Feb. 2, 1954 A. L. STEWART ET AL 2,667,818

MACHINE AND METHOD FOR PRODUCING GEARS

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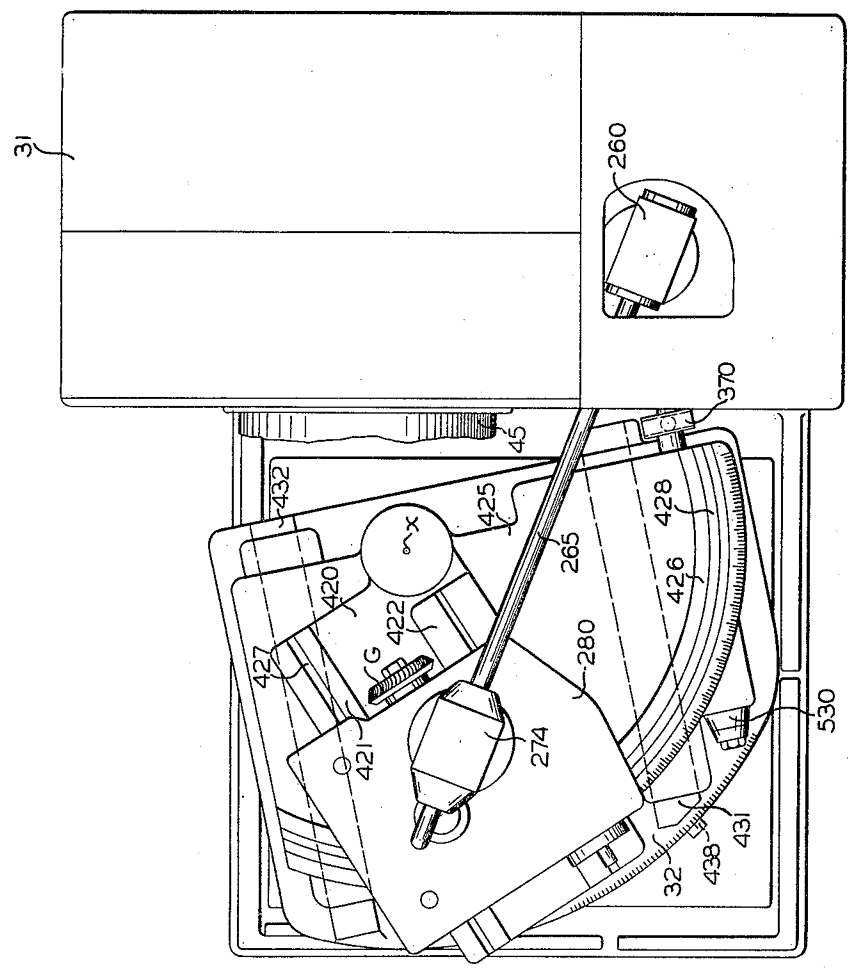


FIG. 2

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MACHINE AND METHOD FOR PRODUCING GEARS

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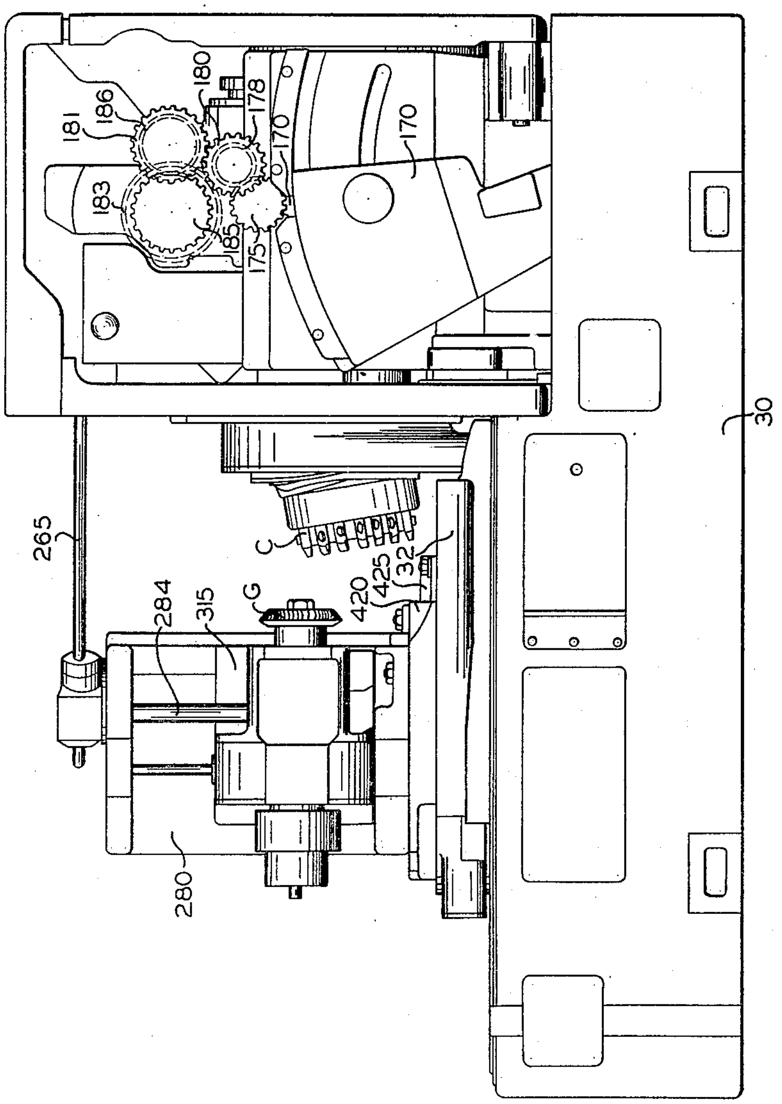


FIG. 1

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MACHINE AND METHOD FOR PRODUCING GEARS

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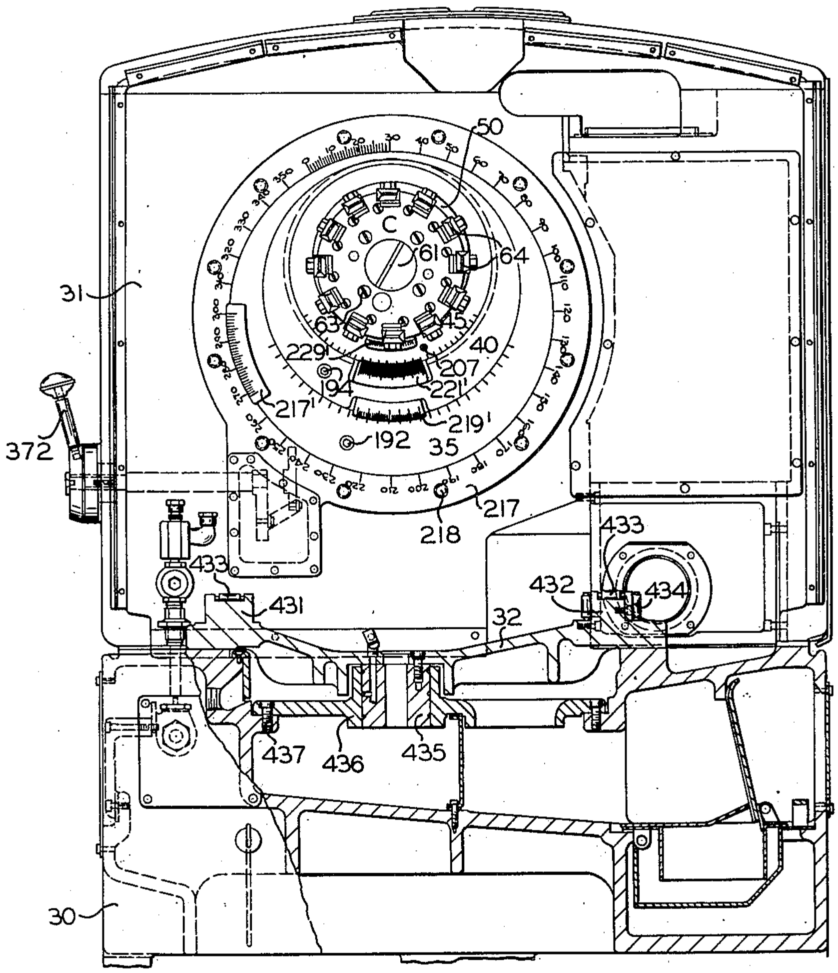


FIG. 3

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MACHINE AND METHOD FOR PRODUCING GEARS

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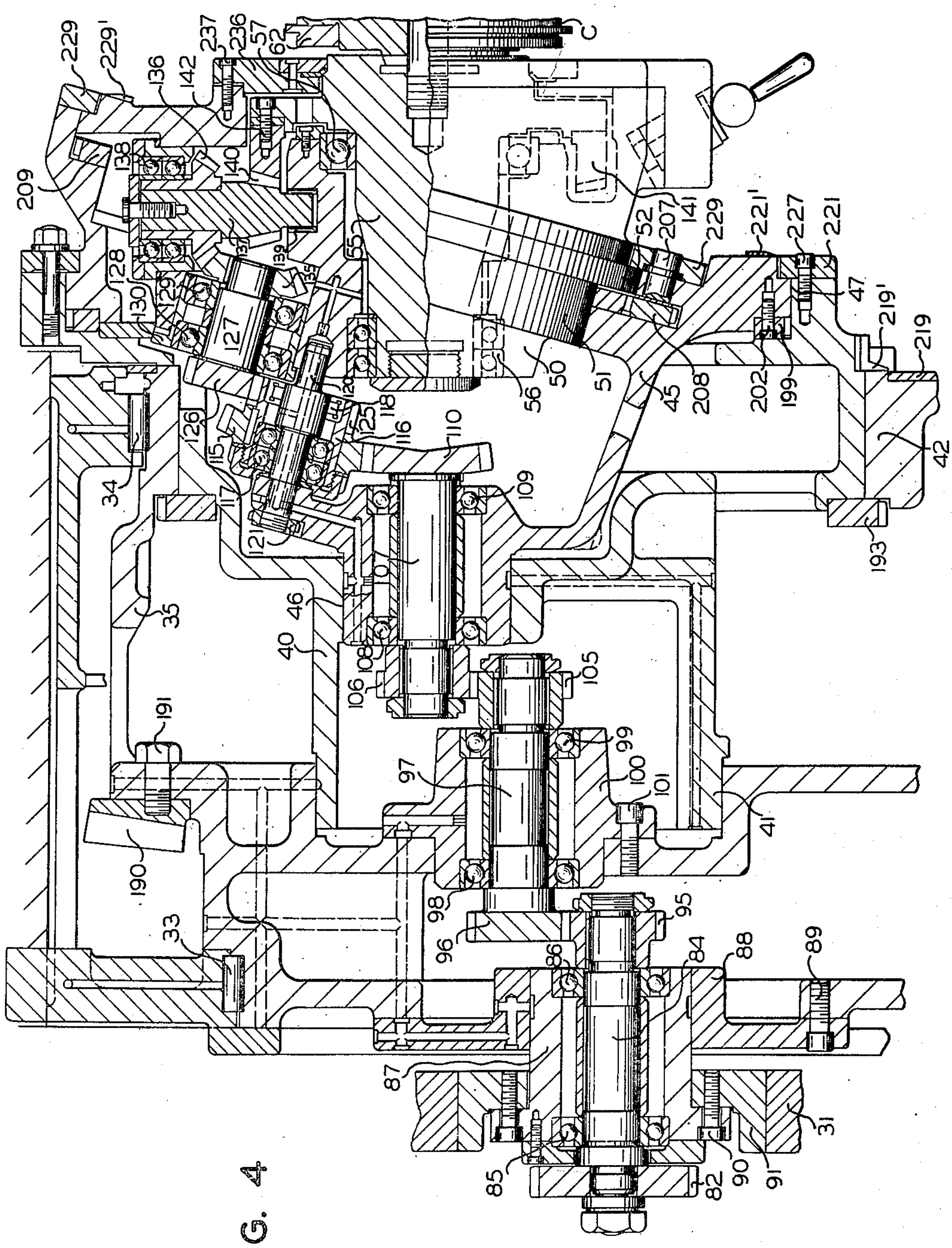

FIG. 4

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MACHINE AND METHOD FOR PRODUCING GEARS

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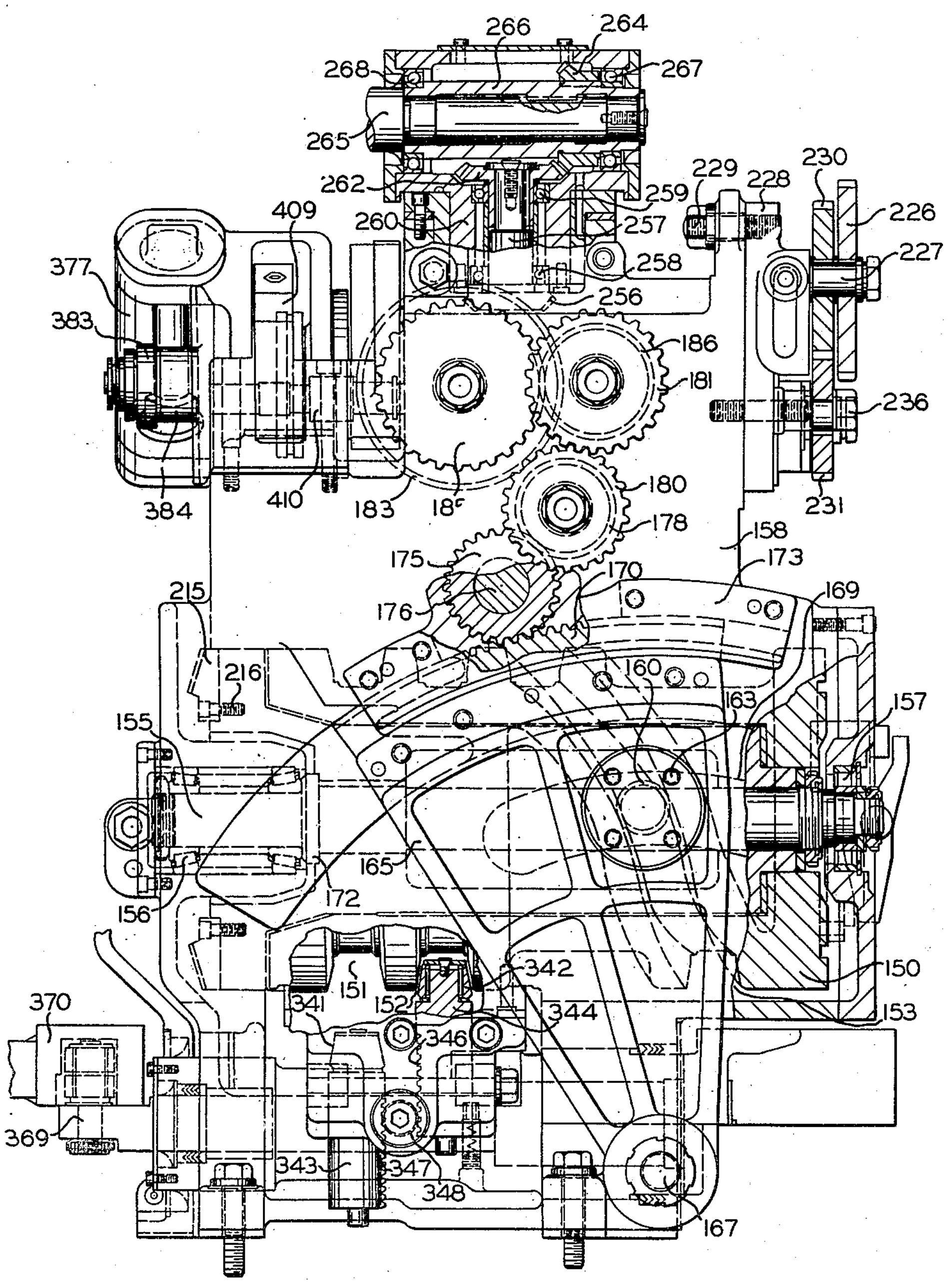


FIG. 5

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MACHINE AND METHOD FOR PRODUCING GEARS

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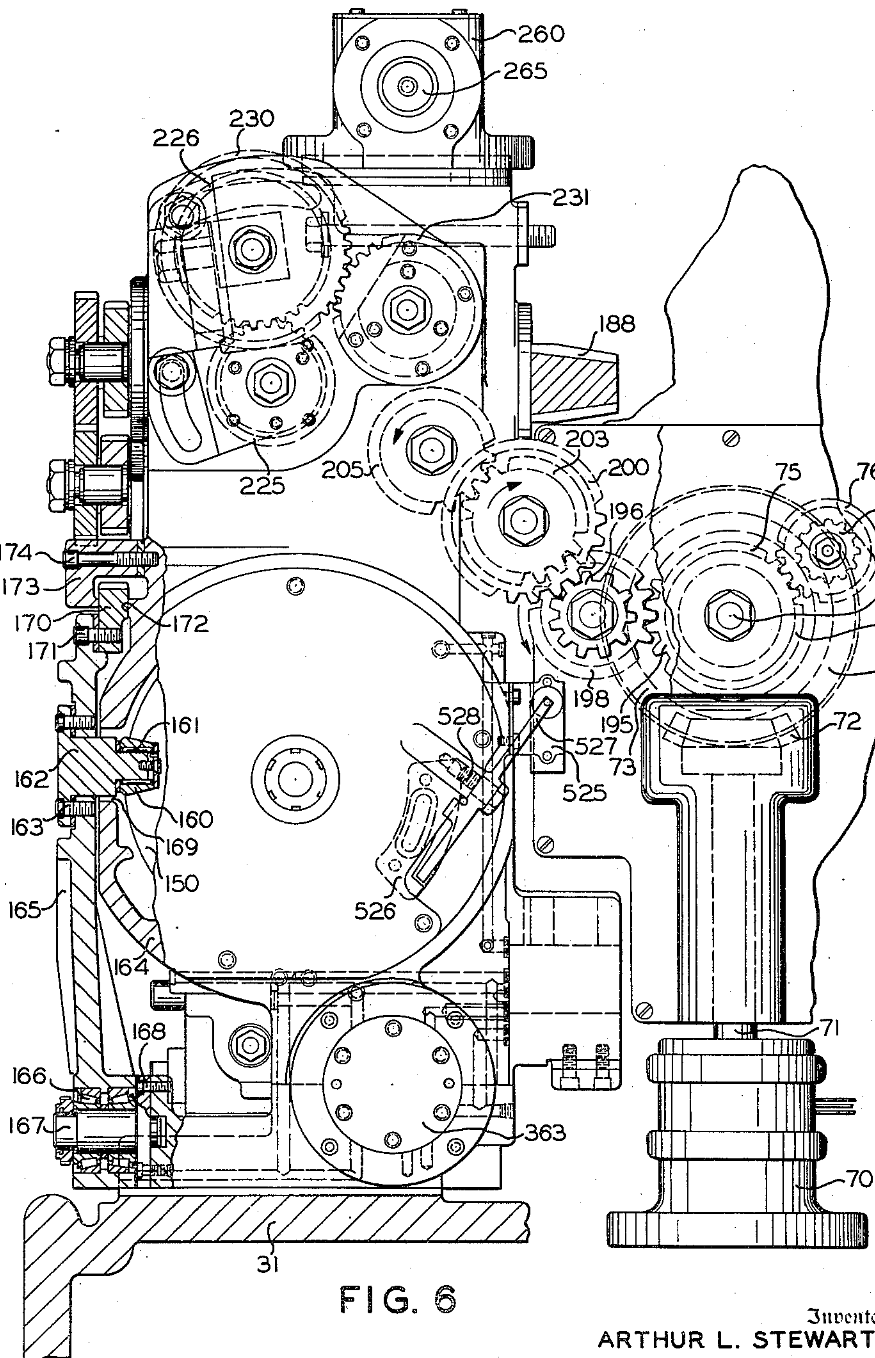


FIG. 6

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MACHINE AND METHOD FOR PRODUCING GEARS

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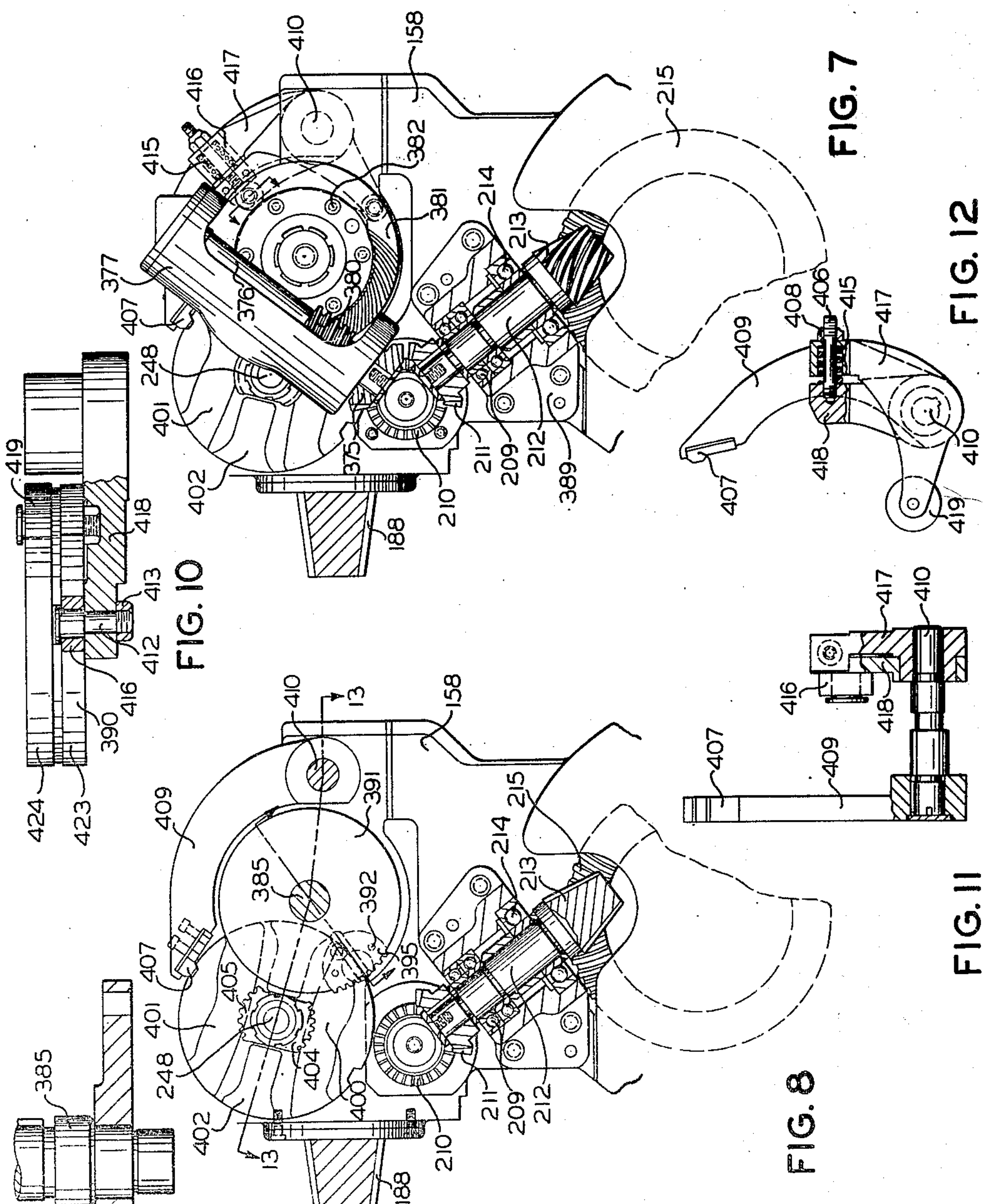


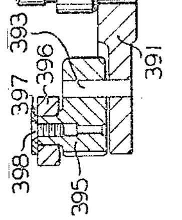

FIG. 9

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MACHINE AND METHOD FOR PRODUCING GEARS



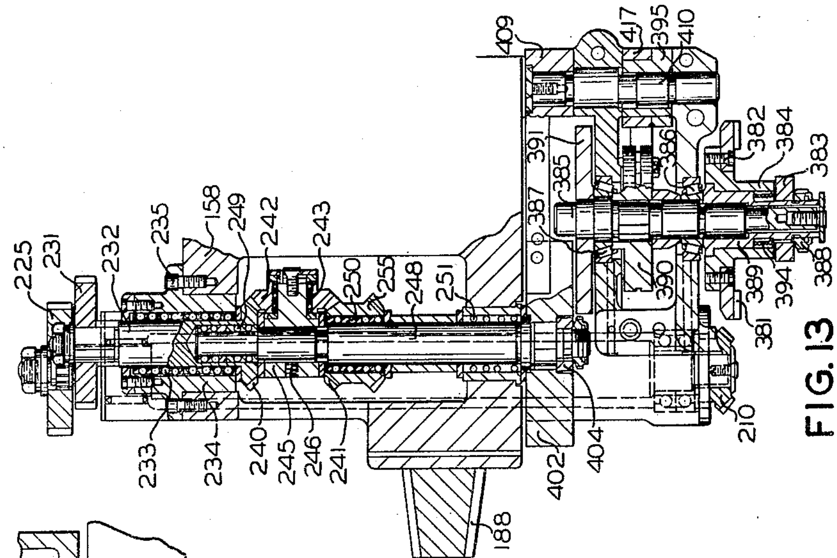


FIG. 13

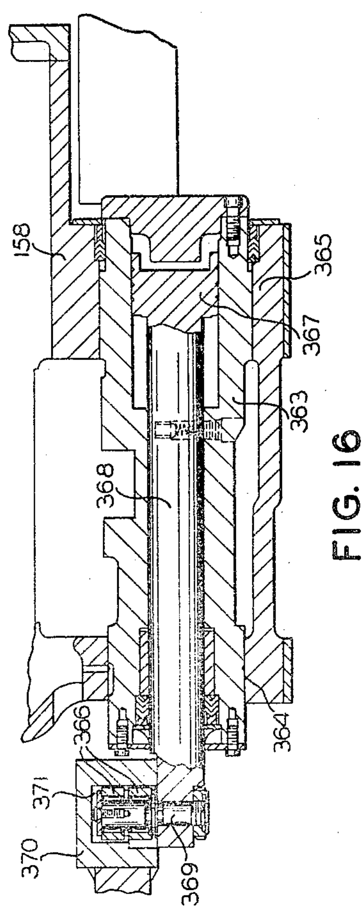


FIG. 16

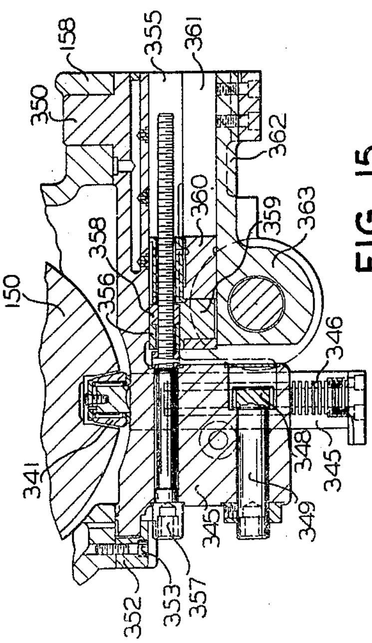


FIG. 15

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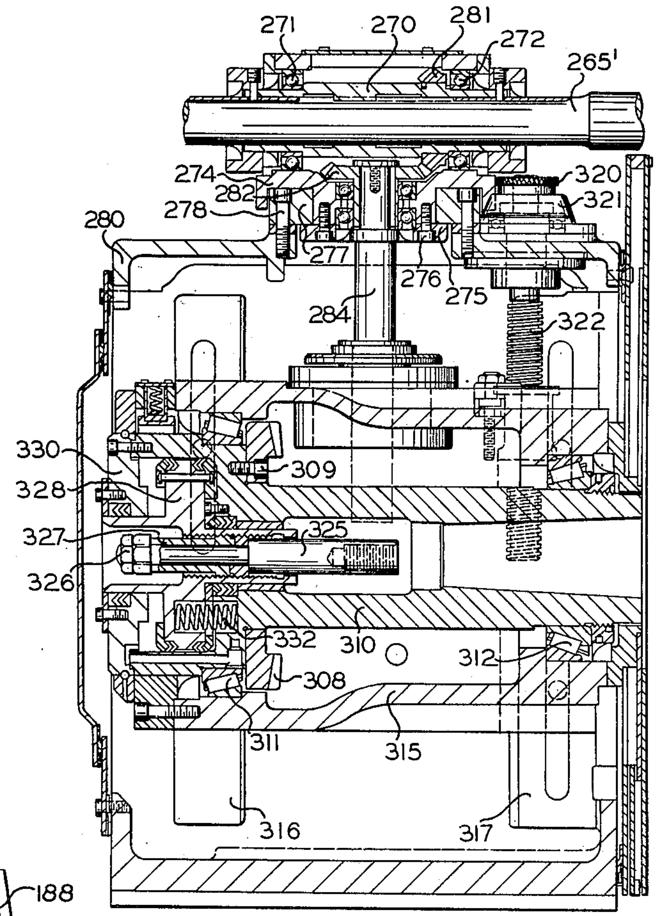


FIG. 18

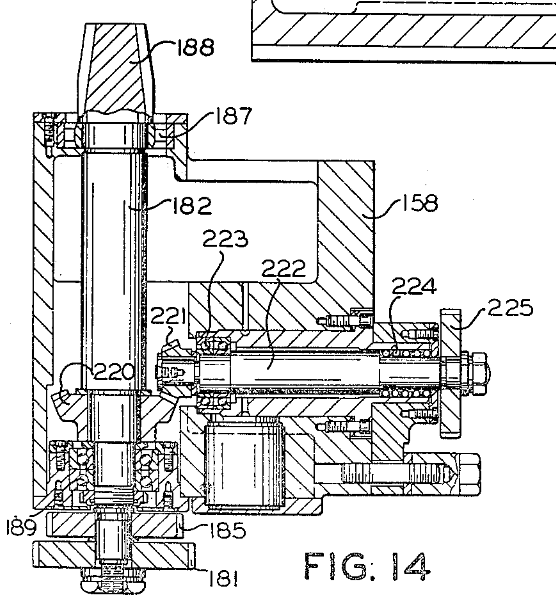


FIG. 14

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MACHINE AND METHOD FOR PRODUCING GEARS

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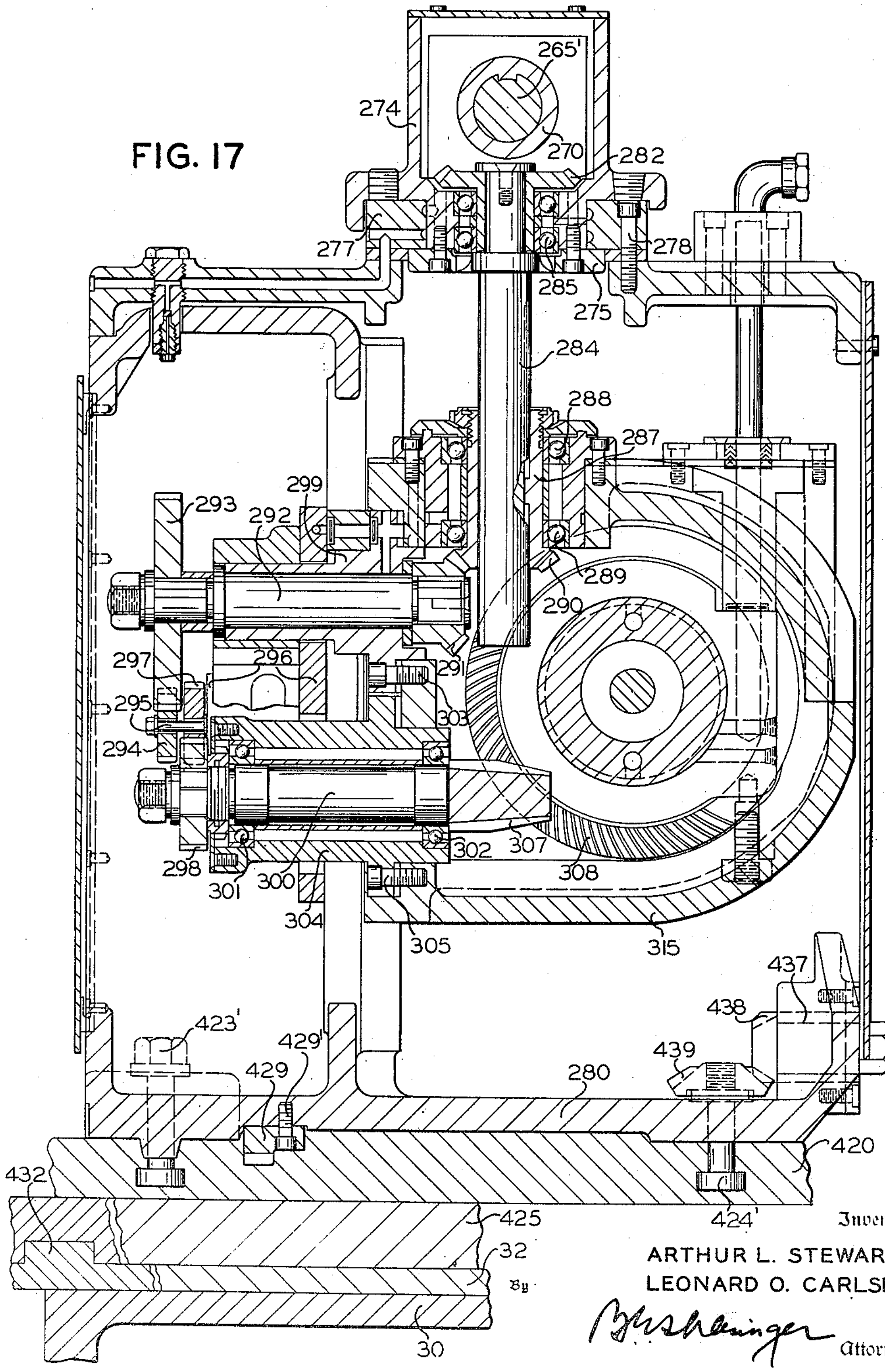
FIG. 17

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MACHINE AND METHOD FOR PRODUCING GEARS

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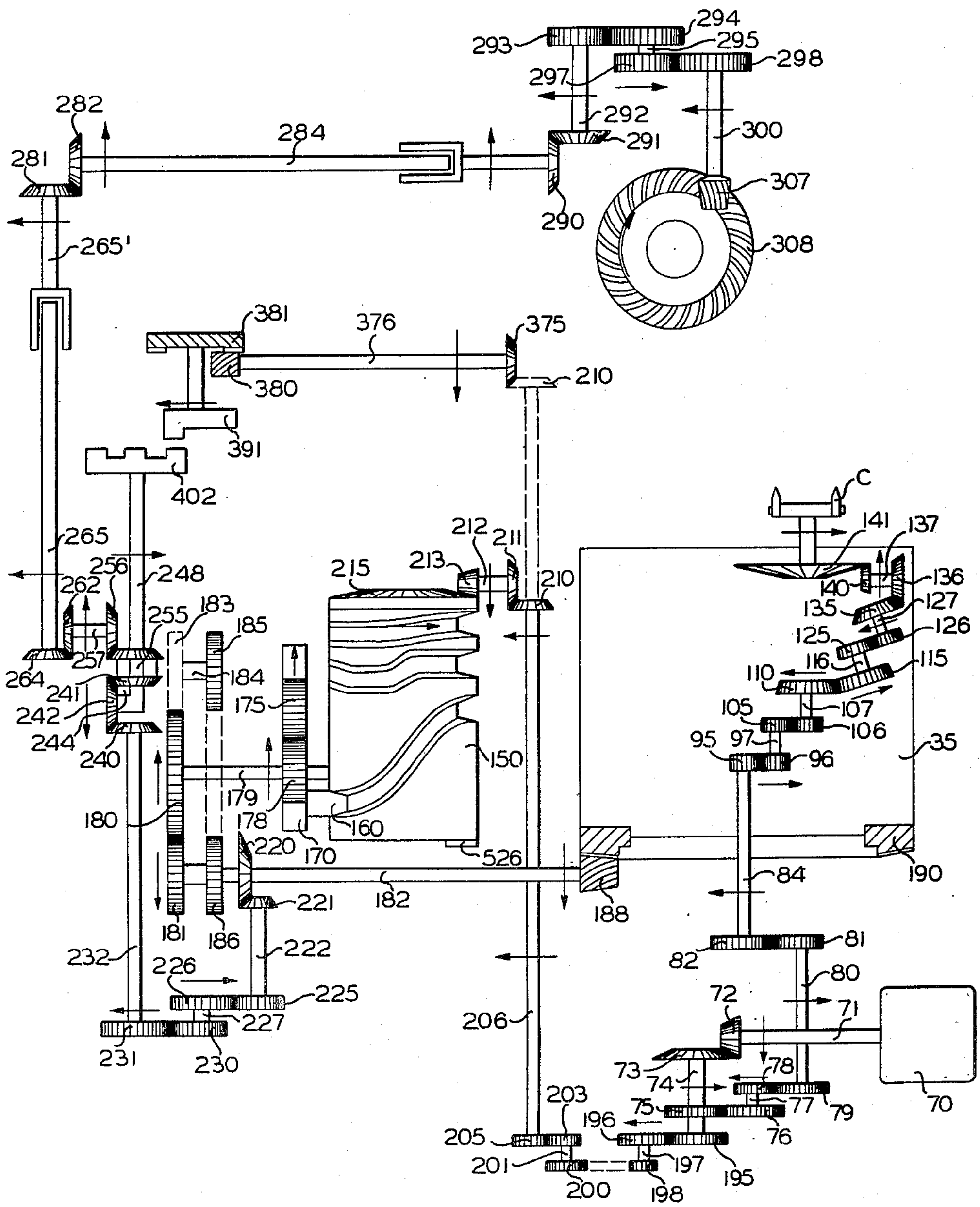

FIG. 19

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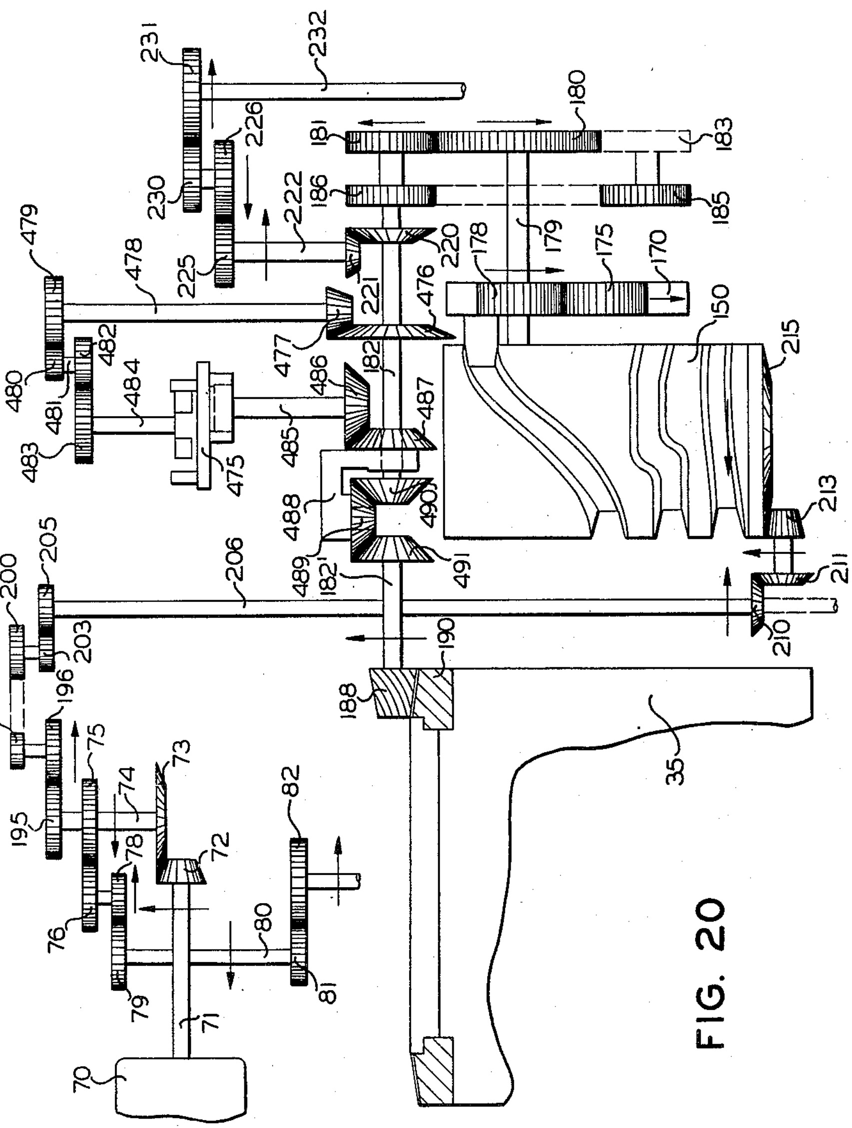


FIG. 20

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MACHINE AND METHOD FOR PRODUCING GEARS

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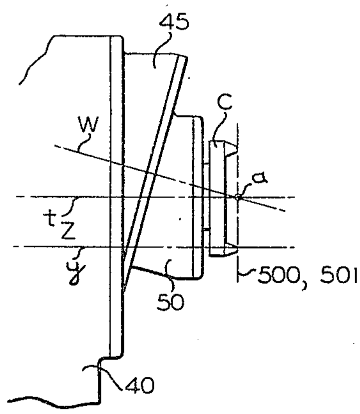


FIG. 21

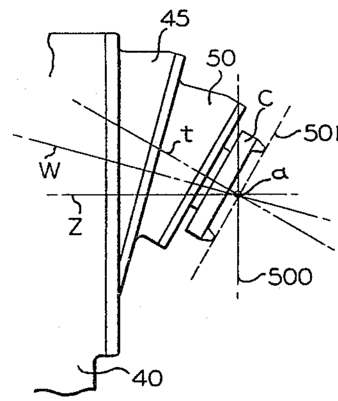


FIG. 22

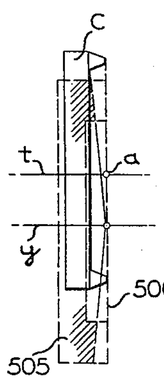


FIG. 23

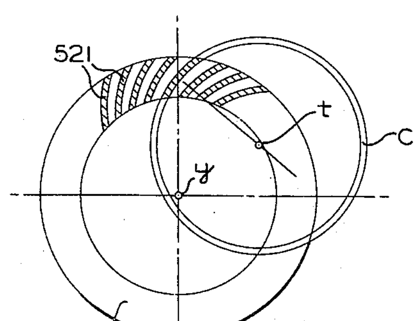


FIG. 25

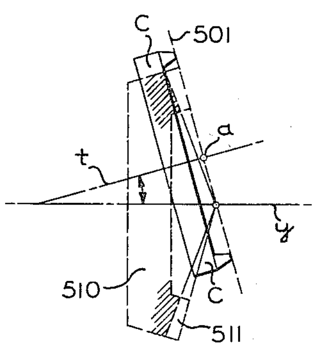


FIG. 24

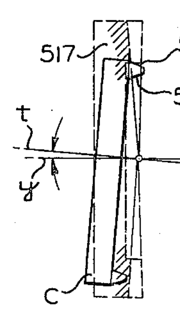


FIG. 26

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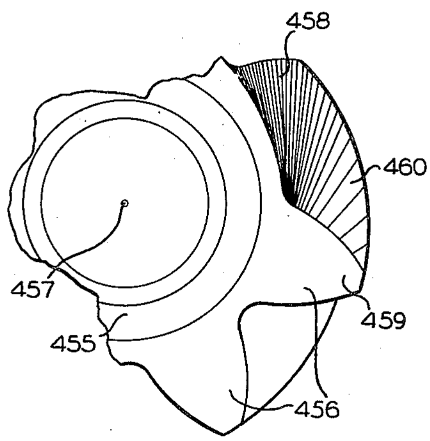


FIG. 30

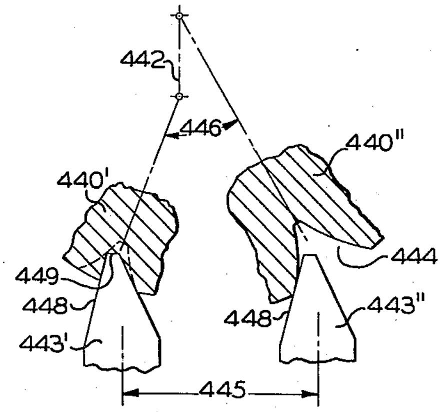


FIG. 27

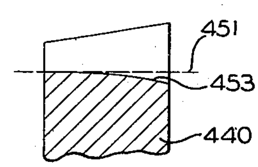


FIG. 28

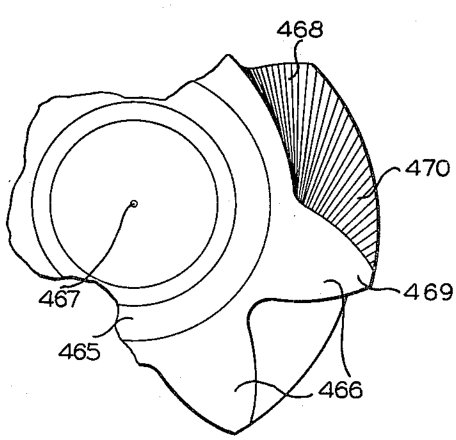


FIG. 31

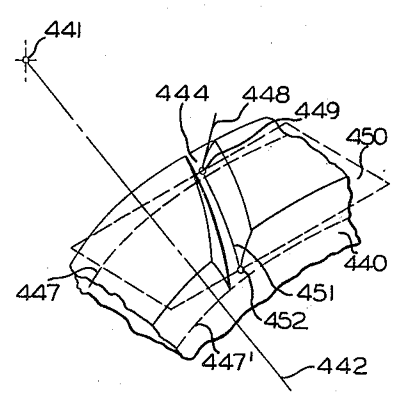


FIG. 29

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Patented Feb. 2, 1954 2,667,818

# UNITED STATES PATENT OFFICE

2,667,818

## MACHINE AND METHOD FOR PRODUCING GEARS

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Application October 15, 1947, Serial No. 779,890

24 Claims. (Cl. 90—5)



The present invention relates to machines for producing gears and particularly to machines for generating longitudinally-curved tooth gears, such as spiral bevel and hypoid gears, in an intermittent indexing operation.

In machines of the intermittent indexing type for generating gears, a cycle of operation comprises feed of tool and work into engagement, roll of tool and work relative to one another to generate a tooth side or sides, withdrawal of the work from engagement with the tool, and indexing of the work. The cycle is repeated for each tooth until the operation on the gear is completed. In a bevel or hypoid gear generator, the rolling motion may be achieved by rocking a cradle, on which either the tool or the work is mounted, and simultaneously, and in time therewith, rotating the work on its axis. Thereby the work is rolled relative to the tool as though it were meshing with a gear of which the tool represents a tooth. Generation may take place during both forward and return movements of the cradle and the work may be indexed at the end of the return roll, or generation may take place during roll in one direction only, and the work may be disengaged from the tool and indexed during the return roll.

Conventional bevel and hypoid gear generators, which operate according to the intermittent indexing principle, are made in two types, namely "segment-roll" and "geared-roll." In "segment-roll" machines, a gear segment, which is connected to the work, meshes with a gear segment that has a fixed relation to the tool, and oscillation of the cradle causes one segment to roll on the other to impart the required rotation to the work in time with the cradle movement. The cradle may be oscillated by a cam or eccentric. In "geared-roll" machines, both the cradle and the work spindle are driven by trains of gearing which include change gears for timing their relative motions, and a reversing mechanism is provided which periodically reverses these trains of gearing to cause oscillation of the cradle and the required rotation of the work.

"Segment-roll" machines are relatively simple in construction because reversal is effected by the cam or eccentric, which rotates continuously in one direction, and because the timing of the motions of tool and work are effected directly through the two segments. "Segment-roll" machines are, however, more or less special purpose machines, because for each different gear that is to be produced, ordinarily at least a different work segment is required. The number and cost of the segments required to cover the full range



of the machine make machines of this type, therefore, unsuitable for general purpose use.

"Geared-roll" machines have the advantage that the ratio of roll between tool and work can be varied for different jobs simply by substitution of change gears, which are relatively inexpensive. In conventional "geared-roll" machines, however, reversing mechanism is required, as above stated; and a reversing mechanism is a complicated device, difficult to time and expensive to construct if it is to operate quietly.

In "geared-roll" machines of the most universal type for generating spiral bevel and hypoid gears in which a face-mill cutter or annular grinding wheel is employed as a tool, there are two angular adjustments provided for the cutter aside from the adjustments required for spiral angle of the gear to be produced. These two angular adjustments permit of general control of the tooth bearing of the gear to be produced, enable a gear to be generated conjugate to a mate form-cut gear as well as to a crown gear or other basic gear, and permit of using a single cutter to cut gears of different pressure angles. Heretofore for at least one of these adjustments tilt about a pivot has been required. Thus the problem of clamping the cutter rigidly in its tilted position is presented.

In conventional spiral bevel and hypoid gear generating machines of the "geared-roll" type, tool and work are rolled together at a uniform rate during generation. This is true even though the ratio of roll may be varied during generation. Spiral bevel and hypoid gears cut on conventional "geared-roll" machines, therefore, have "flats" or generating cuts that are unequally spaced along the lengths of their tooth surfaces. The "flats" are closer together at the inner or small end of the tooth than at the outer or large end of the tooth. This means that the tooth surface finish on a gear generated on a conventional machine is not as good at the large end of the tooth as at the small end thereof.

One object of the present invention is to provide a gear generating machine which combines advantages of "segment-roll" and "geared-roll" type machines without any of their disadvantages.

Another object of the present invention is to provide a gear generating machine which is universal in character but relatively simple in construction.

A further object of the invention is to provide a gear generating machine for bevel and hypoid gears in which both the work and the cradle are driven by gear trains that include change gears but in which oscillation of the cradle is achieved without use of a reversing mechanism.

Another object of the invention is to provide a universal type machine for generating longitudinally curved tooth bevel and hypoid gears in which the cutter mounting and drive will be much more rigid than in prior type machines.

A further object of the invention is to provide a machine of the character described on which the cutter can be adjusted angularly to represent a form-cut tapered gear as well as a basic crown gear and on which the cutter can also be adjusted angularly to cut gears of different pressure angles, and in which both of these adjustments are attained without pivotal movement.

Another object of the invention is to provide a gear cutting machine in which the cutter mounting will be relatively simple and compact despite the number and range of cutter adjustments required.

A still further object of the invention is to provide a spiral bevel and hypoid gear generating machine in which work and cradle can be driven through gear trains including change gears but in which the rate of roll can be varied to secure speeding-up and slowing-down of the roll at different points along the length of a tooth as may be desired.

Still another object of the invention is to provide a spiral bevel and hypoid gear generating machine of the character described on which generating cuts of uniform width can be produced all along the length of a tooth surface so that the same tooth surface finish can be attained at the large end of a tooth as at the small end.

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

In a machine constructed according to the preferred embodiment of the present invention, the generating motion of the machine is controlled by a barrel cam which drives the cradle and the work spindle through a segment and separate trains of gearing, each of which includes change gears. The use of the cam obviates the need for a reversing mechanism and simplifies the whole structure of the machine. Moreover, by suitably shaping the cam track, variation in the rate of roll can be attained. Through use of different ratio of roll change gears for different jobs, this variation in rate of roll can be suitably applied in the cutting of different gears. Through use of a cam having a track formed to produce suitable variation in the rate of roll, also, uniform widths of generating cuts all along the length of a tooth surface of a longitudinally curved tooth bevel or hypoid gear can be secured where desired.

In a spiral bevel or hypoid gear generating machine constructed according to the present invention, the tool spindle is journaled in a carrier which is adjustable in a swivel head through an angle of 360° about an axis inclined to the axis of the tool spindle. This swivel head in turn is mounted eccentrically in an eccentric drum for adjustment through an angle of 360° about an axis parallel to but offset from the axis of the drum. The drum is in turn mounted eccentrically in the cradle and is adjustable therein through an angle of 360° about an axis parallel to but offset from the axis of the cradle. The cradle is not only oscillatable in the base of the machine but is mounted therein to be adjustable through an angle of 360°. Angular adjustment of the drum in the cradle varies the radial position of the tool from the axis of the cradle and adjustment of the cradle on the base of the machine enables the position of the tool to be varied about the axis of the cradle. Thus, the tool may be positioned to cut gears of any desired spiral angle. The angular adjustments of the swivel head and carrier enable a tool to be positioned to represent any tapered gear or basic gear during generation of the work and permit use of a cutter to cut gears of different pressure angles. The whole structure is very compact and rigid.

In the drawings:

Fig. 1 is a side elevation of a machine built according to one embodiment of this invention, the cover plate at one side of the machine being removed better to show certain operating parts;

Fig. 2 is a plan view of the machine with parts broken away;

Fig. 3 is a vertical sectional view through the machine looking at the face of the cutter carrying cradle;

Fig. 4 is a fragmentary longitudinal sectional view through the cutter carrying cradle, showing the cutter mounting and cutter drive;

Fig. 5 is a side elevational view of one of the brackets on the cradle housing, showing parts of the generating and feed mechanisms, parts being broken away;

Fig. 6 is a rear view of the same bracket, parts being broken away;

Fig. 7 is a view looking at the front of these brackets, showing details of the drives to the control cam and to the indexing mechanism of the machine;

Fig. 8 is a similar view, but with parts of the drive to the index mechanism removed in order to show more clearly details of the index mechanism itself;

Fig. 9 is a diametrical sectional view through the drive member of the modified Geneva type index mechanism of the machine;

Fig. 10 is a view showing the trip cam and trip lever of the indexing mechanism;

Figs. 11 and 12 are views at right angles to one another showing in detail the trip and lock-up levers of the index mechanism;

Fig. 13 is a horizontal sectional view taken on the line 13—13 of Fig. 8;

Fig. 14 is a fragmentary sectional view showing details of the drive to the cradle;

Fig. 15 is a fragmentary sectional view, showing details of the feed mechanism of the machine;

Fig. 16 is a sectional view showing details of the mechanism for moving the work between loading and operative positions, this view being taken at right angles to the view of Fig. 15;

Fig. 17 is a transverse vertical sectional view through the work head of the machine;

Fig. 18 is a longitudinal vertical sectional view through the work head, but on a somewhat smaller scale than Fig. 16;

Fig. 19 is a drive diagram of the machine as built according to one embodiment of the invention;

Fig. 20 is a fragmentary drive diagram of a modified form of machine;

Figs. 21 and 22 are diagrammatic views showing different positions to which the cutter may be adjusted by the adjustments of the present machine;

Fig. 23 is a diagrammatic view showing how, when the cutter is adjusted into one position, it may represent a nominal crown gear, that is, a generating gear having a face angle of 90°;

Fig. 24 is a diagrammatic view showing how in another position the cutter may represent a tooth of a generating gear whose pitch cone angle is considerably less than 90°;

Fig. 25 is a diagrammatic view taken at right angles to the views of Figs. 23 and 24, showing one position of the cutter when the gear, which it represents, has teeth of positive spiral angle;

Fig. 26 is a diagrammatic view showing how a cutter with a given blade pressure angle may be adjusted in the machine of the present invention to have different effective cutting pressure angles;

Fig. 27 is a diagrammatic view showing the positions of a cutter and pinion blank at the beginning and end of the roll in generating a spiral bevel or hypoid pinion;

Figs. 28 and 29 are a section taken lengthwise of the tooth space of a longitudinally curved tooth gear or pinion and a fragmentary perspective view of this tooth space, respectively, further illustrating why corresponding parts of the tooth profile are not cut simultaneously along the whole length of a tooth space;

Fig. 30 is a fragmentary view of a spiral bevel pinion such as might be generated on conventional machines, showing the nature of the cuts taken along the height of the tooth profile from one end of the tooth to the other; and

Fig. 31 is a corresponding view showing how these profile cuts may be equi-spaced by use of the machine of the present invention.

Referring now to the drawings by numerals of reference, 30 denotes the base of the machine. Secured to the base at one end thereof is the cradle housing 31 (Fig. 3). Mounted on the base at the other end thereof for angular adjustment thereon is sub-base 32 (Fig. 2). Journaled in the housing 31 on anti-friction bearings 33 and 34 is a cradle 35, shown fragmentarily only in Fig. 4.

Mounted in the cradle on plain bearings 41 and 42 for rotatable adjustment therein through an angle of 360° about an axis eccentric to the axis of the cradle is a drum 40. Journaled in the drum on plain bearings 46 and 47 for rotatable adjustment therein through an angle of 360° about an axis eccentric to the axis of the drum is a swivel head 45. Journaled in the swivel head 45 on plain bearings 51 and 52 for rotatable adjustment therein about an axis angularly inclined to the axis of the swivel head is a carrier 50. Journaled in the carrier on anti-friction bearings 56 and 57 is the cutter spindle 55.

The face mill cutter C, which is adapted to be used on the machine, may be secured to the cutter spindle 55 in any suitable manner as by means of a central bolt 61 which threads into the spindle 55. The cutter shown is of the type disclosed in U. S. Patent No. 2,586,428, granted February 19, 1952, and has a truing disc 62 (Fig. 4) secured to its rear face as by means of screws 63 (Fig. 3). Its cutting blades are denoted at 64.

The cutter spindle 55 is rotated continuously during operation of the machine, being driven from a motor 70 (Figs. 6 and 19) which is mounted at a suitable point in the cradle housing 31. The armature shaft of this motor is connected to a shaft 71 which is journaled in the cradle housing 31 and which carries a bevel pinion 72 that meshes with and drives a bevel gear 73. This gear is mounted on a shaft 74 to which is secured a spur gear 75. This shaft is also journaled in the cradle housing 31.

The spur gear 75 meshes with and drives a spur gear 76 which is secured to a shaft 77. There is a spur pinion 78 secured to this shaft which meshes with and drives a spur gear 79. The gear 79 is secured to a shaft 80 to which is secured a spur gear 81. Shafts 77 and 80 are journaled in cradle housing 31. The gear 81 meshes with and drives a spur gear 82 (Figs. 19 and 4) which is keyed or otherwise secured to a shaft 84 that is journaled on anti-friction bearings 85 and 86 in a sleeve 87. This sleeve is journaled in a bracket 88 that is secured by screws 89 to the cradle 35. It is secured by screws 90 to a bearing 91 that is journaled in cradle housing 31.

The shaft 84 is co-axial with the cradle 35. Keyed to the shaft 84 at its inner end is a spur pinion 95 which meshes with and drives a spur gear 96. This gear is integral with a shaft 97 that is journaled on anti-friction bearings 98 and 99 in a bracket 100 which is secured by screws 101 to the cradle.

The shaft 97 is mounted coaxial with the drum 40. It has a spur pinion 105 keyed to its inner end which meshes with a spur gear 106 which is keyed to the outer end of a shaft 107. This shaft is journaled on anti-friction bearings 108 and 109 in swivel head 45. Integral with this shaft at its inner end is an angular bevel gear 110. This gear meshes with an angular bevel gear 115 which is keyed to a sleeve 116 that is journaled on anti-friction bearings 117 and 118 on a stud 120.

This stud is held against axial movement relative to swivel head 45 by a nut 121 which threads onto the stud. Integral with the sleeve 116 is a spur gear 125. This meshes with a spur gear 126 that is integral with a shaft 127 which is journaled on anti-friction bearings 128 and 129 in a sleeve 130. The sleeve 130 is secured in any suitable manner to the carrier 50.

There is a bevel gear 135 keyed to the inner end of shaft 127. This meshes with a bevel gear 136 which is keyed to a shaft 137. This shaft is journaled on anti-friction bearings 138 and 139 in the carrier 50 with its axis at right angles to the axis of the cutter spindle 55. Integral with this shaft 137 at its inner end is a bevel pinion 140 which meshes with and drives a bevel gear 141 that is secured by screws 142 to the cutter spindle 55 to be coaxial with the cutter spindle.

The stud 120 is coaxial with the carrier 50 and the axis of the carrier is inclined to and intersects both the axis of swivel head 45 and the axis of cutter spindle 55. When supporting ring 50 is adjusted angularly, then, the axis of cutter spindle 55 swings about stud 120 and traces a conical surface about the axis of this stud. In this adjustment gear 126 rolls on gear 125 and the axis of the cutter spindle rolls about the apex of this conical surface.

The cradle 35 is adapted to be swung first in one direction and then in the other. The cutter may cut during swing of the cradle in one direction only or during swing of the cradle in opposite directions, according to any of the well known generating methods.

The swinging movement of the cradle is effected by operation of a barrel cam 150 (Figs. 5, 6, and 19). This cam has a plurality of tracks 151, 152, and 153. It is keyed to a shaft 155 that is journaled on anti-friction bearings 156 and 157 in a bracket 158 that is secured in any suitable manner to the cradle housing 31. The tracks 151 and 152 control the movement of the work to and from operative engagement with the tool as will be described later. The track 153 controls the operation of the cradle.

A tapered cam roller 160 engages in this track 153. It is mounted by means of anti-friction bearings 161 on a stud 162 which is secured by screws 163 to a rocker arm 165. The rocker arm is journaled at its lower end by means of anti-friction bearings 166 on a stud 167 which is secured by screws 168 to the bracket 158. The stud projects through an arcuate slot 169 in cam housing 164 so that roller 160 may engage in cam track 153. The slot 169 is concentric with pivot pin 167.

There is a spur gear segment 170 secured by screws 171 to the outer end of rocker arm 165. This spur gear segment meshes with a spur gear 175 which is secured to a shaft 176 that is journaled in bracket 158. The pinion 175 meshes with a spur gear 178 that is secured to a shaft 179. There is a second spur gear 180 secured to this shaft. This gear may be meshed with a spur gear 181 that is secured to a shaft 182, or it may be meshed with a spur gear 183 that is secured to shaft 184. This shaft has a second spur gear 185 secured to it which meshes with a spur gear 186 that is secured to shaft 182. Shaft 182 is journaled on anti-friction bearings 187 and 189 (Fig. 14) in bracket 158 and has a hypoid pinion 188 integral with it at its inner end. This hypoid pinion meshes with a hypoid gear 190 which is secured by bolts 191 (Fig. 4) to the cradle 35 and which is coaxial with cradle 35.

The segmental gear 170 (Fig. 6) is held against an arcuate guide surface 172 (Fig. 5) by a gib 173 which is secured to cam housing 164 by screws 174, so as to prevent chatter of the rocker arm 165 in its movement. Guide surface 172 is curved about the axis of stud 167.

The cam 150 makes one revolution per tooth of the work as will be described hereinafter more particularly, and the cam track 153 will operate through the gearing described, therefore, to swing the cradle forward and back once per tooth of the work. Whether the cradle swings upward and then downward in a throat-cutting cycle, or, vice-versa, downward and then upward is determined by whether shaft 182 is driven through gears 180 and 181 or through gears 180, 183, 185, and 186. When shaft 182 is to be driven through gears 180 and 181, change gear 183 may be removed from the machine, and when shaft 182 is to be driven in the opposite direction, change gear 181 may be removed.

Shaft 182 may be rotated manually to adjust cradle 35 angularly about its axis. Drum 40 may be adjusted angularly on its axis by rotation of a stub shaft 192 (Fig. 3) which is journaled in the cradle 35 and which carries a spur pinion (not shown) that meshes with a spur gear 193 (Fig. 4) which is secured to drum 40. Swivel head 45 is adjusted angularly in drum 40 by rotation of stub shaft 194 (Fig. 3) which carries a spur pinion (not shown) that meshes with a spur gear 199 (Fig. 4) that is secured by screws 202 to swivel head 45. Carrier 50 may be adjusted angularly in swivel head 45 by rotation of stub shaft 207 (Figs. 3 and 4) which carries a spur pinion 208 that meshes with a spur gear 209 which is secured to carrier 50.

A ring or gib 217, that is secured by screws 218 to cradle housing 31, serves to hold the cradle against forward movement axially in the cradle housing. This gib is graduated as shown in Fig. 3 to read against a vernier 217′ to permit of the angular adjustment of the cradle being made accurately. The vernier is fastened to the cradle. A graduated ring 219, that is secured to cradle 35 and that reads against a vernier 219′ which is fastened to drum 40, serves for accurate adjustment of drum 40 in the cradle. A ring or gib 221 (Figs. 3 and 4), that is secured by screws 227 to drum 40, serves to hold swivel head 45 against movement in one direction axially in the drum. This gib is graduated to read against a vernier 221′, which is secured to the swivel head, to permit accurate adjustment of the swivel head in the drum. A ring or gib 229, that is secured to swivel head 45, serves to prevent axial movement of carrier 50 in swivel head 45. This gib is graduated to read against a vernier 229′, which is secured to carrier 50, to permit accurate adjustment of the supporting ring in the swivel head. A gib 236, which is secured by screws 237 (Fig. 4) to carrier 50, serves to secure cutter spindle 55 in place.

With the shaft 84 mounted coaxial with the cradle, the shaft 97 mounted coaxial with the drum 40, the shaft 107 mounted coaxial with the swivel head 45, and the shaft 120 mounted coaxial with the carrier 50, the drive can be transmitted to the cutter in any position of its adjustment without use of telescoping shafts. Thus the greatest accuracy with freedom from excessive backlash in the drive train is achieved. The front face of the cradle, and the front face of drum 40 are parallel and perpendicular to the axes of these two parts. The front face of swivel head 45 is approximately helical so as to accommodate the carrier 50 whose axis is inclined to the axis of the swivel head. The front face of the supporting ring is perpendicular to the axis of the cutter spindle 55 as shown in Fig. 4.

The barrel cam 150 is adapted to be driven from shaft 74 (Fig. 19). There is a spur gear 195 secured to this shaft which meshes with a spur gear 196. Gear 196 is secured to a shaft 197 which carries a spur gear 198 that meshes with a spur gear 200. Gear 200 is secured to a shaft 201. A spur gear 203, which is secured to this shaft, meshes with a spur gear 205 that is keyed to a shaft 206. There is a bevel miter gear 210 (Figs. 7, 8 and 19) fastened to shaft 206 which meshes with a bevel miter gear 211. The latter miter gear is secured to a shaft 212 which is journaled on anti-friction bearings 209 and 214 in a bracket 389 which is secured to cradle housing 31. A hypoid pinion 213 is integral with shaft 212 at its lower end. This pinion meshes with a hypoid gear 215 that is secured to one end of the barrel cam by screws 216 (Fig. 5). The gearing is so selected that the cam 150 makes one revolution per cycle of the machine, that is, one revolution per tooth side or sides.

During generation of the tooth side or tooth sides, the work is driven in time with the cradle. The generating drive to the work is derived from shaft 182 (Figs. 14 and 19). This shaft has a bevel gear 220 keyed to it which meshes with and drives a bevel pinion 221. This bevel pinion is keyed to a shaft 222 which is journaled on anti-friction bearings 223 and 224 in the bracket 158. There is a spur gear 225 keyed to the shaft 222 at its outer end. This gear meshes with a spur gear 226. This gear is secured to a stud shaft 227 which is journaled in a quadrant 228 (Fig. 5). The quadrant may be of conventional construction and is adapted to swing about stud 229 and to be secured in any adjusted position by bolt 236. Stub shaft 227 carries at its outer end a spur gear 230. Gear 230 meshes with a spur gear 231 which is secured to a shaft 232 (Figs. 13 and 19). This shaft is journaled directly on balls 233 in a sleeve 234 that is secured by screws 235 to the bracket 158.

The shaft 232 has a bevel gear 240 at its inner end which forms one of the side gears of a differential that is designated as a whole at 244. The other side gear of this differential is denoted at 241. 242 designates the planetary pinion of the differential. This meshes with the two side gears 240 and 241. This pinion is journaled directly through balls 243 on a spider member 245 that is secured by a key and by a set-screw 246 to a shaft 248. This shaft is journaled on balls 249 in shaft 232 and on balls 250 in side gear 241 and on balls 251 in the bracket 158.

Integral with the side gear 241 is a bevel gear 255. This gear meshes with a bevel gear 256 (Figs. 5 and 19) that is integral with a shaft 257. This shaft is journaled on anti-friction bearings 258 and 259 in a swivel member 260 that is rotatably adjustable in the top of the cradle housing 31. Secured to the upper end of this shaft 257 is a bevel gear 262. This bevel gear meshes with a bevel gear 264 which is keyed to a sleeve 266 which in turn is keyed to one end of a telescoping shaft 265. The sleeve 266 is journaled on anti-friction bearings 267 and 268 in the swivel member 260.

The opposite end 265′ (Figs. 17, 18 and 19) of the telescoping shaft is keyed to a sleeve 270 which is journaled on anti-friction bearings 271 and 272 in a swivel member 274. This swivel member is secured by a gib 275 and screws 276 to a ring 277, which, in turn, is secured by screws 278 to the top of the work head column 280 of the machine. Fastened to the sleeve 270 is a bevel gear 281 which meshes with a bevel gear 282 that is secured to a vertical shaft 284. This shaft is journaled at its upper end on anti-friction bearings 285 in swivel member 274. At its lower end it has telescoping keyed engagement with a sleeve 287 that is journaled on anti-friction bearings 288 and 289 in the work head 315 of the machine.

Integral with the sleeve 287 is a bevel gear 290. This bevel gear meshes with a bevel gear 291 that is keyed to a horizontal shaft 292. This shaft is journaled in a sleeve 299 which is secured by screws 303 to work head 315. There is a spur gear 293 keyed to the outer end of the shaft 292. This spur gear meshes with a spur gear 294 that is secured to a stub-shaft 295 which is mounted in a quadrant 296. There is another spur gear 297 secured to this stub-shaft which meshes with a spur gear 298 that has splined connection with a shaft 300. The shaft 300 is journaled on anti-friction bearings 301 and 302 in a sleeve 304 that is secured by screws 305 to the work head 315. There is a hypoid pinion 307 integral with the shaft 300 at its inner end. This meshes with a hypoid gear 308 which is secured by screws 309 (Fig. 18) to the work spindle 310 of the machine.

The work spindle is journaled on anti-friction bearings 311 and 312 in the work head 315.

The work head 315 is mounted in the column 280 for vertical sliding movement on plane surfaced ways 316 and 317. Vertical adjustment of the work head may be effected by rotation of the knurled knob 320 which has a graduated dial 321 secured to it. This knob is secured to or integral with a screw 322 that threads into a nut (not shown) which is secured to the work head 315. The adjustment of the work head in the column 280 permits of positioning the work axis in the same plane as the axis of the cradle for cutting spiral bevel gears, or of positioning the work axis above or below the cradle axis for cutting hypoid pinions.



Through the gearing described the work is driven in time with the cradle to effect the generating operation. The gears 225, 226, 230 and 231 are change gears and govern the ratio of the generating roll. The gears 293, 294, 297, and 298 are change gears and govern the number of teeth to be cut in the work. The use of hypoid gears 188 and 190 and 307 and 308 for driving cradle and work spindle permits of fast speed operation of both the cradle and work gear trains, minimizing the effect of any possible errors in the gears of either of these trains on the work produced, a very important item in these days when gears must be cut to accuracies measured in thousandths of an inch.

The gear G (Fig. 1), which is to be cut, may be secured to the work spindle 310 by any suitable chucking mechanism. This chucking mechanism may be actuated by a draw bar 325 which is secured by nuts 326 to a sleeve 327 that is threaded into a piston 328. The piston is adapted to reciprocate in a cylinder which is designated as a whole at 330. The draw bar 325 may be moved rearwardly to chucking position and forwardly to dechucking position by fluid-pressure or it may be moved rearwardly to chucking position by coil springs such as denoted at 332 and forwardly to released position by fluid-pressure. This type of chucking mechanism is well known in the art and need not further be described.

During operation of the machine, the work is fed into operative relation with the cutter and then cutter and work are rolled together to generate a tooth surface or a pair of tooth surfaces of the work, and then the cutter is withdrawn from engagement with the work and the work is indexed. The mechanism for moving the work toward and from operative position is actuated by rotation of barrel cam 150. The cam is provided with two feed track-ways 151 and 152 (Fig. 5), already mentioned. One of these track-ways controls the feed and withdrawal motions during a rough-cutting operation and the other track-way controls the feed and withdrawal motions during a finish-cutting operation. The two cam rollers 341 and 342 are adapted to be engaged selectively with the cam tracks 151 and 152 depending upon whether a rough-cutting or a finish-cutting operation is to be performed. The two rollers 341 and 342 are journaled on posts 343 and 344, respectively, which are mounted for axial reciprocation in a cam lever 345 (Figs. 5 and 15). Racks 346 and 347 are cut into opposed faces of the posts 344 and 343, respectively. A spur pinion 348 is interposed between and meshes with the two racks. This spur pinion is integral with a shaft 349 which is journaled in the cam lever 345 and is manually rotatable to move one or the other roller 341 or 342 selectively into engagement with the tracks 151 and 152 of the cam. When one roller is in operative position, the other is retracted therefrom.

The lever 345 is pivotally mounted by means of a stud or pin 350, which is integral with it, in the cam housing 164. A gib 352, which is secured by screws 353 to the bracket, serves to hold and guide the lever in its pivotal movement.

Slidably mounted in an elongated slot 355 in the lever is a block 356. This block is adjusted by means of a screw shaft 357 which is journaled in the lever and which threads into a nut 358 that is secured in the block 356. There is a pivot pin 359 integral with block 356 and on this pin there is pivotally mounted another block 360 which engages in an elongated slot 361 formed in an extension 362 of a cylinder 363. The cylinder is slidably mounted in aligned bearings or guides 364 and 365 (Fig. 16) of bracket 158. A piston 367 is mounted to reciprocate in the cylinder 363. Integral with this piston is a piston rod 368. This piston rod is connected by a coupling pin 369 with a bar 370. The coupling pin 369 carries rollers 366 that engage in a recess 371 in bar 370. Bar 370 is connected to a sliding base 425 (Fig. 2) which slides on ways 431 and 432 of sub-base 32 of the machine, as will be described more particularly hereinafter.

Fluid under pressure may be admitted to opposite sides of the piston 367 to move the sliding base away from the cutter sufficiently to permit removal of a completed gear and positioning of a new work piece, but during cutting of a gear the piston 367 is held in the position shown in Fig. 16 under fluid pressure and alternate feed and withdrawal of the work are controlled by cam 150 through whichever of its feed tracks 151 or 152 is in operation. Movement of the sliding base to loading position and its return to operative position are controlled by a valve (not shown) which may be operated by a lever 372 (Fig. 3).

The feed and withdrawal mechanism of the machine is similar in many respects to the mechanism disclosed in Carlsen Patent No. 2,302,004, granted November 17, 1942.

As previously stated, the work is indexed periodically. The indexing mechanism may be of any suitable character. That shown is of the type disclosed in the pending application of Ernest Wildhaber, Serial No. 792,570, filed December 18, 1947, now U. S. Patent No. 2,477,105, granted July 26, 1949, and reference may be had to that application for a more complete description thereof. The indexing mechanism is actuated from the bevel gear 210 (Figs. 7, 8, and 19). This gear meshes with and drives not only bevel gear 211 but also a bevel gear 375. This is indicated diagrammatically in Fig. 19, the gear 210 being shown in full lines in engagement with gear 211 and in dotted lines in engagement with gear 375. The gear 375 is keyed at one end of a shaft 376. This shaft is suitably journaled in a bracket 377. Integral with this shaft is a cylindrical pinion 380 which meshes with a hypoid face gear 381. This gear is secured by screws 382 (Fig. 13) to a sleeve 384. The sleeve 384 has face clutch teeth formed on its outer end that are adapted to be engaged by face clutch teeth formed on the opposed face of a ring 383. The clutch is adapted to be held in engaged position by a nut 388 that threads onto a sleeve 389. The ring 383 is keyed to this sleeve 389. A coil spring 394, which surrounds sleeve 389 and seats against ring 383, tends to release the clutch. Sleeve 389 is keyed to a shaft 385. This shaft is journaled on anti-friction bearings 386 and 387 in the bracket 158.

Keyed to the shaft 385 are a cam member 390 and an actuating plate 391. Secured to the actuating plate 391 by screws 392 (Fig. 8) and the dowel pin 393 (Fig. 9) is a spur gear segment 395 and journaled on this segment is a roller 396. The roller is held on the segment by a plate 397 and screw 398. The roller is adapted to engage successively in cam slots 400 and 401 formed in a Geneva plate 402. This Geneva plate is keyed to shaft 248 (Figs. 8, 13 and 19). Keyed to this shaft, also, and positioned within a recess formed in one face of the Geneva plate is a segmental spur gear 404 which has teeth 405 at diametrically opposite sides of its axis registering with the slots 400 and 401, respectively.

The Geneva plate 402 is held against rotation during cutting by a lock dog 407 (Figs. 7, 8 and 12) which engages in a notch in the plate and which is secured to a lever 409 that is keyed to a shaft 410. This shaft is journaled in the bracket 158.

The cam 390 has two trackways 423 and 424 (Fig. 10). The lever 409 is held in locking position by action of a double-armed lever 417 which is also keyed to shaft 410. One arm of this lever carries a roller 419 that rides on one trackway 423 of the cam. The other arm of this lever has a spring 415 housed in it which seats against an arm 418. The arm 418 is mounted rotatably on the hub of lever 417. It carries a roller 416 that rides on the trackway 424 of cam 390. This roller is secured to arm 418 by a bolt 412 and nut 413. A pin 406, which threads into arm 418 (Fig. 12), and a nut 408, which threads onto the pin, serve to limit relative movement of arm 418 and lever 409.

Each of the cam tracks 423 and 424 has a dwell portion of large radius and a dwell portion of small radius, connected by rises, but the major and minor diametral portions of the two cams are slightly spaced angularly relative to one another in accordance with the angular spacing of rollers 416 and 419 so that the portion of one trackway which is of major radius is in alignment with the portion of the other trackway which is of minor radius and vice versa. When the locking dog 409 is in engaging position roller 419 is on the high part of cam surface 424 and roller 416 is on the low part of cam surface 423. The shaft 385 rotates continuously and makes one revolution per cycle of the machine and the cam 390 and actuating plate 391 revolve with it. When the roller 419 rides down off the high part of the cam surface 424 and the roller 416 rides up on the high part of cam surface 423, the lever 409 is swung outwardly to disengage dog 407 from Geneva plate 402. When this occurs, the actuating plate 391 is free to rotate under actuation of the gearing 213—215. The result is that the roller 396 engages in one of the slots 400 or 401, which is then in registry with the roller and the actuating plate 391 drives the Geneva plate 402. The first part of the motion is under control of the roller 396. Thus, it starts slowly and accelerates gradually. When the two plates 391 and 402 have rotated far enough to bring segmental gear 395 into engagement with teeth of segmental gear 404, the motion is continued but at a uniform rate under control of said gearing. When the gears 395 and 404 rotate out of engagement, then the roller 396 again takes control to complete the motion and bring the Geneva plate to a slow stop. As the Geneva plate 402 rotates, an increment of motion is imparted to the shaft 248 which operates through the differential 244 to add or subtract motion from the shaft 232 which drives the work spindle. Thus, indexing of the work spindle is effected. The Geneva plate makes half a revolution during indexing and then is locked up again.

The column 280 (Figs. 1, 2 and 17), which carries work head 315, is mounted upon a swinging base 420 for rectilinear adjustment thereon in the direction of the axis of the work spindle along ways 421 and 422 (Fig. 2). It is adapted to be held in any adjusted position by T-bolts 423' and 424' (Fig. 17) which engage in T-slots 427 formed in said ways. Adjustment of the column on the swinging base may be effected in known fashion by rotation of a shaft (not shown) which is journaled in swinging base 420 and which carries a spur pinion that meshes with a rack 429 which is secured to the underside of the column by screws 423'. Each T-bolt 424 may be tightened or released by manual rotation of a shaft 437. This shaft carries a bevel gear 438 which meshes with a bevel gear 439 that is threaded on bolt 424.

The swinging base 420 is pivotally mounted for angular adjustment about an axis $x$ (Fig. 2) on sliding base 425. A guide way 426 is provided on the sliding base for this purpose. The swinging base is secured in any adjusted position by T-bolts which engage in the arcuate T-slot 428 formed in this guide-way. The sliding base 425 is mounted for rectilinear adjustment and sliding movement upon sub-base 32 being guided by ways 431 and 432 formed on the sub-base and sliding on the rollers 433 and 434 (Fig. 3) that are mounted in the top and sides of these ways. The sub-base is adjustable angularly on the base 30 of the machine. For this purpose it has a trunnion 435 secured to it which is journaled in a plate 436 which is secured by screws 437 to base 30. The sub-base is graduated at its periphery, as shown in Fig. 2 concentric with the axis of trunnion 435 to permit accurate adjustment of the sub-base. The graduations read against a zero mark on a lug 438 which is integral with base 30.

The rectilinear adjustment of column 280 permits of positioning the work in accordance with the cone distance of the gear G to be cut. The angular adjustment of the swinging base 420 permits of adjusting the work in accordance with the cone angle of the gear to be cut.

Machines may be built according to the present invention either for cutting longitudinally curved tooth tapered gears or for grinding such gears. In a grinding machine, angular adjustment of sub-base 32 permits of positioning the ways 431 and 432, when the grinding wheel is positioned to represent a tapered gear other than a crown gear, so that the sliding base 425 will travel in a direction to bisect the angle between opposite sides of the grinding wheel. This insures equal wear on opposite sides of the wheel as the work is fed step-by-step into the wheel as described in detail in pending application of William C. Critchley and Herman A. Male, Serial No. 56,144, filed October 23, 1948, Patent No. 2,566,402, granted September 4, 1951.

In a gear cutting machine there is no particular advantage to moving the sliding base in an inclined direction. Hence in a gear cutting machine, sub-base 32 is set at its zero adjustment so that ways 431 and 432 extend in the direction of the axis of the cradle and the sliding base 425 moves in that direction toward or from operative position.

One of the principal features of the present invention, as already stated, is the use of a cam for actuating the gear trains that drive the cradle and the work and effect the generating roll. The cam eliminates the reversing mechanism and it permits of obtaining any desired variation in rate of roll during generation. One way in which this ability to obtain variation in rate of roll may be taken advantage of is illustrated in Figs. 30 and 31. First, however, we shall refer to the character of the cut obtained on a spiral bevel or hypoid gear with a face-mill cutter.



In a spiral bevel or a hypoid gear each tooth and tooth space curves around the cone of the gear so that the cutter begins to cut in the generating roll at one end of a tooth space and the cuts extend diagonally across the side of the tooth gradually enveloping the tooth surface until the other end of the tooth surface has been generated at the end of the roll.

Figs. 28 and 29 illustrate the character and reason for this kind of cutting action. 440 denotes the gear or pinion which is to be cut; 441 is its apex and 442 its axis. The teeth and tooth spaces taper in depth from end to end. 447 is the root circle of the work at the small end of a tooth space 444, and 447' is the root circle of the work at the large end of the tooth space. 448 denotes a side-cutting edge of a blade of the face-mill cutter used in cutting the work. 449 is the extreme point in this cutting edge. As the cutter revolves in engagement with the work at any one position of the roll, this point travels in a plane perpendicular to the cutter axis. When this point is cutting in the root surface of the work at the small end of the tooth space, 451 is the path of this point as it moves across the face of the work. This is a curved line lying in plane 450 tangent to root circle 447. This line appears as a straight line, however, in Fig. 28, which is a section looking at one side of the tooth space. The point 452 is the point at the large end of tooth space 444 which lies in plane 450. 453 is the bottom of the tooth space. This appears curved in Fig. 28 because it is wrapped around the cone of the work.

The cut proceeds from the small end of a tooth space to the large end thereof during the generating roll, and as cutter and blank roll together, the blades of the cutter take successive diagonal cuts along the height of the tooth profile from the small to the large end of the tooth, enveloping by these cuts the tooth surface to be generated. The smoothness of the tooth surface produced will depend on the number of these cuts. Fig. 27 illustrates the generating roll. Here 400' and 440'' denote, respectively, two positions of a pinion blank at the beginning and end of the generating roll, respectively. 443' and 443'' denote fragmentarily the corresponding positions of the face mill cutter which is employed. The pinion is inclined to the cutting plane of the cutter by its root angle or other suitable angle to obtain the desired taper in tooth depth.

As the work rotates on its axis 442, then, the motion of the cradle swings the cutter about the axis of the gear represented by the cutter. During the time that the work rotates about its axis 442 through the angle 446 from position 440', where the cutter is cutting at the small end of the tooth space to the position 440'', where the cutter is cutting at the large end of the tooth space, the cutter will have moved through distance 445 from position 443' to position 443''. The cuts diagonally across the tooth surface generate and envelope the required tooth shape all along the length of the tooth.

In conventional "geared-roll" type machines, the rate of roll is uniform throughout generation. As a result, the cuts or "generating flats" are spaced further apart at the large end of a tooth than at the small end thereof, because the tooth has a greater height at the large end.

Fig. 30 illustrates diagrammatically the type of cut achieved with prior types of "geared roll" generating machines. 455 designates a spiral bevel pinion; 456 are its teeth; and 457 its axis. 458 denotes the small end of a pinion tooth and 459 the large end thereof. The cuts taken on the tooth surface in the generating roll are designated at 460. These cuts or so-called "generating flats" have been closer together heretofore, as shown, at small end of the tooth than at the large end thereof because the roll is uniform and each part of the tooth height rolls at the same rate under the rotating cutter. As a result of the method of operation of the prior types of machines, then, the finish at the large end of a spiral bevel or hypoid pinion is coarser at the large end of the tooth than at the small end thereof.

With the machine of the present invention, however, the same finish can be attained at the large end of the tooth as at the small end. This is achieved through provision of a cam track 153 on the barrel cam 150 which will produce a variation in the rate of roll such that the cradle moves more slowly during generation of the large end of the tooth than during generation of the small end of the tooth. The result is illustrated in Fig. 31. Here 465 denotes the pinion being cut, 466 its teeth, 467 its axis, 468 the small end of a tooth and 469 the large end thereof, and 470 the flats or profile cuts taken on the tooth during the generating operation. It will be noted that on the pinion 465, the "generating flats" are of equal width along the whole length of the tooth.

A further advantage in structure of the present machine is that the same cam 150 be used on all jobs within the range of the machine. Suitable variation in the rate of roll for each given job is obtained simply by selection and use in the gear train of proper ratio change gears 225, 226, 230 and 231 (Fig. 19).

The advantages of the variation in rate of roll are not limited either to a machine in which uniform ratio of roll is employed. They can still be achieved even where for any reason it is desired to vary the ratio of roll during generation, as to modify the tooth profile shape, increase the range of usefulness of the machine, etc.

Modification in ratio of roll can be obtained by providing a suitable ratio varying mechanism of the type disclosed, for instance, in Wildhaber Patent No. 2,342,232, granted February 22, 1944. This mechanism is denoted generally at 475 in Fig. 20. It may be driven from shaft 182, which is split for this purpose, through a bevel gear 476 which is secured to that shaft and which meshes with a bevel pinion 477 that is fastened to a shaft 478. The latter shaft carries a spur gear 479 which meshes with a spur gear 480 on shaft 481. Shaft 481 has a second spur gear 482 secured to it which meshes with a spur gear 483 on a shaft 484. This shaft carries the cam or eccentric rollers which produce the modification in motion. The head or block which engages with the cam or the rollers and is actuated thereby is secured to a shaft 485. This shaft may have a miter bevel gear 486 secured to it which meshes with a miter bevel gear 487. The bevel gear 487 is secured to a spider 488 which is rotatable on shaft 182. The spider carries and rotatably supports a planetary bevel pinion 489. This pinion meshes with bevel side-gears 490 and 491. Gear 490 is secured to shaft 182 and gear 491 is secured to the axially aligned shaft 182′.

The gears 489, 490 and 491 constitute a differential permitting the variation in motion produced by mechanism 475 to be superimposed on the cradle drive. The differential is here used because the cradle is driven by hypoid gearing. Its action is like the reciprocal motion imparted to the cradle worm in the Wildhaber patent mentioned. It superimposes a varying motion on the cradle drive which modifies the ratio of roll of cutter and work during generation. This is separate from and independent of any variation in rate of roll that may be produced by cam 150.

Another outstanding feature of the invention is the cutter adjustment.

Fig. 21 illustrates diagrammatically the zero position of adjustment of the cutter. Here the axis $t$ of the cutter spindle 55 is parallel to the axis $y$ of the cradle 35 and coincides with the axis $z$ of the swivel head 45. W denotes the axis of the cutter carrier 50. As already stated this axis is inclined to and intersects the axis of the cutter spindle. The point of such intersection is denoted at $a$. It lies in the central plane 500 of the machine.

Fig. 22 illustrates diagrammatically an extreme position of adjustment of the cutter. Here the cutter carrier 50 has been swung about the axis $w$ of shaft 120 (Fig. 4) through 180°. Axis $t$ of the cutter spindle 55 is now inclined to axis $z$ of swivel head 45, and the cutter spindle has been swung so far about cone center $a$ that axis $w$ of cutter carrier 50 bisects the angle between axes $z$ and $t$. Plane 501 of the tips of the cutter blades is now inclined to central plane 500 of the machine.

When the cutter is in the zero position of its adjustment, it may represent, as shown in Fig. 23, a nominal crown gear 505, that is, a basic gear having a face cone angle of 90° but a pitch angle of slightly less than 90°. Here the axis $t$ of the cutter is parallel to the axis $y$ of the cradle and the tip surface 501 of the cutter lies in the face plane 506 of the crown gear. When the cutter is in this position, tooth surfaces will be generated on the gear being cut which are conjugate to the nominal crown gear.

By adjusting swivel head 45 and cutter carrier 50, the cutter can be positioned to represent a form-cut tapered gear and the mate gear can be generated conjugate to such a gear, or the cutter can be positioned to cut a gear of a different pressure angle from the pressure angle of the cutter.

Fig. 24 shows the cutter positioned to represent a tooth of a generating gear 510 whose pitch angle is considerably less than 90°. Here the axis $t$ of the cutter is inclined at an acute angle to the axis $y$ of the cradle, which represents the axis of gear 510, and the tip plane 501 of the cutter is tangent to the conical face surface 511 of the generating gear. When cutter and blank are rolled together then in the machine, tooth surfaces will be generated on the blank which are conjugate to the tooth surfaces of gear 510.

Fig. 26 shows diagrammatically how through angular adjustment of swivel head 45 and cutter carrier 50, a cutter C, which has side-cutting edges 515 and 516 of a certain pressure angle, may be positioned to represent a tooth of a generating gear 517, the opposite sides of whose teeth are of different pressure angle. Here cutter axis $t$ is tilted with reference to axis $y$ of cradle and of basic gear 517 by the amount required to produce the necessary pressure angle on the work in the generating roll. Through different amounts of tilt, a single cutter can be positioned to cut gears of different pressure angles.

The construction of the present machine not only provides rigidity in the cutter mounting but simplifies calculation of the cutter settings. Heretofore the cutter has been tilted about an axis intersecting the cutter spindle in a point approximately midlength of the cutter spindle. The effect at the tip of the cutter of any angular adjustment about such axis has had heretofore to be calculated and allowed for. By tilting the cutter about a point *a* of intersection of swivel head and cutter axis, the angle of tilt can be computed directly.

The generating gear represented by the cutter may have, of course, teeth of any spiral angle. Fig. 25 shows the cutter positioned to represent a basic gear 520 whose longitudinally curved teeth 521 have a positive spiral angle. The cutter axis *t* is offset from the axis *y* of the cradle and of the basic gear and is so positioned angularly about the axis *y* that the cutter in its rotation will represent a tooth 521 and sweep and generate teeth on the work conjugate to this basic gear 520. This position of the cutter is achieved by adjustment of the eccentric 40 and the cradle 35. The adjustment of the eccentric 40 gives the desired radial position of the cutter axis with reference to the axis of the cradle and the adjustment of the cradle brings the cutter into the desired angular position about the cradle axis.

The operation of the machine will be understood from the preceding description but may be briefly summed up here. Assuming that the cutter has been properly positioned relative to the work by adjustment of cradle, eccentric, swivel head, and cutter carrier, and that the work has been properly positioned by adjustment of subbase 32, sliding base 425, swinging base 420, column 280 and work head 315, and that the gear G, which is to be cut, has been chucked, the first step is to move the work from loading position to operative position by movement of piston 367 (Fig. 16). Then motor 70 (Fig. 19) is started. Cam 150 starts to revolve and track 151 or 152 of the cam, whichever is operative, depending on whether the gear is being roughed or finished, swings lever 345 (Fig. 15) to feed the work into operative relation with the tool. Cam track 153 may be shaped to hold cradle and work stationary during this feed or feed may be effected during the first part of the generating roll. In any event, when the actuating part of track 153 of cam 150 becomes operative, the generating roll begins and cradle and work are rotated on their respective axes through the trains of gearing shown in Fig. 19. The cam 150 makes a revolution per cycle and drives these gear trains first in one direction and then in the other.

If the work is to be cut on roll in one direction only, cam tracks 151 and 152 are shaped to cause withdrawal of the work from the tool during the return roll. If the work is to be cut on both forward and return rolls, cam tracks 151 and 152 are shaped to effect withdrawal near the end of the return roll. When the work has been withdrawn clear of the tool, then the Geneva plate 402 (Fig. 7) is released, so that it may be driven by actuating member 391 to superimpose through differential 244 (Figs. 13 and 19) an algebraic motion on the work to index the work. When indexing is completed, the Geneva plate is locked up again, and the work is fed back into operative relation with the cutter to begin a new cycle. When the machine has completed as many cycles as there are teeth in the gear to be cut, the automatic stop 525 (Fig. 6) is tripped and the machine is stopped. The piston 367 (Fig. 16) is then actuated to move the sliding base 425 to loading position, and the completed gear is dechucked and removed from the machine, and a new blank is chucked thereon to be cut.

The automatic stop 525 may be of conventional structure. It is secured to cam housing 164 (Fig. 6) and is adapted to be actuated by a cam-like trip member 526 which is secured to the back of cam 150 and which operates on each revolution of cam 150, that is once per cycle, to swing lever 527 about its pivot stud 528 and advance the stop mechanism one step. Stud 528 threads into housing 164.

Aside from the advantages previously noted, the provision of both feed and generating trackways in a single cam 150 simplifies the construction of the machine and makes for compactness. Reversal of the generating trains is quiet and easy with the cam trackway 153. The sliding base 425 is adjustable to compensate for change in height of the cutting blades due to sharpening. This adjustment may be effected in conventional fashion. The bar 370 may be threadedly connected with the sliding base 425 and a graduated dial 530 (Fig. 2) may be used to adjust the effective length of the bar, thereby to adjust the work toward or from the cutter, as required.

While the machine illustrated is a cutting machine, it will be understood as previously stated that the invention may be applied also to machines for grinding longitudinally curved tooth tapered gears. Since a grinding wheel is a tool having an infinite number of cutting edges it will be understood then that when the terms "cutter" and "cutting" are used in the specification and claims they are intended to include "grinding wheels" and "grinding."

In some aspects, moreover, the invention is not limited to the cutting of longitudinally curved tooth gears or even to the cutting of tapered gears. This application is intended, therefore, 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 our invention, what we claim is:

1. In a machine for generating gears, a tool support, a work support, a rotary work spindle journaled in the work support, a movable carrier upon which one of said supports is mounted, a rotary cam, means operable on rotation of the cam to effect movement of the carrier, and a train of gearing, including change gears, for connecting said means with the work spindle to rotate the work spindle in time with the movement of the carrier.

2. In a machine for generating gears, a tool support, a work support, a rotary work spindle journaled in the work support, a movable carrier upon which one of said supports is mounted, a rotary cam, a train of gearing for actuating said carrier, a second train of gearing, including change gears, for rotating the work spindle in time with the carrier movement, means operable on rotation of the cam for driving said trains of gearing first in one direction and then in the other, and means for periodically imparting an additional algebraic motion to the train of gearing

which drives the work spindle, to effect indexing of the work spindle.

3. In a machine for generating gears, a tool support, a work support, a rotary work spindle journaled in the work support, a movable carrier upon which one of said supports is mounted, a rotary cam, a pivotally mounted spur gear segment operatively connected to the cam to oscillate on rotation of the cam, a train of gearing operatively connecting said segment to the carrier, a second train of gearing operatively connected with the first train and including change gears and adapted to drive the work spindle in time with carrier, and means for periodically imparting an additional algebraic motion to the train of gearing which drives the work spindle, to effect indexing of the work spindle.

4. In a machine for generating longitudinally curved tooth tapered gears, a tool support, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, a rotary cam, a train of gearing for actuating said cradle, a second train of gearing, including change gears, for rotating the work spindle in time with the cradle movement, means operable on rotation of the cam for driving said trains of gearing first in one direction and then in the other and at a varying rate during movement in one direction at least, and means for periodically imparting an additional algebraic motion to the train of gearing which drives the work spindle, to effect indexing of the work spindle.

5. In a machine for generating longitudinally curved tooth tapered gears, a tool support, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, a train of gearing for driving the cradle, a second train of gearing, including change gears, for rotating the work spindle in time with the cradle movement, a rotary cam, means for rotating said cam, a follower engaging said cam, and means operatively connected to said follower for driving said trains of gearing on rotation of the cam, said cam being constructed so that the rates of work spindle and cradle movements vary progressively during movement of the cradle in one direction.

6. In a machine for generating tapered gears, a tool support, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, a rotary cam having two trackways formed thereon, means operatively connected with one of the trackways to effect relative movement of the tool and work supports toward and from one another, and means comprising a train of gearing, including change gears, operatively connected with the other of the trackways to effect rotation of the cradle and work spindle in timed relation.

7. In a machine for generating tapered gears, a tool support, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, a sliding base on which the other support is mounted, a rotary cam having two trackways formed therein, means operatively connected with one of the trackways to reciprocate the sliding base to effect relative movement of the tool and work supports toward and from one another, a train of gearing for driving the cradle, a second train of gearing for driving the work spindle and including change gears for timing the relative movements of the work spindle and cradle, means operatively connected with the other trackway of the cam for driving both trains of gearing alternately in opposite directions, and means for periodically imparting an additional algebraic motion to the second train of gearing to index the work spindle.

8. In a machine for producing longitudinally curved tooth tapered gears, a support, and a rotary annular cutter mounted on said support for adjustment thereon about two axes which intersect in a point that lies in the plane of the tip of the cutter and one of which intersects the axis of the cutter in said point.

9. In a machine for producing longitudinally curved tooth tapered gears, a support, a cutter carrier rotatably adjustable on said support, a cutter spindle journaled in said carrier, a rotary annular cutter secured to said cutter spindle to rotate therewith, said cutter spindle having its axis extending at other than right angles to and intersecting the axis, about which the cutter carrier adjusts, in a point lying in the plane of the tip of the cutter and constituting the apex of a cone which is traced by the axis of the cutter spindle in adjustment of the cutter carrier.

10. In a machine for producing longitudinally curved tooth tapered gears, a support, a cutter spindle rotatably mounted on the support a rotary annular cutter secured to said spindle to rotate therewith, said spindle being adjustable on said support about two axes, one of which is inclined at an acute angle to the other and also is inclined at an acute angle to the axis of the cutter spindle, and both of which intersect the axis of the cutter spindle at the same point.

11. In a machine for producing longitudinally curved tooth tapered gears, a rotatable cradle, and a cutter spindle rotatably mounted on the cradle and adjustable thereon about two axes, the first of which is parallel to the cradle axis, the second of which is inclined at an acute angle to the first and also is inclined at an acute angle to the axis of the cutter spindle, and both of which intersect the axis of the cutter spindle at the same point.

12. In a machine for producing longitudinally curved tooth tapered gears, a support, a swivel head angularly adjustable in said support through an angle of 360°, a carrier mounted in said swivel head for angular adjustment therein through an angle of 360° about an axis which is inclined to and intersects the axis of adjustment of the swivel head at other than right angles, and a tool spindle journaled in said carrier, a rotary tool secured to said tool spindle, said tool spindle having its axis inclined to and intersecting the axis of adjustment of the carrier at other than right angles in a point which lies in a plane perpendicular to the axis of the tool spindle, the axis about which said swivel head adjusts also intersecting said plane in said point.

13. In a machine for generating longitudinally curved tooth tapered gears, a base, a cradle rotatably mounted in the base and adjustable therein through an angle of 360°, a drum mounted eccentrically in the cradle for adjustment therein through an angle of 360° about an axis offset from but parallel to the cradle axis, a swivel head mounted eccentrically in the drum for adjustment therein through an angle of 360° about an axis offset from but parallel to the axis of adjustment of the drum, a carrier mounted in the swivel head for adjustment therein through an angle of 360° about an axis inclined to and intersecting the axis of adjustment of the swivel

head, and a cutter spindle journaled in the carrier with its axis inclined to and intersecting the axis of adjustment of the carrier.

14. In a machine for generating longitudinally curved tooth tapered gears, a base, a cradle rotatably mounted in the base and adjustable therein through an angle of 360°, a drum mounted eccentrically in the cradle for adjustment therein through an angle of 360° about an axis offset from but parallel to the cradle axis, a swivel head mounted eccentrically in the drum for adjustment therein through an angle of 360° about an axis offset from but parallel to the axis of adjustment of the drum, a carrier mounted in the swivel head for adjustment therein through an angle of 360° about an axis inclined to and intersecting the axis of adjustment of the swivel head, a cutter spindle journaled in the carrier with its axis inclined to and intersecting the axis of adjustment of the carrier, means for rotating the cradle, and means for rotating the cutter spindle, said last-named means comprising a shaft journaled in the base coaxial with the cradle, a shaft journaled in the cradle coaxial with the drum, a shaft journaled in the swivel head coaxial with said head, a shaft journaled in the swivel head coaxial with the carrier, gearing connecting said shafts, and gearing connecting the last-named shaft with the cutter spindle.

15. In a machine for generating longitudinally curved tooth tapering gears, a work support, a tool support, a work spindle journaled in the work support, a rotary cradle on which one of said supports is mounted, means for rotating the work spindle and cradle in timed relation at a varying rate to generate the tooth profiles of the work, means for varying the ratio of the rotations of work spindle and cradle during generation, and means for periodically indexing the work spindle.

16. In a machine for producing longitudinally curved tooth tapered gears, a work support, a tool support, a work spindle journaled in the work support, a rotary annular tool mounted on the tool support, means for producing a relative rolling movement at a progressively varying rate between the tool and work supports so that the generating cuts taken on the work are of the same width all along the side of a tooth from the small end to the large end thereof, and means for periodically indexing the work spindle.

17. In a machine for producing longitudinally curved tooth tapered gears, a base, a work support, a tool support, a work spindle journaled in the work support, a cradle journaled in the base and carrying one of said supports, a rotary cam, a lever pivotally mounted at one end in the base and having a gear segment secured to its free end, a cam follower mounted on said lever between its ends and operatively engaging said cam, a train of gearing driven by said segment for rotating the cradle, a train of gearing driven in time with said first-named train for rotating the work spindle, means for rotating the cam continuously at a uniform velocity to make one revolution per tooth of the gear to be generated, and means for indexing the work once per revolution of the cam.

18. The method of producing a longitudinally curved tooth tapered gear which comprises rotating an annular cutting tool in engagement with the work while effecting a relative rolling movement between the tool and work at a varying rate to take generating cuts of equal width on a tooth profile of the work along the whole length of the tooth.

19. In a machine for producing longitudinally curved tooth tapered gears, a support, a swivel head adjustable angularly on said support, a carrier adjustable angularly on the swivel head about an axis that intersects at an acute angle the axis about which said swivel head is adjustable, a cutter spindle journaled in said carrier for rotation on an axis that intersects the axis, about which said carrier adjusts, at an acute angle equal to said first-named acute angle, the axis about which said swivel head is adjustable and the axis about which said carrier is adjustable intersecting the axis of said cutter spindle in a common point, and means for rotating said cutter spindle.

20. In a machine for producing longitudinally curved tooth tapered gears, a support, a swivel head adjustable angularly on said support, a carrier adjustable angularly on the swivel head about an axis that intersects at an acute angle the axis about which said swivel head is adjustable, a cutter spindle journaled in said carrier for rotation on an axis that intersects the axis, about which said carrier adjusts, at an acute angle equal to said first-named acute angle, a rotary annular cutter secured to said cutter spindle, the axis about which said swivel head is adjustable and the axis about which said carrier is adjustable intersecting the axis of said cutter spindle in a common point which lies in the plane of the tip of said annular cutter, and means for rotating said cutter spindle.

21. In a machine for generating longitudinally curved tooth tapered gears, a tool support, a tool mounted on said tool support, means for actuating said tool, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, means for oscillating said cradle comprising a rotary cam, means for driving said cam continuously in one direction, a member operatively connected to said cam to move to and fro on rotation of said cam, and a train of gearing, having change gears incorporated therein, for driving said cradle oscillatably from said member, and a second train of gearing, having change gears incorporated therein and operatively connected to said member to be driven thereby, for rotating said work spindle in time with the movement of said cradle.

22. In a machine for generating tapered gears, a tool support, a tool mounted on the tool support, means for actuating said tool, a work support, a work spindle journaled in the work support, an oscillatory cradle upon which one of said supports is mounted, means for oscillating said cradle about an axis angularly disposed to the axis of said work spindle comprising a rotary cam, means driving said cam continuously in one direction, a pivotally mounted spur gear segment operatively connected to said cam to oscillate about its pivot upon rotation of said cam, and gearing operatively connecting said segment to said cradle, a train of gearing including change gears driving said work spindle in time with said cradle for generation of the tooth profiles of the work, and means for periodically indexing the work spindle.

23. In a machine for producing longitudinally curved tooth tapered gears, a base, a work support mounted on said base, a tool support mounted on said base, a work spindle journaled in the work support and a rotary annular cutter ro-

tatably mounted on the tool support for adjustment thereon about two axes which intersect in a point that lies in the plane of the tip of the cutter, one of said supports being adjustable on the base about a third axis inclined to the cutter axis.

24. In a machine for generating gears, a tool support, a work support, a rotary work spindle journaled in the work support, a movable carrier upon which one of said supports is mounted, a rotary cam, a train of gearing for actuating said carrier, a second train of gearing for rotating the work spindle in time with the carrier movement, and means operable on rotation of said cam for driving said trains of gearing first in one direction and then in the other, one of said trains of gearing including change gears.

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