 that has a sliding splined connection with a spur pinion 147. The pinion 147 is suitably journaled in slide 45 and meshes with a spur gear 148 that is keyed to a shaft 149. The shaft 149 is suitably journaled in the same slide 45 and has integral with it a bevel pinion 150. The bevel pinion 150 meshes with the bevel gear 151 which is keyed to the cutter spindle 46.

The feed cam 110 is driven in time with the rotation of the cutter spindle so that the cutter spindle makes an integral number of revolutions during a cycle of operation of the machine. The drive to the feed cam 110 is from the shaft 143. This shaft has a spur gear 155 (Figs. 12 and 15) keyed to one end. This spur gear 155 forms one of a set of change gears of which the other members are denoted at 156, 157, and 158, respectively. Gears 156 and 157 are mounted on a stud or post forming part of a standard quadrant. The gear 156 meshes with the pinion 155 and the gear 157 meshes with the gear 158. The gear 158 is secured to shaft 160 which is suitably journaled in the base or frame of the machine. The shaft 160 has a worm 161 formed integral with it (Figs. 8, 12, and 15). The worm 161 meshes with a wormwheel 162 which is keyed to a vertical shaft 163. The vertical shaft 163 is suitably journaled in the base of the machine. The feed cam 110 is keyed to the upper end of this shaft 163. It seats against a shoulder on the shaft and is held against axial movement relative to the shaft by the nut 164.

In the machine illustrated in the drawings, a universal or worm and wormwheel type index mechanism is provided. This index mechanism is driven from a separate motor 170 (Figs. 14 and 15) which is mounted in the work head 52. During actual cutting of a tooth space, the work spindle is held stationary on its axis and is rotated only for indexing. Keyed to the armature shaft 171 of the motor 170 is a worm 172. This worm meshes with a wormwheel 173 (Figs. 13, 14, and 15) which is keyed to the sleeve portion 174 of a ratchet wheel 175. The ratchet wheel 175 and its sleeve 174 are journaled by means of the bushing 176 on a shaft 177. Keyed to the shaft 177 is a stop-plate 178. This stop plate surrounds the ratchet wheel 175 and is coaxial therewith. It is provided with a circumferential slot 179 within which is pivoted by means of the pin 180, a pawl 181. The pawl is adapted to be engaged periodically with the ratchet wheel 175 to transmit the motion of the motor 170 to the stop plate 178 and the shaft 177 to effect indexing of the work spindle.

The pawl 181 is urged constantly toward operative position by a spring-pressed plunger 182 which is housed in the stop plate 178 and which engages with the tail of the pawl. The pawl is held out of engagement with the ratchet wheel, during cutting, by means of a dog 184. This dog is pivotally mounted in the work head 52 by means of the pin 185. The dog is adapted to engage a lug 186 that is formed on the pawl.

The dog 184 serves, also, to prevent rotation of the stop plate 178 in one direction, for it is adapted to engage a shoulder formed on the periphery of the stop plate. Rotation of the stop plate in the opposite direction is prevented by means of a second dog 188. This second dog 188 engages a second shoulder formed on the periphery of the stop plate. The second dog is also keyed to the pin 185.

The two dogs 184 and 188 are normally pressed into position where they will engage the stop plate to prevent rotation thereof in opposite directions and where the dog 184 will engage the lug 186 of the pawl 181 to hold that pawl out of engagement with the ratchet wheel, by means of the spring pressed plungers 189 and 190, respectively. The dog 184 is moved out of operative position against the resistance of the spring pressed plunger 189 by a rod 192 which is pivotally connected at 193 to the dog 184 and which is integral with the plunger 194 of the solenoid 195.

The solenoid is operated periodically by the closing of a normally open switch 196 (Figs. 8 and 15) which is suitably mounted in the base of the machine. This switch is operated by a cam 197 that is secured in any suitable fashion to a plate 198 which is keyed to the same shaft 163 on which the feed cam 110 of the machine is mounted. Thus the switch 196 may be closed in time with the rotation of the feed cam so that when the cutter is withdrawn from the work at the end of the cutting of a tooth space of the gear blank, the switch 196 is closed to actuate the solenoid 195 to withdraw the dog 184 from operative position and allow the pawl 181 to engage the ratchet wheel 175 under actuation of the spring-pressed plunger 182, permitting motion to be transmitted from the motor 170 to the stop plate 178 and shaft 177. When the switch 196 is closed, the circuit is made to the solenoid 195 through the lines 199 and 199' (Fig. 15).

There is a spur pinion 200 (Figs. 13 and 15) fastened to the upper end of the shaft 177. This spur pinion forms one of a set of index change gears of which the other members are denoted at 201, 202, and 203. The gears 201 and 202 are mounted on a stub shaft forming part of a quadrant of usual construction. The gear 201 meshes with the pinion 200 and the gear 202 meshes with the gear 203. Gear 203 is keyed to a shaft 205 which is suitably journaled in the work head 52. There is a worm 206 integral with the shaft 205, and this worm meshes with a wormwheel 207 which is keyed to the work spindle 53. Thus when the pawl 181 is in engagement with the ratchet wheel 175, rotation is transmitted from the motor 172 to the work spindle 53 to index the work spindle through an angular distance determined by the index change gears 200, 201, 202, and 203. The cam 197 holds the switch 196 closed only for an instant and then allows the switch to open again so that when the stop plate 178 has made one revolution, the dog 184 is returned into engagement with the stop plate and with the ledge portion 186 of the pawl 181 to withdraw the pawl from engagement with the

ratchet wheel, and the indexing cycle is complete.

The plate 198 (Fig. 8) carries a cam 210 which operates the automatic stop mechanism of the machine. This may be in the form of an automatic stop 211 of any suitable construction. This stop mechanism is advanced once for each tooth space to be cut and, when all of the tooth spaces of the blank have been cut, operates to stop the motors 135 and 170, stopping the machine. The completed gear blank may then be removed from the machine and a new blank chucked.

The chucking mechanism may be of any suitable construction and forms no part of the present invention. The work head may be withdrawn from operative position for removal of the completed work piece or chucking of a new blank, and returned to operative position again, by hydraulically operated mechanism. The movements of the work head to and from chucking position, the clamping of the work head in operative position and the chucking of the gear blank may also be hydraulically controlled. These several hydraulically actuated mechanisms may be operated from a single valve controlled by a hand lever 215 (Fig. 7) in known manner. Any other suitable construction may, however, be employed.

The operation of the machine will readily be understood from the preceding description but may be briefly summed up here. First of all, of course, the work is adjusted for root angle, cone distance, and height position by adjustment of the work head 52, on the plate 51 and of the plate 51 on the slide 50. The depth feed of the cutter slide 45 is adjusted by adjustment of the block 95 (Fig. 9) on the lever 92, and the eccentricity of the cutter is adjusted by adjustment of the plate 66 on the head 65 of tool spindle 46. The work is then chucked and brought into operative relation with the cutter. Then the machine may be started. The work spindle is held stationary during cutting by engagement of the lock dogs 184 and 188 with the stop plate 178, the pawl 181 being held out of engagement with the ratchet wheel 175 by the dog 184. During operation of the machine, the cutter spindle 46 rotates continuously being driven from the motor 135 through the gearing 138, 139, 141, 142, 144, 145, 147, 148, 150, and 151 (Figs. 8, 12 and 15). This causes the cutter C to be rotated and to be moved back and forth across the face of the gear blank. Because the cutter is mounted eccentrically of the spindle 46 and because of the engagement of the arm 83 with the contact block 90, as the cutter spindle 46 rotates, a back and forth movement in a direction perpendicular to the root line of the blank is imparted to the slide 45 and to the cutter spindle. This causes the cutter to travel back and forth across the face of the gear blank as it rotates in engagement with the blank. Simultaneously the cutter is fed into the blank, under actuation of the rotating feed cam 110 to cut a tooth space to proper depth. The cutter makes several revolutions and several passages back and forth across the face of the blank while it is being fed into depth, the number of passages being controlled by the feed cam. The feed cam is, of course, rotated in time with the rotation of the cutter spindle through the gearing 155, 156, 157, 158, 161, and 162 (Figs. 8, 12, and 15). When the tooth space has been cut to full depth, the feed cam allows a quick withdrawal of the cutter away from the gear blank through operation of the spring 116 as the roller 107 rides down off of the high spot of the cam 110 onto the lowest portion thereof. When the cutter has been withdrawn, the cam 197 operates to close the switch 196 (Figs. 8 and 15) to actuate the solenoid 195. This causes the lock dog 184 to be withdrawn from engagement with the stop plate 178, allows the pawl 181 to drop into engagement with the ratchet wheel 175 and causes the work spindle 53 to be indexed through operation of the gearing 172, 173, the pawl 181 and ratchet wheel 175, shaft 177, gearing 200, 201, 202, 203, 206, and 207 (Figs. 13, 14, and 15). During indexing, the lock dog 188 ratchets idly over the periphery of the stop-plate 178. When the indexing has been completed, the work spindle 53 is again locked against rotation by return of the stop dog 184 into engagement with the pawl 181 and stop plate 178 under actuation of the spring pressed plunger 189. The cam 110 operates, then, to feed the cutter back into engagement with the gear blank and the cycle begins anew to cut a new tooth space of the gear blank.

Thus the operation proceeds, the cutter being revolved in engagement with the gear blank and passed back and forth across the face of the blank until a tooth space is cut, and then being withdrawn, and the blank indexed. When all of the tooth spaces of the blank have been cut, the cam 210 (Figs. 8 and 15) operates to trip the automatic stop mechanism 211 of the machine and the machine is stopped. Then the roughed gear may be taken off of the machine and a new blank chucked.

While the invention has been described particularly in connection with a process and machine for rough-cutting gears, it will be understood that this same process and machine may be employed for finish cutting, if desired. In this case, the blades of the cutter must be relieved quite accurately. This may be done by the process of relieving blades of "Revacycle" cutters.

In the machine described, it will be seen that adjustment of the block 95 (Fig. 9) on lever 92 varies the amount of the depth feed transmitted from the cam 110 to the feed lever 92, and that adjustment of the plate 66 with reference to the cutter spindle 46 by means of the screws 74 and 75 changes the amount of eccentricity of the cutter center with reference to the axis of the cutter spindle 46. Both the depth feed and the relative feed lengthwise of the teeth of the gear blank are therefore independently adjustable. This makes for great flexibility and is particularly valuable for jobbing work.

Now while the invention has been described in connection with use of a cutter that has blades of progressively different effective cutting action, it is to be understood that conventional milling cutters may also be used on the machine at reduced advantage, but still at an advantage as compared with bevel gear roughing machines of the prior art which employ conventional disc milling cutters. The advantage lies in the use of large cutters which take long sweeping cuts and in a combination in effect of depth feed and lengthwise feed so that long runouts are avoided. Ordinarily a cutter will be employed that has a diameter equal to twenty or more times the height of the gear teeth to be cut.

In the machine described, the plate 104 has a plane front face. It will be understood, however, that this plate may be slightly concave or made of any other desired shape. When a concave plate is used, the center of the cutter does not move exactly in a straight line lengthwise of a

tooth space but approaches a little closer to the work at both ends of the relative lengthwise feed movement. In other words, it is possible with such a plate to cut a little deeper at the tooth ends and thereby reduce the length of tooth bearing. In this way, it is possible to obtain a localized tooth bearing on the gear being cut so that when the gear is run with its mate, the pair may accommodate themselves readily to the variations in tooth loads and mountings that occur in practice.

Fig. 20 illustrates the operation of the cutter in cutting a gear with localized tooth bearing. Here **220** denotes the gear to be cut, **221** is its axis and **222** its apex. To produce a localized tooth bearing, a plate **90** may be used that has, as stated, a concave control surface. Then as the cutter spindle rotates and the slide **45** moves forward and back, the center of the cutter will travel in a concave path such as denoted at **223**, the concavity of this path depending, of course, upon the concavity of the control surface. **224** denotes a position of the cutter center when the cutter is cutting at the small end of the tooth; **224'** denotes the position of the cutter center when the cutter is cutting at the center of the tooth, and **224''** denotes the position of the cutter center when the cutter is cutting at the large end of the tooth. **225** and **226** denote the outside and inside circles, respectively, of the cutting blades when the cutter center is at the mean position **224'**. In this position, the mean point of contact between the cutter and the side tooth surface **228** of the gear is at **227**, while **229** is a line of contact between cutter and tooth surface for this mean position. It will be noted that, as already indicated, the line of contact **229** is inclined at an angle I of more than **45°** to the radius **230** of the cutter at the mean contact point **227**. **232** is the point of tangency between the outside circle **225** of the cutter and the root line **233** of the blank. When the cutter center is moved in a curved path **223**, as described, the bottom of the tooth space will be convex, as denoted at **235**, unless the blades of the cutter are varied in height to compensate for this condition.

Fig. 21 shows on a somewhat enlarged scale a gear cut to have crowned teeth according to the method of this invention. The teeth of the gear are denoted at **236**. As will be seen, opposite side tooth surfaces **238** and **238** of the teeth are longitudinally crowned. When such a gear is meshed with a mate cut in the same way or with a mate cut without crowning, it will mesh with the mate with a localized tooth bearing.

In general it may be said that while the invention has been described in connection with a particular embodiment thereof, it will be understood that it is capable of further modification and use and that 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 gear art 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. The method of producing a gear which comprises cutting each tooth space of the gear with a rotary disc milling cutter, that has a plurality of radially disposed cutting blades, by rotating said cutter about an eccentric axis while producing a relative reciprocatory movement between the cutter and the work in the direction of tooth depth in time with the cutter rotation and of a harmonic nature so that the cutter will move back and forth across the face of the work during a revolution, and periodically indexing the blank.

2. The method of producing a gear which comprises cutting each tooth space of the gear with a rotary disc milling cutter, that has a plurality of radially disposed cutting blades, whose corresponding side-cutting edges have different effective profile shapes, by rotating said cutter about an eccentric axis while producing a relative reciprocatory movement between the cutter and the work in the direction of tooth depth in time with the cutter rotating and of a harmonic nature so that the cutter will move back and forth across the face of the blank during a revolution, and effecting a relative depthwise feed movement between the cutter and blank to cut the tooth space to full depth, and then effecting a relative withdrawal movement between the cutter and blank, and indexing the blank.

3. The method of cutting a gear which comprises cutting each tooth space with a rotary disc milling cutter, that has a plurality of radially disposed cutting blades whose corresponding side-cutting edges are of the same circular arcuate profile shape but whose successive corresponding side-cutting edges are differently inclined to a plane of rotation perpendicular to the axis of the cutter, by rotating said cutter in engagement with a gear blank while effecting a relative reciprocatory motion of a harmonic nature between the work and the cutter in time with the cutter rotation in a direction perpendicular to the root line of the tooth space so that the center of the cutter travels back and forth in the direction of said root line during a revolution of the cutter, and periodically indexing the blank.

4. The method of cutting a straight tooth tapered gear which comprises cutting each tooth space with a rotary disc cutter that has a plurality of cutting blades disposed radially of a common axis whose corresponding side-cutting edges are of the same circular arcuate profile shape but whose successive corresponding side cutting edges are differently inclined to a plane of rotation perpendicular to the axis of the cutter, by rotating said cutter in engagement with a gear blank about an axis eccentric to said common axis while effecting a relative reciprocatory movement of a harmonic nature between the cutter and the work in time with the cutter rotation and in a direction perpendicular to the root line of the work, and periodically indexing the blank.

5. The method of cutting a straight tooth tapered gear which comprises cutting each tooth space of the gear with a rotary disc cutter that has a plurality of radially disposed cutting blades whose corresponding side cutting edges are of the same circular arcuate profile shape but whose successive corresponding side-cutting edges are differently inclined to a plane of rotation perpendicular to the axis of the cutter, by rotating said cutter on an eccentric axis while causing the center of the cutter, during rotation of the cutter, to reciprocate back and forth in a line parallel to the root line of the tooth space being cut at the rate of a reciprocation per revolution of the cutter, and effecting a relative depthwise feed movement between the cutter and blank, and periodically indexing the blank.

6. In a machine for producing gears, a work spindle, a tool spindle, a slide on which one of said spindles is mounted, a support on which the

slide is mounted for reciprocation in a direction at right angles to the axis of the tool spindle, a rotary disc milling cutter secured to the tool spindle with its center eccentric of the axis of said tool spindle, means for rotating the tool spindle, means for moving said slide back and forth in time with the cutter rotation at the rate of a reciprocation per revolution of the tool spindle, and means for periodically indexing the work spindle.

7. In a machine for producing gears, a work spindle, a tool spindle, a slide on which one of said spindles is mounted, a rotary disc milling cutter secured to said tool spindle with its center eccentric of the axis of said spindle, means for rotating the tool spindle, means for imparting to said slide a harmonic movement back and forth in a direction perpendicular to the root line of a tooth space of the gear in time with the cutter rotation during a revolution of the tool spindle, means for simultaneously imparting to said slide a movement of feed in the described direction and for periodically withdrawing said slide from cutting position, and means for periodically indexing the work spindle.

8. In a machine for producing gears, a work spindle, a tool spindle, a slide on which one of said spindles is journaled, a rotary disc milling cutter secured to said tool spindle with its center eccentric of the axis of said spindle, means for rotating the tool spindle to rotate the cutter, means responsive to the rotation of the cutter for effecting reciprocation of said slide in time with the cutter rotation and at the rate of a reciprocation per revolution of the tool spindle, and means for periodically indexing the work spindle.

9. In a machine for producing gears, a work spindle, a tool spindle, a slide on which the tool spindle is journaled, a plate secured to the tool spindle and having a peripheral surface eccentric of the axis of the tool spindle, a disc milling cutter secured to said plate with its center eccentric of the axis of the tool spindle, a yoke member connected to said plate to oscillate on rotation of said plate, a relatively fixed abutment co-acting with said yoke member to reciprocate said slide on oscillation of said yoke member, means for rotating the cutter spindle, and means for periodically indexing the work spindle.

10. In a machine for producing gears, a work spindle, a tool spindle, a slide on which the tool spindle is journaled, a plate secured to the tool spindle and having a peripheral surface eccentric of the axis of the tool spindle, a disc milling cutter secured to said plate with its center eccentric of the axis of the tool spindle, a yoke member connected to said plate to oscillate on rotation of said plate, a relatively fixed abutment co-acting with said yoke member to reciprocate said slide on oscillation of said yoke member, means for advancing said abutment to feed the cutter into depth, means for rotating the cutter spindle, and means for periodically indexing the work spindle.

11. In a machine for producing gears, a work spindle, a rotary disc milling cutter, means for rotating said cutter, means for moving the cutter back and forth across the face of a gear blank in time with and once per cutter rotation, means for producing a relative feed movement between the cutter and work to cut a tooth space of the gear to full depth and for then withdrawing the cutter from engagement with the work, means for driving the last named means in time with the cutter rotation so that the cutter makes a plurality of revolutions during a cycle of feed and withdrawal, and means for periodically indexing the work spindle.

12. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc cutter having a plurality of radially disposed cutting blades whose corresponding side-cutting edges are of the same arcuate profile shape but whose successive corresponding side-cutting edges are differently inclined to a plane of rotation perpendicular to the axis of the cutter, secured to said tool spindle, means for rotating the tool spindle, means for moving the tool spindle back and forth in time with the cutter rotation to pass the cutter back and forth across the face of the work, means for effecting a relative depthwise feed movement between the cutter and work to cut a tooth space of the work to full depth and for then withdrawing the cutter from engagement with the work, means for driving the last named means in time with the rotation of the cutter spindle so that the cutter makes a plurality of revolutions during a cycle of feed and withdrawal, and means for periodically indexing the work.

13. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc milling cutter secured to the tool spindle with its center eccentric of the axis of the tool spindle, a slide in which the tool spindle is journaled, a yoke member secured to the cutter to oscillate on rotation of the tool spindle, a relatively fixed abutment co-acting with the yoke member to reciprocate the slide on oscillation of the yoke member, said abutment having a plane active face extending parallel to the root line of the tooth space being cut, and means for rotating the tool spindle, and means for periodically indexing the work spindle.

14. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc milling cutter secured to the tool spindle with its center eccentric of the axis of the tool spindle, a slide in which the tool spindle is journaled, a yoke member connected to the cutter to oscillate on rotation of the tool spindle, a relatively fixed abutment co-acting with the yoke member to reciprocate the slide on oscillation of the yoke member, said abutment having a plane active face parallel to the root line of the tooth space being cut in the work, means for alternately advancing the abutment towards the work spindle to feed the cutter into depth and for periodically withdrawing the abutment through the amount of said advance, and means for indexing the work spindle after withdrawal of the abutment.

15. The method of cutting a gear which comprises cutting each tooth space with a rotary disc milling cutter, that has a plurality of radially disposed cutting blades whose corresponding side cutting edges are of the same concave profile shape but whose successive corresponding side cutting edges are differently inclined to a plane of rotation perpendicular to the axis of the cutter, by rotating said cutter in engagement with a gear blank about an axis eccentric of the cutter center while effecting a relative reciprocatory motion of a harmonic nature between the cutter and blank in time with the cutter rotation in a direction perpendicular to the root line of the tooth space so that the center of the cutter travels back and forth in the direction of said

root line during a revolution of the cutter, and periodically indexing the blank.

16. The method of producing a gear which comprises employing a disc milling cutter, that has a plurality of cutting blades disposed radially about a common center, and rotating said cutter in engagement with a gear blank about an axis eccentric of said center while constraining the cutter so that during rotation of the cutter its center moves from one end of a tooth space of the blank to the other in a path parallel to the root line of the tooth space, and periodically indexing the blank, the offset of the center of the cutter from its axis of rotation being equal to one-half the desired movement of the cutter lengthwise of the tooth space.

17. In a machine for producing gears, a work spindle, a tool spindle, a slide on which the tool spindle is journaled, a plate secured to the tool spindle and having a peripheral surface eccentric of the axis of the tool spindle, a disc milling cutter secured to said plate with its center eccentric of the axis of the tool spindle, a yoke member connected to said plate to oscillate on rotation of said plate, a relatively fixed abutment coacting with said yoke member to reciprocate said slide on oscillation of said yoke member, said abutment having a concavely curved active surface, means for rotating the cutter spindle, and means for periodically indexing the work spindle.

18. In a machine for producing gears, a work spindle, a tool spindle, a disc milling cutter secured to said tool spindle, a slide on which one of said spindles is mounted, means for rotating the tool spindle, means for reciprocating the slide to move the cutter back and forth lengthwise of a tooth space of the work, means for controlling said movement of the slide comprising a fixed abutment and a follower which is secured to the slide, said abutment having a curved surface so that the cutter will cut deeper at the ends of a tooth space than at the center thereof during movement of the slide, and means for periodically indexing the work.

19. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc milling cutter secured to the tool spindle with its center eccentric of the axis of the tool spindle, means for rotating the tool spindle, means for effecting a relative movement of a harmonic nature between the tool and work spindles in a direction perpendicular to the root line of a tooth space of the work and in time with the cutter rotation and at the rate of once per cutter revolution, and means for periodically indexing the work spindle.

20. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc milling cutter, that has a plurality of cutting blades disposed radially about a common axis, secured to the tool spindle with said axis eccentric of the axis of the tool spindle, means for rotating the tool spindle, and means operatively connected to the cutter to cause the axis of the cutter to move in a path parallel to the root line of a tooth space of the gear being cut as the tool spindle revolves.

21. In a machine for producing gears, a work spindle, a tool spindle, a rotary disc milling cutter, that has a plurality of cutting blades disposed radially of a common axis, secured to the tool spindle with said axis eccentric of the axis of the tool spindle, said cutter having blades all of the same height but corresponding side-cutting edges of said blades having progressively varying inclination to a plane perpendicular to the axis of the cutter, means for rotating the tool spindle on its axis, and means operatively connected to the cutter to cause the axis of the cutter to reciprocate once per revolution of the tool spindle in a path parallel to the root line of the tooth space of the gear being cut as the tool spindle revolves.

22. The method of cutting a gear which comprises cutting each of its tooth spaces with a rotary disc milling cutter that has a plurality of cutting blades disposed radially about a common center, by rotating said cutter in engagement with the work about an axis eccentric of the cutter center while constraining said cutter so that during its rotation its center moves from one end of the tooth space to the other in a path parallel to the root line of the tooth space.

23. The method of cutting a gear which comprises cutting each of its tooth spaces with a rotary disc milling cutter that has a plurality of cutting blades of curved profile shape and varying point-width which are disposed radially about a common center, by rotating said cutter in engagement with the work about an axis eccentric of said center while constraining the cutter so that during its rotation its center moves from one end of the tooth space to the other in a path parallel to the root line of the tooth space.

24. The method of cutting a gear which comprises cutting each of its tooth spaces with a rotary disc milling cutter that has a plurality of cutting blades of curved profile and varying point-widths which are disposed radially about a common center, by rotating said cutter in engagement with the work about an axis eccentric of said center while effecting relative movement between the cutter and work in the direction of tooth depth first inwardly and then outwardly as the cutter makes a revolution so that on each revolution, the cutter will travel from one end of the tooth space to the other and back.

25. In a machine for producing gears, a work spindle a tool spindle, a rotary disc milling cutter, that has a plurality of cutting blades disposed radially of a common axis, secured to the tool spindle with said axis eccentric of the axis of the tool spindle, the blades of said cutter being all of the same height but being of varying point-width, means for rotating the tool spindle on its axis, and means for effecting a relative reciprocatory movement between the tool and work spindles once for each revolution of the tool spindle in a direction perpendicular to the axis of the tool spindle so that on each revolution the cutter will travel from one end of a tooth space of the work to the other and back.

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