Oct. 7, 1941. E. W. MILLER 2,257,850

GENERATIVE GEAR GRINDING MACHINE

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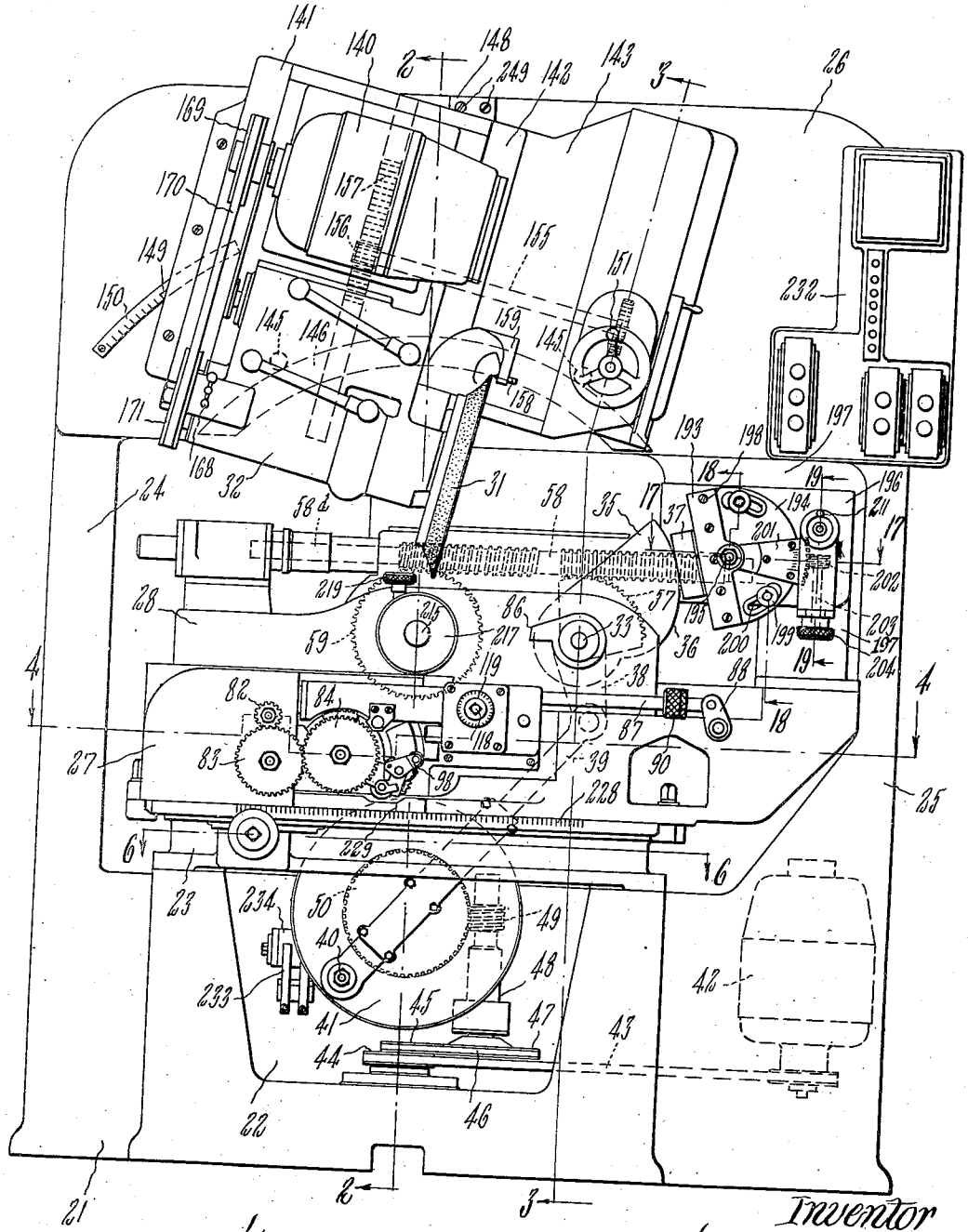


Fig. 1.

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GENERATIVE GEAR GRINDING MACHINE

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Fig. 2.

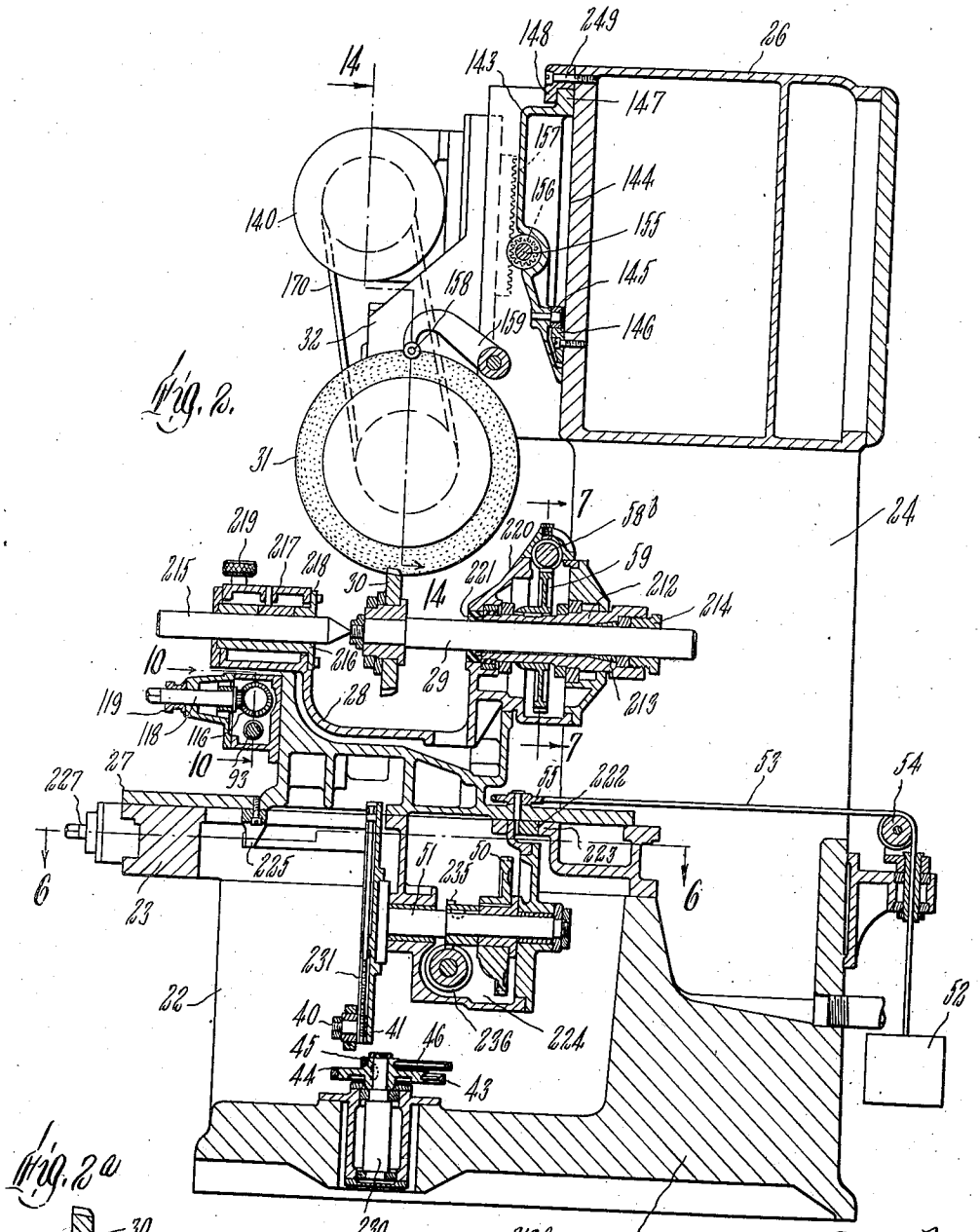


Fig. 2a

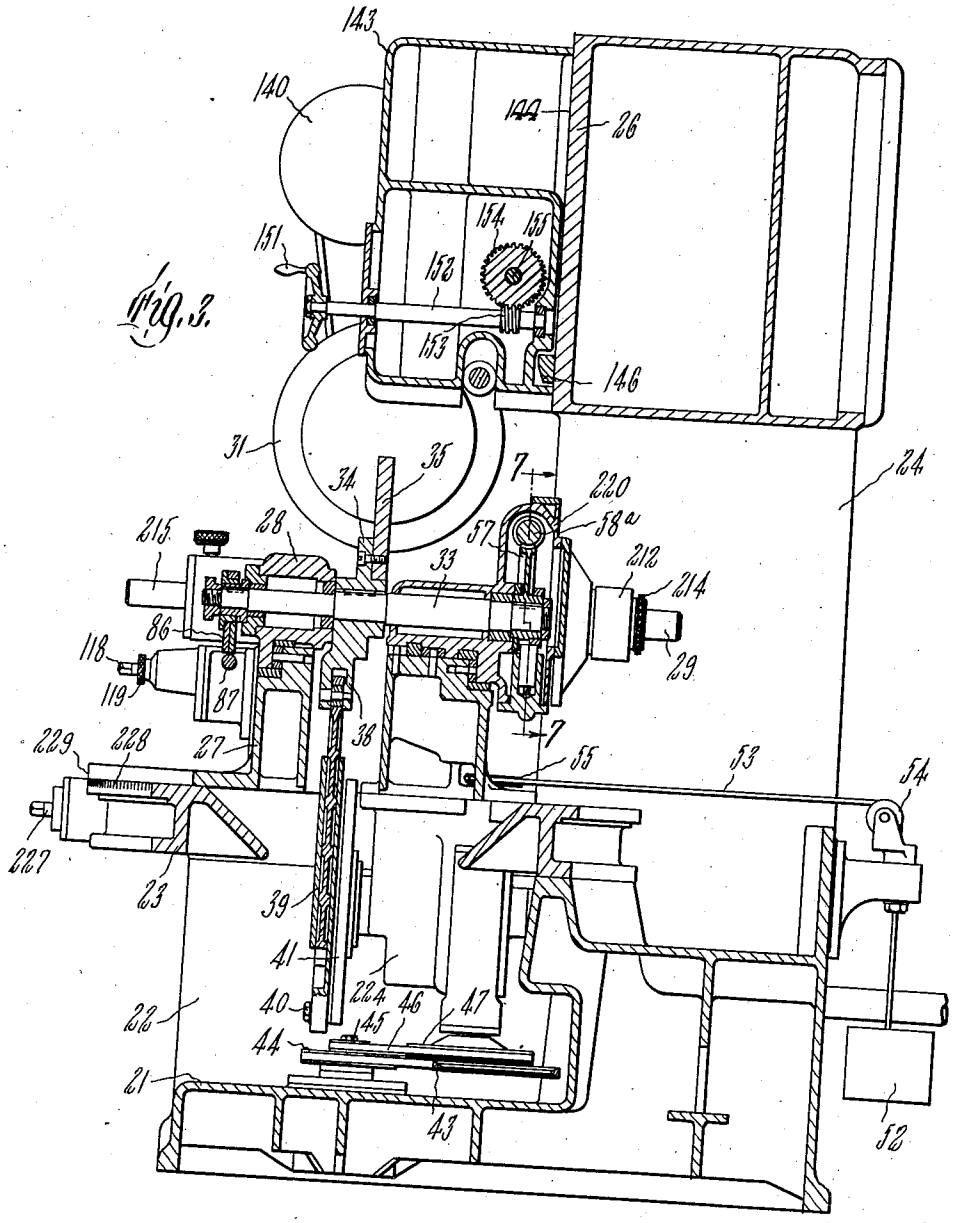
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GENERATIVE GEAR GRINDING MACHINE

Filed March 16, 1939 6 Sheets-Sheet 3

Fig. 3.



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GENERATIVE GEAR GRINDING MACHINE

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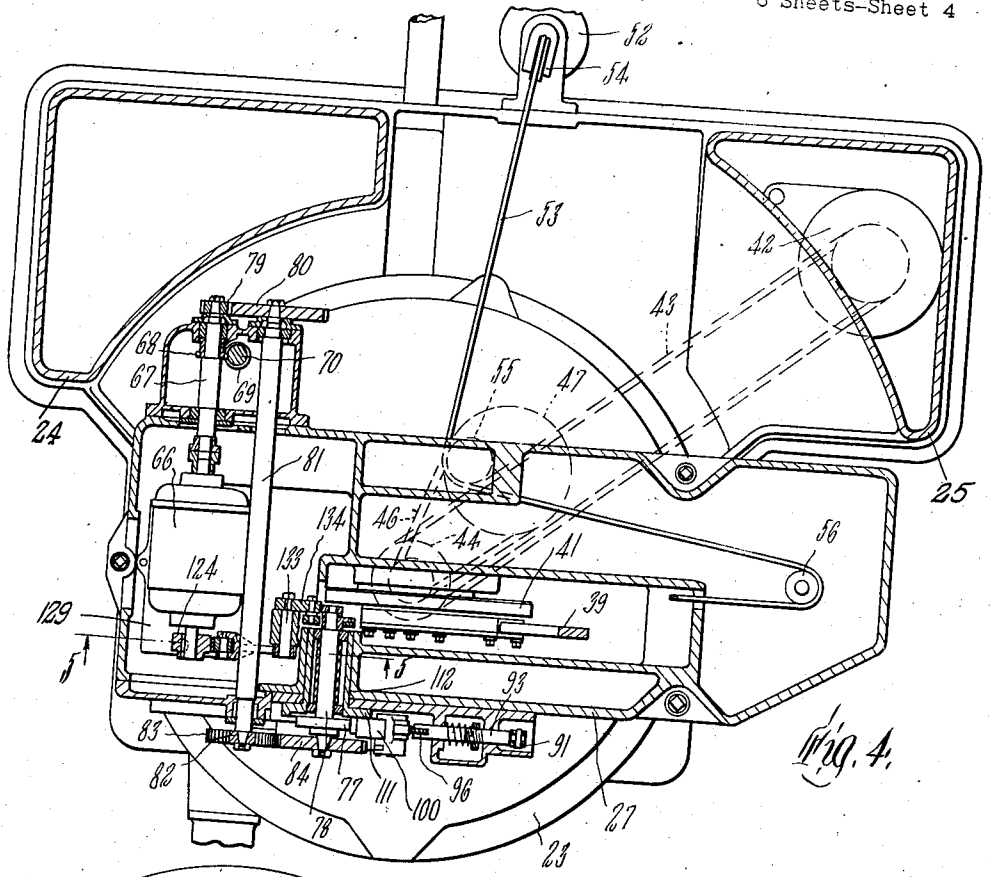


Fig. 4.

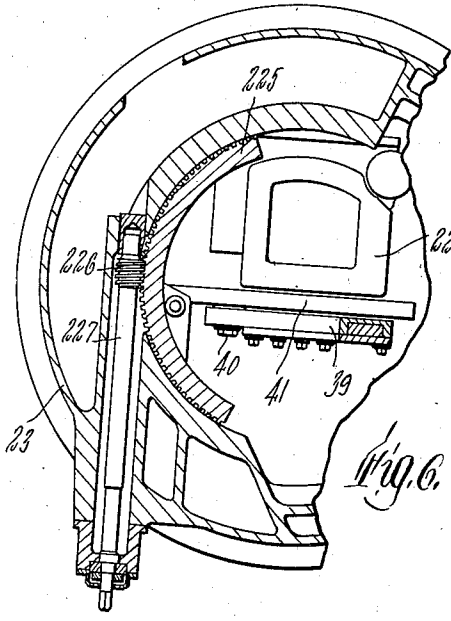


Fig. 6.

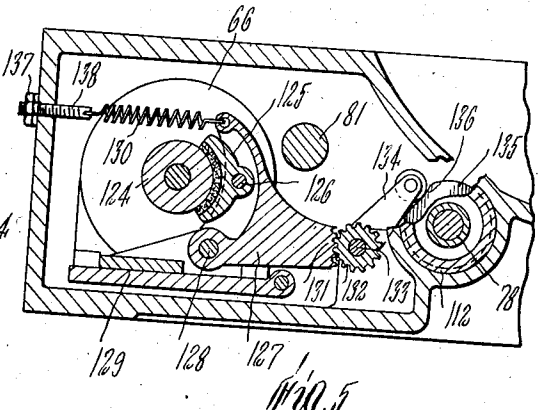


Fig. 5.

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GENERATIVE GEAR GRINDING MACHINE

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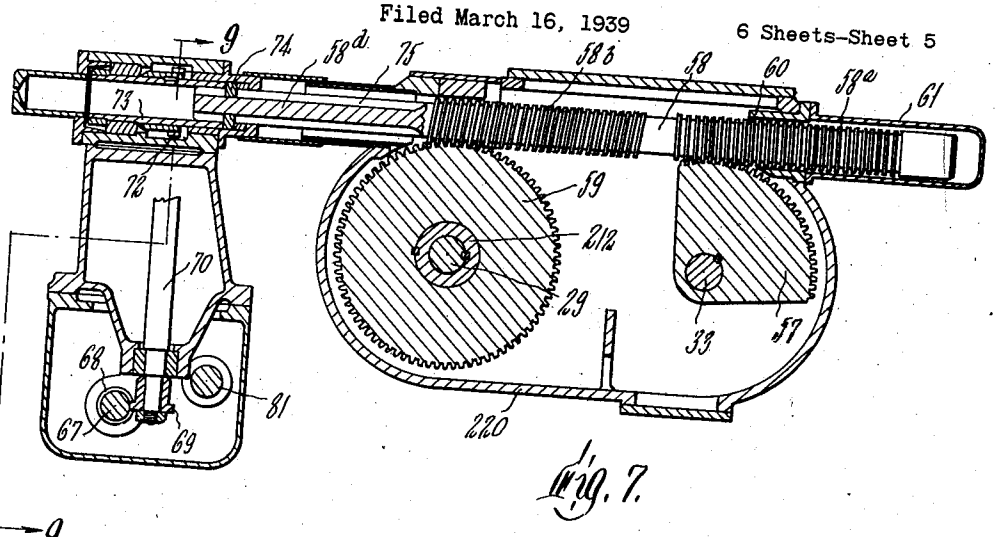


Fig. 7.

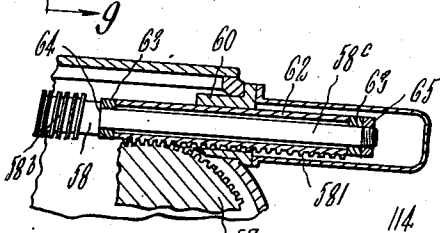


Fig. 8.

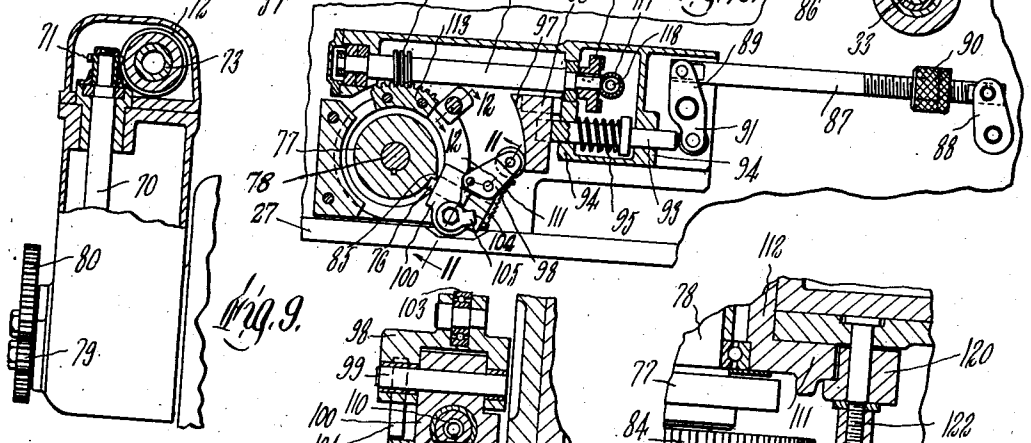


Fig. 9.

Fig. 10.

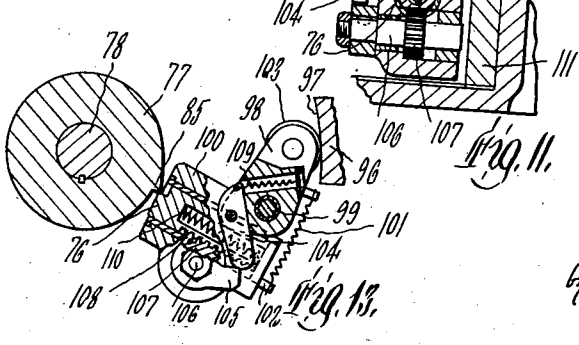


Fig. 11.

Fig. 12.

Fig. 13.

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GENERATIVE GEAR GRINDING MACHINE

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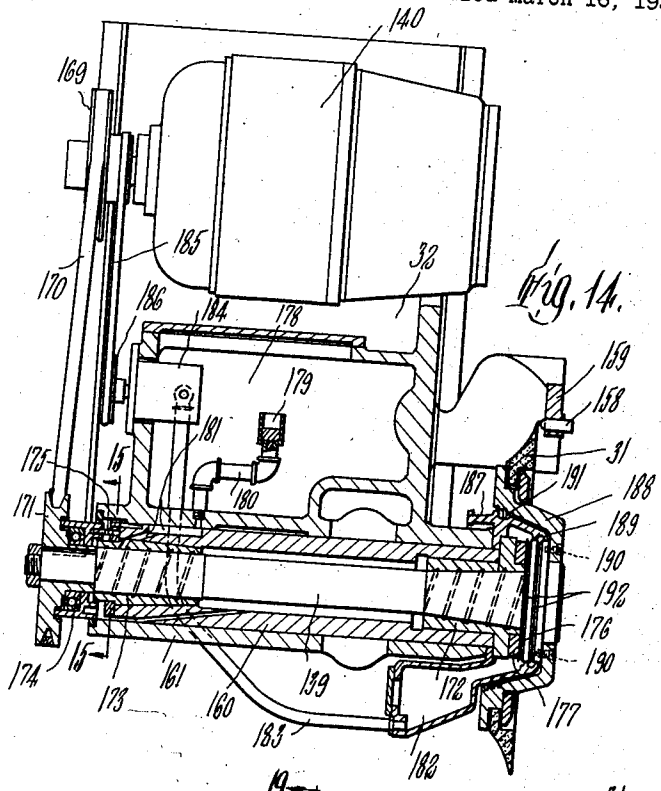


Fig. 14.

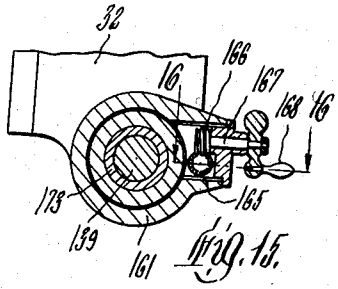


Fig. 15.

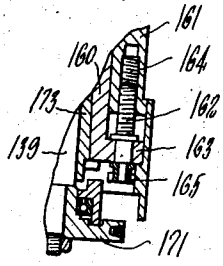


Fig. 16.

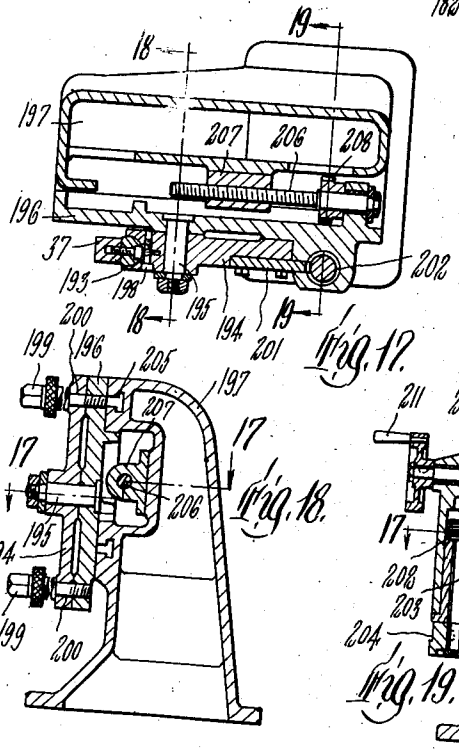


Fig. 17.

Fig. 18.

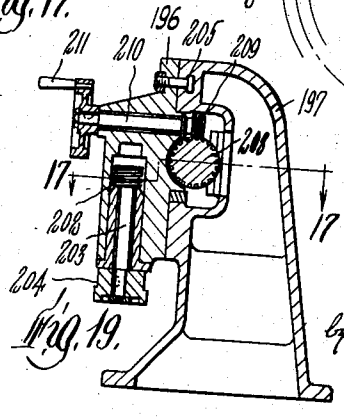


Fig. 19.

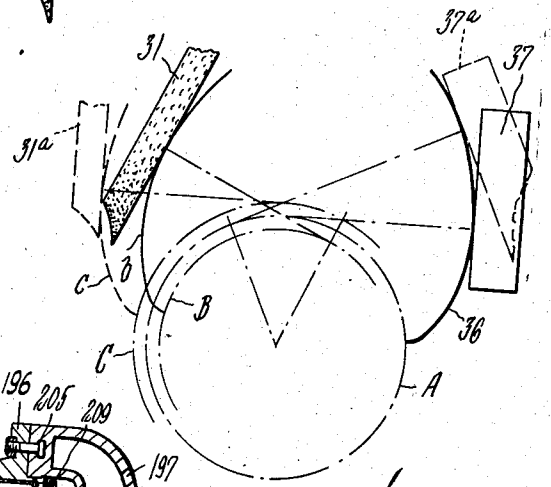


Fig. 20.

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Patented Oct. 7, 1941 2,257,850

UNITED STATES PATENT OFFICE

2,257,850

GENERATIVE GEAR GRINDING MACHINE

Edward W. Miller, Springfield, Vt., assignor to The Fellows Gear Shaper Company, Springfield, Vt., a corporation of Vermont

Application March 16, 1939, Serial No. 262,125

16 Claims. (Cl. 51—123)

The subject matter of the present invention is a machine for generating the tooth curves of gears, gear shaper cutters and the like, of either spur gear or helical gear characteristics. In the preferred embodiments of the invention, including that illustratively shown and described herein, the operating tool is a grinding wheel; and for that reason the machine is called a grinding machine. But this title is not intended as a limitation to grinding in contradistinction to cutting by tools of other characteristics, (such as milling cutters for instance). Hence, although in the following description I shall generally refer to the action of the machine as grinding and to the tool as a grinding wheel, it is to be understood that such description is intended to include as well equivalent cutters of specifically different characteristics and the operations performed by their use. Likewise the use of the term "gear" in the following description to designate the work piece operated on by the machine is intended to embrace generically also other articles of forms similar to gears, such as gear shaper cutters and all machine elements having curved surfaces capable of generation by combined motions of rotation and translation with reference to a cutting tool.

The main objects of the invention are to increase the speed and accuracy of generating gear teeth to finished form and dimensions; to permit ready adjustment of one machine for generating gear tooth curves based on a wide range of rolling circles easily and with substitution of a relatively small number of interchangeable parts; to simplify the operation of, and means for, indexing the work, and avoid the tendency to inaccuracy which has accompanied the indexing means of prior machines of the generative grinding type; and to accomplish subsidiary objects related to the foregoing, as will appear from the following description. The nature of the invention, the principles and novel features which it contains, and its utility can best be explained and understood in connection with a full description of a specific embodiment. Such a description follows with reference to illustrative drawings. In these drawings,

Fig. 1 is a front elevation of a gear grinding machine containing the invention;

Fig. 2 is a vertical section taken on line 2—2 of Fig. 1 and including the axis of the work holder;

Fig. 2a is a fragmentary view showing an alternative means for holding, clamping and rotating the work supporting arbor;

Fig. 3 is a vertical section taken on line 3—3 of Fig. 1;

Fig. 4 is a horizontal section taken on line 4—4 of Fig. 1;

Fig. 5 is a vertical section taken on line 5—5 of Fig. 4 showing on a larger scale the details of a braking means for the work indexing motor;

Fig. 6 is a horizontal section taken on line 6—6 of Figs. 1 and 2;

Fig. 7 is a vertical section taken on line 7—7 of Fig. 2 and represented on a larger scale;

Fig. 8 is a fragmentary view similar to Fig. 7 and illustrating a modification of one of the details of the mechanism there shown;

Fig. 9 is a vertical section taken on line 9—9 of Fig. 7;

Fig. 10 is a vertical section of a detail of the mechanism taken on line 10—10 of Fig. 2 and shown on a larger scale;

Figs. 11 and 12 are detail sectional views taken on lines 11—11 and 12—12 respectively of Fig. 10;

Fig. 13 is a detail sectional view of the means for controlling the stop for the indexing mechanism, taken on a plane parallel to that of Fig. 10;

Fig. 14 is a sectional view taken on line 14—14 of Fig. 2 showing the tool head;

Fig. 15 is a detail cross section taken on line 15—15 of Fig. 14 and showing means for adjusting the tool to compensate for wear;

Fig. 16 is a detail sectional view taken on line 16—16 of Fig. 15;

Fig. 17 is a horizontal sectional view taken on line 17—17 of Figs. 1, 18 and 19;

Figs. 18 and 19 are sectional views taken on lines 18—18 and 19—19 respectively of Figs. 1 and 17;

Fig. 20 is a diagram illustrating the principles according to which angular adjustment of the grinding wheel and of the abutment which controls the translative movement of the work varies the rolling circle with respect to which the tooth curves are generated.

Like reference characters designate the same parts wherever they occur in all the figures.

Describing first the general principles of the machine, with reference to Figs. 1, 2 and 3, the frame comprises a base 21 having a recess 22 in its forward side, an annular bed 23 secured to the base 21, uprights 24 and 25 rising from opposite sides of the base 21, and a cross beam 26 supported on said uprights 24 and 25; all of these parts being of suitably massive and rigid construction. The bed 23 supports a table 27 on

which is mounted a slide or carriage 28 carrying a work holding head, which includes a work spindle or arbor 29, by which the work piece 30 is rotatably supported. The tool 31, here shown as a grinding wheel having a plane operating face, is supported by a tool head 32 secured adjustably, by means later described, to the cross beam 26 of the frame structure.

In operation the work piece is moved bodily transversely of the plane of the grinding wheel and at the same time is given a component of angular movement such that the ultimate effect is the same as if the work piece were rolled on a circumference of given diameter over a plane surface toward and away from, or across, the plane of the grinding face, whereby an involute curve is generated in whatever part of the work piece engages the grinding face. The following mechanism is provided for imparting these movements to the work.

The carriage 28, which is constrained to travel in a straight line on the table 27, supports a rotatable shaft 33, preferably parallel to the work spindle 29, as here shown, although it is not necessarily so. On this shaft 33 is keyed a cam holder 34, to which is affixed in a detachable manner a cam 35. The cam has a face 36 of involute curvature bearing on an abutment 37 mounted adjustably on the table 27 in a manner later described. The cam holder 34 includes an arm 38 which is coupled by a connecting rod 39 with a crank pin 40 on a disk 41. The crank disk 41 is driven by a motor 42 by means of a belt drive 43 to a pulley 44 coaxial with the table bed 23; a pulley 45 coaxial with pulley 44, belt 46, pulley 47, shaft 48 to which pulley 47 is secured, worm 49 on shaft 48, and worm wheel 50 on the shaft 51 which carries the crank disk 41. When the cam 35 is turned in clockwise rotation with respect to Fig. 1 by this mechanism, the carriage 28 is moved to the left. It is moved in the opposite direction when the cam 35 turns counterclockwise, by a weight 52 suspended from a cord 53 which passes around guides 54, 55, 56 and is secured to the carriage 28. Guide 54 is mounted on the base 21 and guides 55 and 56 are mounted on table 27. The weight 52 maintains a firm engagement between the cam 35 and the abutment 37, taking up backlash, at all times. This mechanism gives the translative component of movement to the work.

The angular component of rolling motion is transmitted through a gear segment 57 keyed to the shaft 33, a compound rack bar 58 and a gear 59 secured to the work holding arbor 29. The element above described as a compound rack bar 58 is so called because it has portions cooperating with the gear elements 57 and 59 in the manner of a rack. It also cooperates with gear 59 in the manner of a screw or worm to cause indexing of the work. This rack bar 58 is mounted for free endwise and rotary movement in a bushing 60 in a housing 61. It is made with a rack portion 58*a* of which the teeth are encircling disconnected ribs without helical lead, which mesh with the gear segment 57, and with a second rack portion 58*b* of which the teeth have a helical lead and are successive convolutions of a screw thread or a plurality of threads. Angular movement of the segment 57 is transmitted by the rack bar 58 to the gear 59,—in equal measure when the pitch radii of the gear segment 57 and gear 59 are the same, as is the case here. Rotation of the rack bar 58 about its own axis rotates the gear 59 in the manner of worm and wheel gearing without rotating the segment 57, and is employed for indexing the work.

It is not essential that the rack element 58*a* be a circular rack integral with the bar 58. Fig. 8 shows an equivalent variation in which the rack 58*l* consists of teeth on one side of a sleeve 62 fitted to a reduced extension 58*c* of the rack bar 58 so that the latter may rotate within it, and confined from relative endwise movement by anti-friction thrust bearing 63 between a shoulder 64 on the bar 58 and a nut 65 screwed to the end of the bar 58.

Power for indexing the work piece is delivered from an electric torque motor 66 (see Fig. 4). The armature of this motor is coupled to a shaft 67 on which is a gear 68 meshing with a gear 69 on an upright shaft 70 (see also Figs. 7 and 9). The latter carries on its upper end a gear 71 meshing with a gear 72 on a sleeve 73 which is coaxial with the rack bar 58 and is connected with the end or extension 58*d* thereof by a coupling including keys 74 entering longitudinal grooves 75 in the sides of the bar extension 58*d*.

The torque motor 66 exerts a constant torque tending to rotate the rack bar 58 but is restrained during the grinding operation by a stop plunger 76 and index plate or head 77 (Fig. 10). The index plate 77 is secured to a shaft 78 (Fig. 4) which is driven by the torque motor 66 through shaft 67, a pair of changeable ratio gears 79, 80, shaft 81 on which gear 80 is secured, a change gear 82 on the forward end of shaft 81, idle gear 83 (Fig. 1) and change gear 84 on shaft 78. By suitable selection of the gears 79, 80, 82, 83 and 84 the ratio of rotation of the index plate 77 to the rotation of the rack bar 58 may be varied to cause rotation of the work through any desired angle while the index plate 77 makes a complete rotation. In this illustration the index plate 77 has a single stop shoulder 85, but it may be provided with any number of shoulders.

Release of the locking pin 76 is caused by the carriage driving mechanism when the carriage 28 is at the end of its retracting stroke and the work is clear of the grinding wheel. An arm 86 is secured to the shaft 33 in the same plane with a rod 87 supported by pivotally mounted levers 88, 89 on the table 27 and carrying an adjustable collar 90. The collar 90 is so adjusted that it is engaged by the arm 86 and moved to the right (with respect to Figs. 1 and 10) when the carriage 28 reaches the end of its traverse from left to right or, at least, has progressed far enough in that direction to withdraw the work piece clear of the grinding wheel 31; and is so moved far enough to cause displacement of the locking pin 76 from the index plate shoulder 85. This movement of the collar 90 swings arm 91 of lever 89 to the left. Said lever arm 91 bears against the end of a rod 93 which is movable in guideways 94 and is pressed toward arm 91 by a spring 95. It extends toward the index plate 77 and carries on its end adjacent to the latter a pusher block or head 96 having a pusher face 97 concentric with the index plate 77. An arm 98 is pivoted at 99 to a bracket 100 in which the stop plunger 76 is slidingly mounted. This arm 98 is acted on by a spring 101 (which reacts on an anchor pin 102 on bracket 100) so that a roll 103 on its outer end is constantly pressed against the pusher face 97. Arm 98 carries a pivoted pawl 104 in position to act on an arm 105 secured to a shaft 106, which rotates in a bearing in the bracket 100 and carries a pinion

107 meshing with rack teeth 108 on the side of the plunger 76. A spring 109 normally holds the pawl 104 against a shoulder on the arm 98 but permits the outer end of the pawl to yield away from the axis of shaft 106. Thus when the pusher head 96 is moved to the left, it swings the arm 98 from the position of Fig. 10 to that of Fig. 13 and causes the pawl 104 to turn arm 105 and thereby retract the stop plunger 76. The lengths and angular relationship of the pawl 104 and the arm 105 are so made that, when the plunger 76 has been withdrawn clear of the index plate stop shoulder 85, the pawl 104 slips past the end of arm 105, leaving the latter free to be moved backward by a spring 110 which constantly forces the plunger 76 toward the index plate 77. As the pawl 104 is then free to yield away from the arm 105, it permits the plunger 76 to bear on the circumference of the index plate 77 ready to obstruct the plate 77 when it has completed its rotation. This is a safety measure which prevents the work from being indexed through more than the prescribed angle in case the indexing movement is completed before the carriage has advanced far enough on the next working traverse to permit return of the arm 98. But when this arm returns to normal position (Fig. 10) the pawl 104 is returned to acting position after passing clear of arm 105.

The bracket 100 is secured to a flange 111 (Fig. 4) on a sleeve 112 which fits rotatably in a bearing in the table 27 and within which the shaft 78 is coaxially supported. Flange 111 carries a gear segment 113 (Fig. 10) with which is meshed a worm 114 on a shaft 115. A face gear 116 is keyed to shaft 115 and meshed with a pinion 117 on a shaft 118 which protrudes at the forward side of the carriage and carries a knob 119 (Fig. 2) by which it may be manually turned. This mechanism is a manually operated means for feeding the work to increase the depth of cut. It advances the stop plunger 76 angularly around the axis of the index plate 77, allowing the latter to turn through an incremental angle and consequently permitting the work piece to be turned through a fraction of this angle toward the grinding wheel. When the desired depth of cut has been obtained, the bracket 100 is locked by a clamp 120 (Fig. 12) which is forced against the flange 111 by a nut 121 threaded on a screw stud 122 and carrying a handle 123.

In order to soften the shock when the indexing plate 77 is arrested by the locking bolt 76, a brake is provided and brought into action shortly before the shoulder 85 reaches the bolt 76. The brake consists of a drum 124 (Figs. 4 and 5) on the armature shaft of the torque motor 66 and a complemental shoe 125. The brake shoe 125 is connected by a pivot pin 126 with a carrier lever 127 pivoted at 128 to the motor base 129 and connected with a spring 130 which is arranged to exert force tending constantly to press the brake shoe 125 against the brake drum 124. The carrier lever 127 is provided also with a toothed arm 131 constituting a gear segment meshing with a pinion 132 on a rock shaft 133. An arm 134 is secured to this rock shaft 133 and bears at its free end on a cam 135 secured to the shaft 78 of the index plate 77. The gearing is so arranged, substantially as shown in Fig. 5, that the spring 130 causes arm 134 to bear on the cam 135, and the latter is of a radius such that it holds the brake shoe 125 away from the drum 124 throughout most of the rotation of the index plate 77. The cam 135 has a depression 136 located so that it releases the arm 134 and permits application of the brake shortly before arrival of the index plate shoulder 85 at the locking bolt 76. The tension of spring 130 may be regulated by adjustment of nuts 137 on the threaded anchor pin 138; and it is so adjusted as to cause substantial retardation of the motor 66, without stopping it. The rise of the cam 135 following the depression 136 releases the brake when the index plate 77 is arrested by the bolt 76, enabling the motor 66 to start when the bolt 76 is retracted.

The grinding wheel is adjustable vertically for work gears of different diameters, angularly to generate involute curves to different base circles, or rolling circles, and pressure angles, and axially to maintain its active face true and in a given plane. These adjustments are made possible and effected by the following means. The tool head 32 carries the tool spindle 139 (Fig. 14) and an electric motor 140 for driving the spindle 139. The tool head 32 is made as a slide fitted to guideways 141 and 142 on a tool head base 143 (Figs. 1 and 2), which constrain the slide to move in a path parallel to the plane of the grinding wheel face. The tool head base 143 is mounted against the plane forward surface 144 of the cross beam 26 of the frame, being supported by rolls 145 resting on the arcuate upper surface of a bar or ledge 146 secured to said face 144. The base 143 is further provided with an arcuate flange 147 which is held against the face 144 by a clamp 148 and releasable bolts 249. The flange 147 and curved face of ledge 146 are coaxial, with the axis of their curvature in or near the plane in which the axis of the work spindle 29 travels and transverse to the direction of such travel. Upon loosening clamp 148 the tool head base may be tilted about this axis between the position where the grinding wheel face is vertical (i. e. perpendicular to the plane of travel of work spindle 29) and the maximum practicable angle or inclination. The maximum angle is determined by the art of gear manufacture and may be as much as 25° or more from the vertical. The degree of such inclination is measured by an index 149 on the tool head base 143 with reference to a scale 150 on an adjacent part of the frame. Vertical adjustments, (by which I mean movements of the tool head in the prescribed path, whether such path is exactly vertical or inclined, due to the tilting of the head base), are effected by a hand wheel 151 on the forward end of a shaft 152 mounted in the tool head base 143. This shaft carries a worm 153 meshing with a gear 154 on a shaft 155 which also carries a gear 156 meshing with a rack 157 on the tool head slide.

Correction for wearing of the grinding wheel face, and maintenance of such face in a prescribed plane, is effected by adjustment of the wheel axially in conjunction with a truing tool 158 carried by an arm 159 which is pivoted to the forward end of the tool head 32 in a position such that the truing tool 158 may be passed from a point outside of the circumference of the wheel 31 across the entire width of the active zone thereof. The tool spindle 139 rotates in a sleeve 160 which is movable endwise in a housing 161 forming part of the tool head 32. A screw 162 (Figs. 15 and 16) is mounted rotatably in a flange 163 of sleeve 160 and engages the threads of a tapped hole 164 in the adjacent

housing wall 161. A pinion 165 on the shaft of screw 162 meshes with a worm 166 on a shaft 167 which carries a crank 168 on its exposed outer end.

The mounting of the tool spindle, the means for lubricating it, and means for excluding dust from its bearings involve useful features which may well be described at this point. The tool spindle 139 is driven by a belt and pulley drive 169, 170, 171 from the motor 140 and is mounted at its forward end (that to which the wheel is attached) in an internally tapered bearing 172. A bearing 173 at its other end is split and slightly tapered externally so that it can be drawn up within the sleeve 160 to compensate for wear. At the rear end a thrust bearing 174 is provided which is forced outwardly against the rigidly secured pulley 171 by a series of springs 175 reacting against the sleeve 160, whereby a shoulder 176 on the forward end of the spindle is held tightly against a thrust washer 177 and the latter against a shoulder on the bearing 172.

Lubrication is accomplished by using kerosene oil which occupies a chamber 178 in the tool head to a height sufficient to enter a filter 179 at the upper end of a pipe 180 which leads to an oil channel 181 in the sleeve 160. Oil grooves and channels conduct the oil between the spindle and its bearings and eventually into a settling basin 182. From the basin 182 the oil is returned to chamber 178 through a pipe 183 by a pump 184 driven from the motor 140 by a belt and pulley drive 185, 186. The use of a large volume of kerosene or other light oil enables a close fit between the spindle and bearings to be maintained and keeps the bearing surfaces cool.

Dust is excluded from the front bearing by a stationary housing 187 in cooperation with the wheel center 188. The housing 187 is a portion of the structure which contains the settling basin 182 and is extended with a conical formation 189 so as to embrace the shoulder 176 of the spindle 139. The wheel center 188, which is secured by screws 190 to shoulder 176, (and to the peripheral part of which an abrasive annulus is secured), embraces the conical part 189 of the stationary housing 187. Recesses and grooves are provided at 191 and 192 to contain oil and entrap dust.

Adjustment of the abutment 37 angularly and translatively is accomplished by the following means, shown in Figs. 1, 17, 18 and 19. The abutment 37 projects from the open side of a straight channel in the edge portion 193 of a disk or plate 194 pivotally mounted on a stud 195 which projects from a slide 196 supported movably on a bracket 197 which rises from the table 27 adjacent to the cam 35 and to that part of the carriage 28 on which the cam holder 34 is mounted. The lips of the channel are clamped against the base of the abutment 37 by screws 198, and may be relaxed to permit endwise adjustment of the abutment 37. The plate 194 is clamped to the slide 196 by clamp bolts 199 passing through slots 200 in the plate 194 into threaded connection with slide 196, which bolts may be loosened to permit swinging movement of plate 194 about the pivot 195. A toothed segment 201 is secured to the plate 194 coaxial with pivot 195 and is meshed with a worm or screw 202 on a shaft 203 to which is secured in accessible position a knob 204. Movement of the slide 196 in the path (parallel to the directions in which the carriage 28 travels) prescribed by headed studs occupying guideways 205 in the bracket 197, is effected by a screw 206 carried by the slide 196 meshing with a nut 207 affixed to the bracket 197. A gear 208 on the screw 206 meshes with a worm 209 on a shaft 210 which carries an accessible crank 211. Shafts 203 and 210 are both supported in bearings in slide 190. By rotation of knob 204 the abutment 37 may be swung from a position where its contact face (which is a plane face) is vertical, to any desired inclination within the structural and operative limits of the machine; and by rotation of crank 211 its location may be altered at the same time to accommodate changes of inclination, and also as needed to make contact with one or another of interchangeable cams 35 throughout a range of movement of the carriage 28 which suffices to carry the work piece through any prescribed grinding traverse and clear of the grinding wheel to permit indexing.

Novel features conducive to accuracy by eliminating eccentricity of the work piece are embodied in the work holding head. The arbor or spindle 29 passes through a sleeve or quill 212 fitted to rotate in accurately alined bearings in the head 28 and on which the worm gear 59 is keyed and made fast. The outer end portion of spindle 29 is clamped and centered in the quill 212, in the construction shown in Fig. 2, by a split taper collet 213 and a nut 214 which is screwed into the outer end of the quill 212. Otherwise the spindle 29 is clear of the quill 212, being smaller in diameter than the interior of the quill 212. The free end of spindle 29 is supported by a dead center 215 mounted in a bushing 216 contained in a tail stock structure 217 on the carriage 28 at the forward side of the space in which the work is located. The bushing 216 is centered accurately with the quill 212 and secured by screws passing through a flange 218 into the tail stock structure 217. A knob 219 is mounted on a shaft which is rotatably supported in the tail structure and carries a pinion (not shown) meshing with teeth cut in the side of the center 215. Thereby the center 215 may be moved as required for placing and removing work pieces. The work may be positioned correctly with respect to the grinding wheel by releasing the nut 214 and moving spindle 29 endwise to the desired position. This arrangement enables the work to be set accurately concentric with the prescribed axis of oscillation, and in such position lengthwise of its axis as places it in desired relationship to the grinding wheel, and eliminates the use of thickness washers, commonly used heretofore and containing sources of error.

Various other means may be used for connecting the arbor 29 to the quill 212 with similar effect. One such is shown in Fig. 2*a*. It consists of a split sleeve 213*a*, secured to the quill 212 and furnished with internal teeth, and an external gear 213*b* secured to the work arbor. Gear 213*b* is in effect an external clutch member complemental to the internal teeth and grooves of the sleeve 213*a*. Its teeth are crowned or barreled sufficiently to permit a slight lateral movement in any direction of the end of the arbor 29 which engages the dead center 215, while at the same time enabling the split sleeve 213*a* to be clamped on the gear without applying a bending stress to the arbor 29. Except for the connection with the quill 212 made through the clutch members 213*a* and 213*b*, the arbor 29 is clear of the quill 212 and free to move laterally to the extent necessary to bring the work piece exactly concentric with the axis of rotation. The clutch sleeve 213*a* is long enough to permit ad-

justment of the work arbor 29 in the axial direction and placement of the work piece in the desired relation to the grinding machine without need of using thickness washers.

The gearing 58b, 59 and the bearings for the quill 212 are enclosed in a housing 220 and protected from foreign matter by a flexible bushing 221 (which may be of rubber composition) in the end of the housing 220 nearest to the work.

The work spindle axis and the path of movement of the carriage may be adjusted to any desired inclinations with respect to the plane of the grinding wheel as needed to finish helical gears and cutters or to grind the necessary clearance on spur cutters. For this purpose the table 27 is mounted rotatably on the bed 23 and is engaged therewith by curved guides 222, 223 concentric with a vertical line intersecting or passing near to the axis of angular adjustment of the grinding wheel; and the crank shaft 51 and gearing for driving it, including the pulley 47, are mounted in a housing 224 suspended from the table 27 in the open space 22 of the base 21. An annular gear segment 225 (Fig. 6) is connected coaxially with the table 27 and meshed with a worm 226 on a shaft 227 which is mounted in the bed 23 and projects at its forward end into accessible position for application of a wrench. A scale 228 on the bed serves in connection with an index 229 on the table to measure the angular adjustments so effected. The shaft 230 (Fig. 2) on which the pulleys 44 and 45 of the crank shaft drive are secured, is coaxial with the table 27; so that when the table 27 is rotated, the pulley 47 swings around its driver 45 without affecting the tension of the belt 46.

Other adjustments are effected by lengthening or shortening the two part connecting rod 39 previously described, whereby both limits of travel of the carriage are equally shifted in the same direction, and my moving the crank pin 40 in the radial slot 231 in the face of the crank disk 41, in a well known manner, whereby the travel of the carriage may be lengthened or shortened.

With the aid of the various adjustments described, together with substitution of different cams like cam 35 but developed from different base circles, a wide variety of gears and cutters may be generated and finished on the same machine. By way of illustration I may say that with one design of such a machine which I have built, the range of rolling circles is from less than an inch up to twelve inches. Other ranges are accommodated by machines of the same type having different dimensions.

The capacity for inclining both the grinding wheel and the abutment 37 to any angles between their extreme limits is an important factor in that it enables the same cam to be used through a large fraction of the total range of rolling circles accommodated in the machine. An indication of the range possible with one cam is given in Fig. 20. This figure is a diagram in which the curve 36 represents the involute face of a cam of which the base circle is A. The curve *b* represents the tooth curve generated when the abutment and grinding wheel are in the relative positions shown in full lines at 37 and 31 respectively; the face of the abutment being perpendicular to the travel of the gear and the face of the grinding wheel being inclined. The base circle from which the curve *b* is generated is found by the geometry of involute curves to be B. When the abutment is set at a certain inclination, which is indicated by the dotted line position 37*a*, and the grinding wheel is set in the position 31*a* where its face is perpendicular to the line of travel of the work, a curve *c* is generated of which the base circle is C. Intermediate angular settings of either the abutment or wheel alone, or both in conjunction, produce involutes of base circles between the circles B and C; while with other settings involutes of base circles larger than C and smaller than B may be generated.

The combined generating and indexing control accomplished by the rack bar 58 and associated gears has this conspicuous advantage, that it eliminates all change gears, locking devices, etc. from the rolling head, (i. e., the work spindle and its oscillating means). The rolling head is thus reduced to the extreme of simplicity and it is perfectly balanced. Hence there is nothing to impede rapid oscillation or to cause any lack of accuracy due to unbalance when oscillated rapidly. Perfect equality between the angular movement of the involute cam and the angular movement of the work is assured by the equality in pitch radius of the gear elements 57 and 59 and by absence of backlash between these elements and the rack elements 58*a* and 58*b*. It is immaterial whether these gears are equal in radius at their pitch circles to the radius of the base circle of the cam face or of different radius, or to what degree their radius is different. Whatever angle of rotation is imparted to the segment 57 during traverse of the carriage, the same angle of rotation is transmitted to the worm gear 59. If these gear elements are of different radius than the base circle referred to, the rack element is moved endwise at the same time; in the opposite direction to the travel of the carriage if the gear radius is larger, and in the same direction as the carriage if smaller.

An electrically controlled switch board for the motors 42 and 140 is shown at 232 in Fig. 1. It comprises means of known character for starting and stopping each motor and for causing the motor 42 to operate through any selected number of complete cycles before being stopped. An auxiliary switch 233 includes rotatable contacts 234 driven from the crank shaft 51 by gearing 235, 236 (Fig. 2), and set to cause the motor 42 to be stopped only when the carriage 28 is at the extreme rear position away from the grinding wheel 31.

Although in the foregoing description I have referred to certain parts of the machine as being horizontal or movable horizontally, and other parts and movements as being vertical, it must be understood that these terms are merely descriptive of the particular machine here shown and not limiting as to the invention. Any machine which has similar structural and functional relationships between its parts to those herein described is within the scope of the invention claimed however its corresponding parts may be related to the plane of the horizon.

What I claim and desire to secure by Letters Patent is:

1. A machine of the character described comprising a supporting structure, a cutting tool rotatably mounted on the supporting structure and having an active face, a carriage movable in a path transverse to the active face of the tool, a work spindle mounted rotatably on the carriage adapted to support a toothed work piece with the side of a tooth thereof in contact with said active face, a cam mounted rotatably on

the carriage, an abutment mounted on the supporting structure in position to receive the thrust of said cam, gear elements connected with the spindle and cam respectively, and a bar having rack elements in mesh with said gear elements for transmitting angular movement from the cam to the spindle, the rack element which is meshed with the gear element on the spindle having its teeth in the form of continuous helical convolutions and being rotatable for indexing the work spindle.

2. In a machine of the character described, a carriage, a work spindle and a cam rotatably mounted on said carriage, driving mechanism coupled with the cam for oscillating it, an abutment against which the cam acts to propel the carriage, gears connected to the spindle and cam respectively, a worm and a rack in tandem connection, the worm being rotatable and in mesh with the gear which is connected to the spindle, and the rack being in mesh with the gear connected to the cam, and means for rotating said worm whereby to index the work spindle.

3. In a machine of the character set forth, a carriage, a spindle and a cam rotatably mounted on the carriage, gears connected to the spindle and cam respectively, an endwise movable bar having a worm and a rack in tandem arrangement, of which the former is meshed with the spindle-connected gear and the latter with the cam-connected gear, an abutment against which the cam reacts for moving the carriage, driving mechanism connected with the cam to oscillate it, potentially active motive means in geared connection with said bar tending constantly to rotate it, an index plate in driven connection with said motive means, a displaceable stop normally preventing movement of said index plate, and means operable by the carriage for displacing said stop.

4. A machine of the character described comprising a supporting structure, a carriage movable reciprocatively thereon, a work spindle rotatably mounted on the carriage with its axis transverse to the path of carriage movement, a cutting tool mounted on the supporting structure in position to generate tooth curves on a work piece mounted on said spindle when the carriage is moved and the spindle simultaneously rotated, a cam rotatably supported on the carriage with its axis transverse to said path in a location displaced from the spindle to one side thereof, an abutment on the supporting structure located to receive the reactive thrust of the cam, mechanism for oscillating the cam, and a combined rotation transmitting and spindle indexing means between the cam and spindle for transmitting angular movement from the cam to the spindle and imparting independent angular movement to the spindle for indexing the work.

5. A machine for the purpose set forth having the characteristics set forth in claim 4, combined with a table mounted on the supporting structure and on which the carriage is mounted, said table being angularly movable in a manner to cause generation of spur or helical tooth face curves in the work.

6. A machine for the purposes set forth comprising a supporting structure, an angularly adjustable table mounted thereon, a carriage mounted to move in a path transverse to the axis of adjustment of the table, a power driving train for the carriage including a rotatable machine element concentric with said axis, a work spindle rotatably mounted on the carriage and adapted to hold a work gear, and a rotatable cutting tool mounted on the supporting structure in position to generate tooth curves on such a work gear, said tool being mounted with provision for adjustment to various inclinations to the path of travel of the carriage.

7. In a tooth curve generating machine, a cutting tool mounted for cutting operation in a stationary location, and means for transporting a work piece with a rolling motion toward and away from said location comprising a carriage guided to move in a path transverse to the operating plane of the tool, a work spindle and a cam rotatably mounted on said carriage to rotate about separate axes both transverse to the path of the carriage and spaced apart from one another in the direction of such path, a stationary abutment mounted in position to be engaged by said cam and, by reaction, cause movement of the carriage when the cam is rotated in one direction, means for imparting angular movement to the cam about its axis, and means for transmitting rotary movement from the cam to the spindle in a predetermined ratio.

8. The combination as set forth in claim 7, in which the means for transmitting rotary movement from the cam to the spindle is adapted to transmit equal degrees of rotation in the same relative direction.

9. In a tooth curve generating machine, a cutting tool mounted for cutting operation in a stationary location, and means for transporting a work piece with a rolling motion toward and away from said location comprising a carriage guided to move in a path transverse to the operating plane of the tool, a work spindle and a cam rotatably mounted on said carriage to rotate about separate axes both transverse to the path of the carriage and spaced apart from one another in the direction of such path, a stationary abutment mounted in position to be engaged by said cam and, by reaction, cause movement of the carriage when the cam is rotated in one direction, means for imparting angular movement to the cam about its axis, gear elements secured to the cam and spindle respectively, and a rack bar mounted with freedom to move endwise relatively to the carriage having teeth engaged with both of said gear elements for transmitting angular movement from one to the other.

10. The combination as set forth in claim 9, in which the gear elements connected to the cam and spindle respectively are of substantially equal pitch radii.

11. The combination as set forth in claim 9, in which the teeth of the rack bar engaging the gear element which is connected to the work spindle are helical and are revoluble about their helix axis, for imparting an increment of rotation to the spindle additional to that imparted by angular movement of the cam.

12. A machine for generating the tooth curves of gears and the like comprising a supporting structure, a carriage mounted on said supporting structure and guided to move thereon in a rectilinear path, a work spindle and a cam mounted on said carriage with provision for rotation about separate axes both transverse to said path and spaced apart one from the other in the direction of said path, transmission gearing between said spindle and cam for causing one to rotate when angular movement is imparted to the other from an external source, means ex-

ternal to the carriage coupled to one of the elements constituted by the cam and spindle for imparting angular movement to said element, an abutment mounted on the supporting structure in position to engage the cam, said cam having an engaging face of involute curvature and the abutment having a plane contact face, means for adjusting the abutment to place its said contact face at different angles to the path of the carriage, whereby to alter the distance traversed by the carriage in consequence of a given angular movement of the cam, a cutting tool having an active face arranged in position to generate tooth curves on a work piece mounted on said work spindle, when the carriage is traversed across the plane in which said active face operates, and provisions for adjusting the tool to bring the plane of operation of said active face at different inclinations to the path of the carriage, whereby to generate involute curves of different base circles in the work.

13. In a machine of the character set forth, a base, a carriage mounted to reciprocate in a given path on said base, a support adjacent to one end of the path of said carriage, an abutment having a plane face transverse to said path mounted on said support and being adjustable angularly to vary the angle between said plane face and said path, a cam having an involute face mounted on said carriage to bear at its involute face on the said abutment face and being angularly rotatable about an axis substantially parallel to the axis of angular adjustment of the abutment, a work spindle mounted rotatably on the carriage with its axis substantially parallel to the axis of said cam and displaced therefrom along the path of travel of the carriage, a tool head base secured to the supporting structure with provision for angular movement about an axis substantially coinciding with one of the positions occupied by the axis of the work spindle in the course of travel of the carriage, a tool head mounted on said tool head base, a cutting tool having an active face rotatably mounted on said tool head with its active face substantially in a plane radial to the axis of adjustment of the tool head base and in a position to engage a work piece mounted on said spindle, mechanism between said cam and spindle for transmitting angular movement from one to the other, and means for imparting such angular movement from an external source to one of the elements constituted by the cam and work spindle.

14. In a tooth curve generating machine, a supporting structure, a cutting tool having an active face mounted to rotate in a relatively stationary location on said structure, a carriage mounted on said supporting structure and guided to move in a path crossing the plane in which said active face rotates, a work spindle rotatably supported on said carriage with its axis transverse to the path of movement thereof adapted to carry a toothed work piece and to roll the faces of the teeth of such work pieces in contact with the active face of the tool, a cam mounted on the carriage to rotate about an axis transverse to the path of the carriage and at one side of the work spindle, means for imparting angular movement to the cam, an abutment mounted on the supporting structure in contact with the face of the cam for receiving the thrust thereof when the cam is turned in one direction, gear elements secured to the cam and work spindle respectively, a rack bar having teeth engaged with both said gear elements and being free to move lengthwise, the portion of said rack bar which engages the gear element on the work spindle being rotatable about the length dimension of the bar and its teeth being of helical form, and means for rotating said portion of the rack bar whereby to give an increment of angular movement to the work spindle additional to that imparted by the cam.

15. In a machine of the character described, a supporting structure, a carriage mounted to move in a given path on said structure, a work spindle and a cam mounted rotatably on said carriage on axes beside one another and transverse to the movement of the carriage, gear elements secured to said spindle and cam respectively, a compound rack having helical teeth meshing with the gear element which is secured to the work spindle and other teeth meshing with the gear element which is secured to the cam, that portion of the rack which carries said helical teeth being rotatable about the length dimension of the rack, an electric torque motor mounted on the supporting structure, a gear train between said motor and the rotatable portion of said rack for transmitting rotation to the rack, a stop normally restraining the motor from rotation, and means operated by the carriage in the course of its travel for displacing said stop.

16. A machine for the purpose set forth comprising a base, a carriage movable translatively on said base, a work spindle rotatably mounted in the carriage adapted to hold a work gear element, a cutting tool rotatably supported in position to cut the tooth faces of work gears mounted on said spindle, means for reciprocating the carriage and simultaneously imparting an angular component of movement to the work spindle including a gear secured to the spindle and a rack bar having helical teeth meshing with said gear and being rotatable about the axis of the helical teeth, a potentially active motor in geared connection with said rack bar tending constantly to rotate it, an index head in geared connection with said motor provided with a stop shoulder, a displaceable stop normally engaging said shoulder for preventing action of the motor, and means operated by the carriage at a predetermined point in its travel for withdrawing said stop, whereby the motor is permitted to act.

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