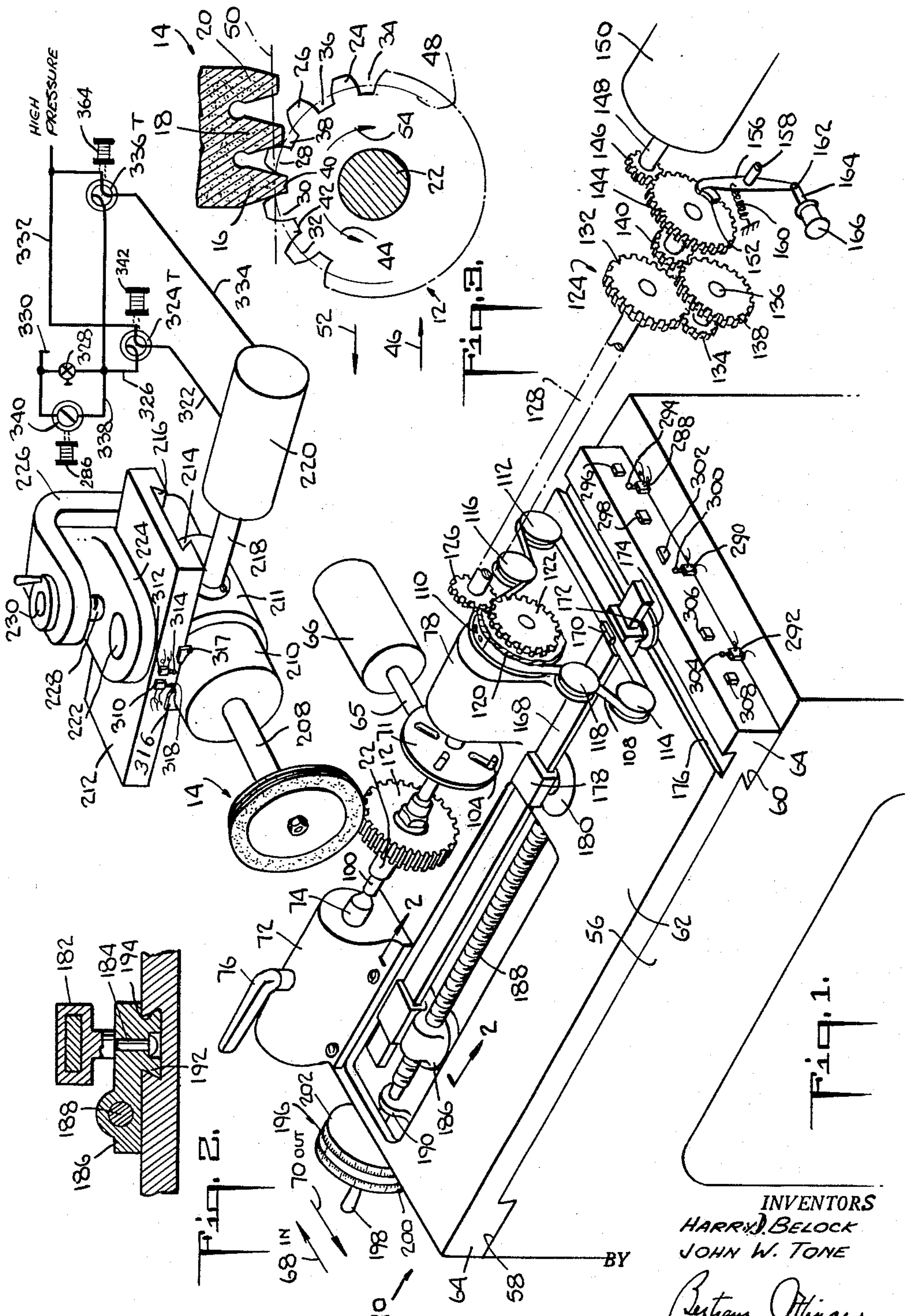
Sept. 5, 1961 H. D. BELOCK ET AL 2,998,678

METHOD AND MACHINE FOR GRINDING GEARS

Filed June 7, 1955 3 Sheets-Sheet 1



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METHOD AND MACHINE FOR GRINDING GEARS

Filed June 7, 1955 3 Sheets-Sheet 2

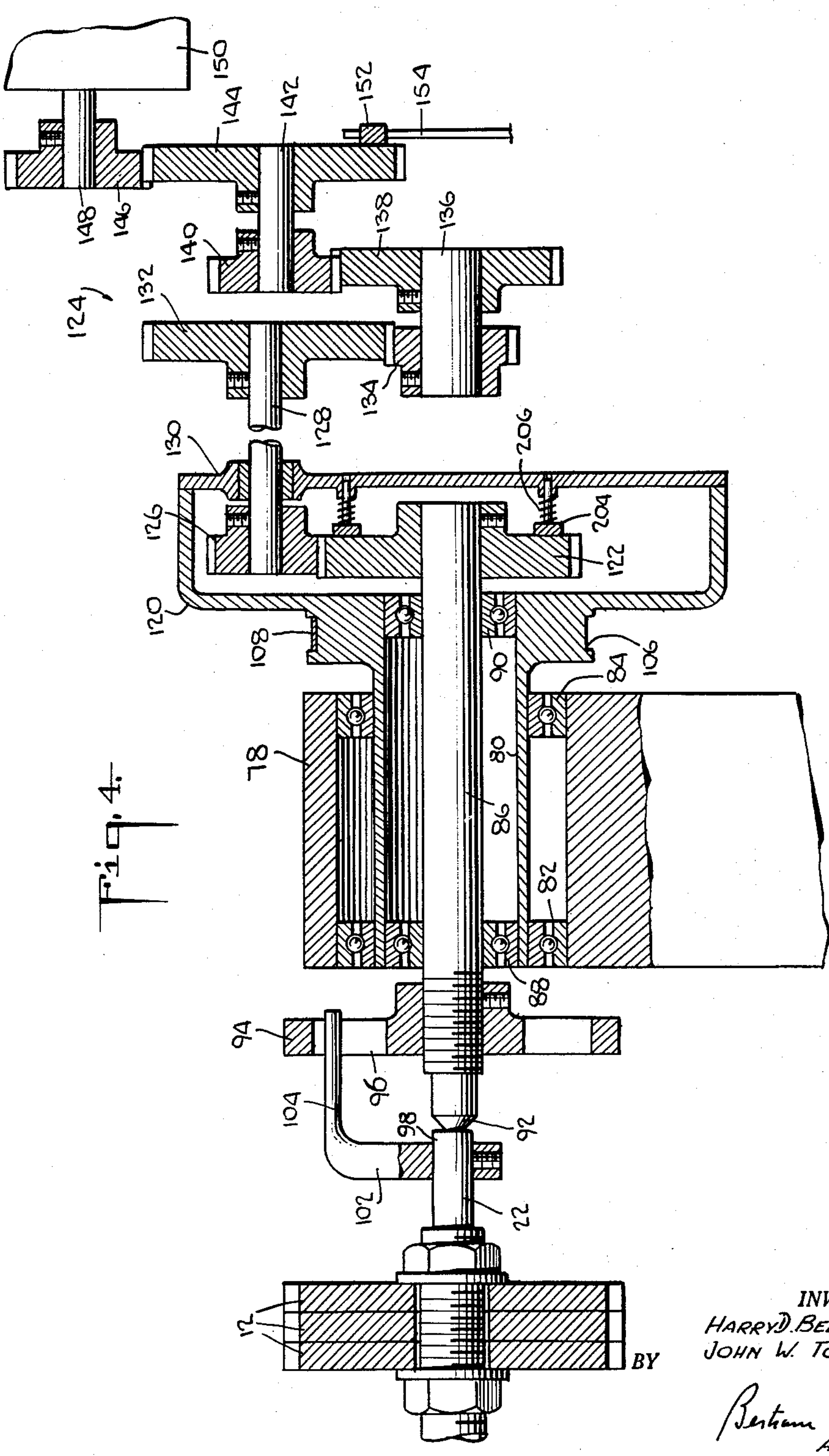

Fig. 4.

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Filed June 7, 1955 3 Sheets-Sheet 3

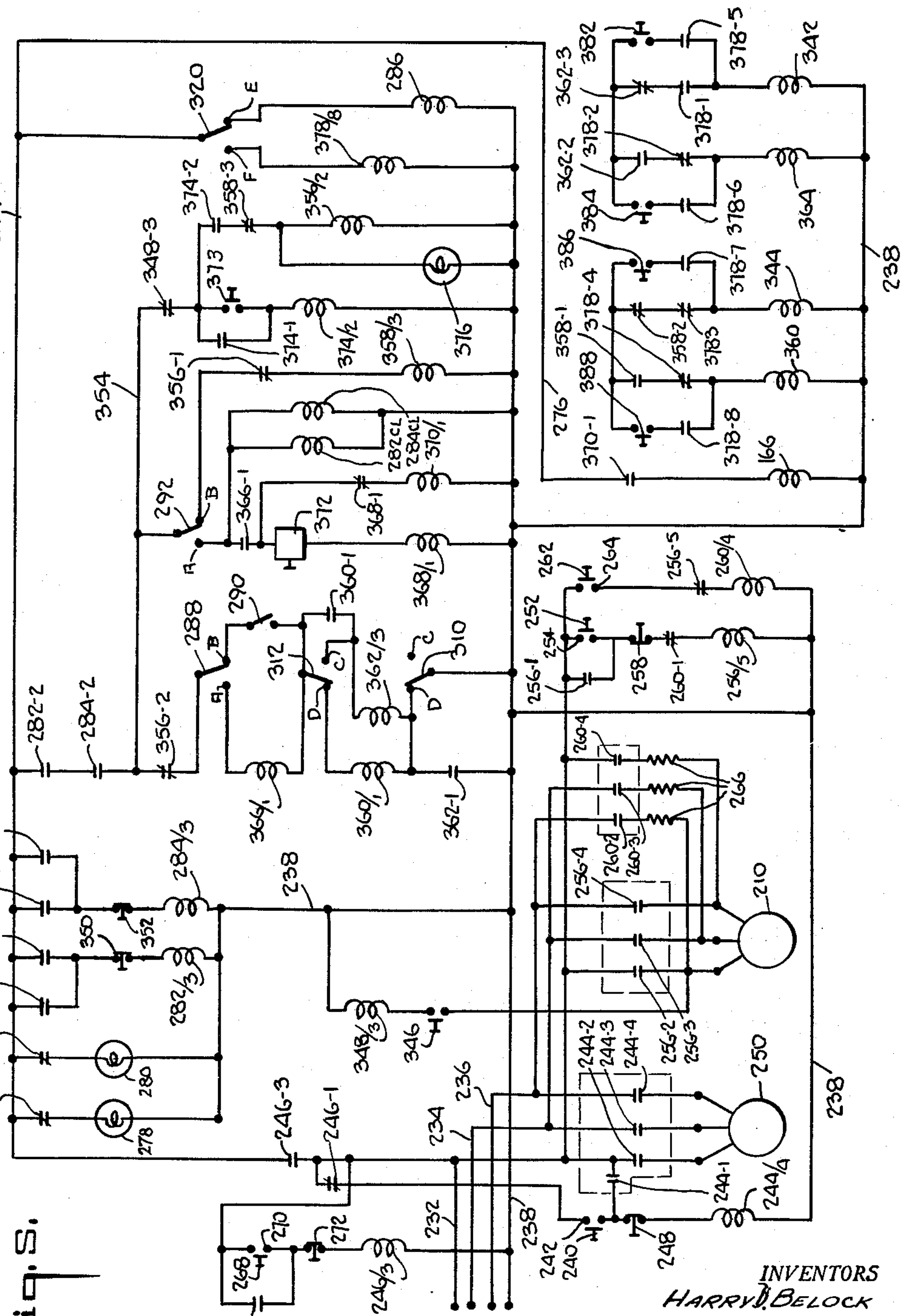

Fig. 5

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METHOD AND MACHINE FOR GRINDING GEARS

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14 Claims. (Cl. 51—52)

This invention relates to a method and apparatus for grinding gears. More particularly, the invention is specially applicable, although not so limited, to a gear grinder and a gear grinding method for precise finishing of plain or roughed out gear blanks that may have been heat treated for hardening and tempering.

Conventionally, after gear teeth have been rough formed on a gear blank by hobbing, milling, shaping, forging or any other appropriate method, the blank is hardened and, optionally, tempered by known heat treating processes. Such processes distort the flanks of the teeth to an extent which limits the load carrying ability. The only commercially feasible method of correcting this defect and forming exact involute flanks on the teeth after hardening presently constitutes grinding the flanks of the teeth.

The usual gear grinding method now employed involves the use of a grinding wheel having its edge profile shaped in the form of a basic rack tooth which would accurately mesh with the finished gear teeth. The wheel is rotated and, as it rotates, is rapidly reciprocated between two adjacent gear teeth on the rough blank. At the same time the blank is slowly revolved and its axis of revolution slowly bodily translated in a plane parallel to the axis of revolution of the grinding wheel in a fashion such that the pitch circle of the blank rolls, in effect, on the pitch line of the basic rack form of the grinding wheel. Thus the desired precise involute flanks of the gear teeth are ground by a generating action.

For accurate results it is usual to grind each entire flank of each tooth (a grinding of the flanks of two adjacent teeth of a gear blank is commonly referred to as a "single pass" and a single grinding of the flanks of all the teeth is referred to as "complete pass") several, conventionally three or more, times in order to secure the desired precision and surface finish, the grinding wheel being reset to a greater depth after each complete pass. During a single pass the grinding wheel is reciprocated many times as it progressively works its way from the tip to the root of a tooth, or vice versa. After a single pass the gear axis is returned to its starting position and indexed to bring the next valley (intertooth space) into position for a single pass. Accordingly several complete passes are required, each consisting of a number of single passes equal to the number of teeth on the roughed blank.

The set up time and expensive equipment for an operation of this nature makes the price of precision gears extremely high and, indeed, the cost of single or small lots of gears is prohibitively high. Moreover due to the construction of present-day grinders great skills are called for and the use of special precision auxiliary tools such as master gears and racks, index plates, sine bars and gauge blocks many of which must be provided in sets of different sizes for different gear blanks.

It is the principal object of the present invention to provide a gear grinding apparatus and method which obviates the foregoing drawbacks.

It is a specific object of the present invention to provide a machine and process of the character described which enables a gear blank to be precisely ground to the desired dimensions and finish in but a single complete pass.

It is another specific object of the invention to provide a machine and process of the character described which will substantially reduce the set up time and costs, as well as operating time and costs, and thereby considerably lower the expense involved in precision gear grinding.

It is another specific object of the invention to provide a compact gear grinder of small size, nominal price, increased productivity and durable construction.

It is another specific object of the invention to provide a gear grinder whose operation is fully automatic so that lesser skills are required of an operator and one operator can handle several machines.

It is another specific object of the invention to provide a gear grinder which can be set up in a very short time without using gauge blocks and without changing master gears and racks, index plates or sine bars.

It is another specific object of the invention to provide a gear grinder the set up of which can be changed simply by shifting a few controls and replacing a few change gears, operations which obviously involve but little time.

It is another specific object of the invention to provide a gear grinder which can be utilized to produce gears for applications which formerly were considered uneconomical.

It is another specific object of the invention to provide a gear grinder having simple unique mechanisms for slowly rotating a gear blank during a single pass, for selectively varying the angular rate of rotation of the blank during a pass, for indexing the blank at the end of a single pass, and for selectively varying the indexing angle.

It is another specific object of the invention to provide a gear grinder having an electrical control circuit which renders operation of the gear grinder automatic and fool proof.

Other objects of the invention in part will be obvious and in part will be pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts and series of steps which will be exemplified in the apparatus and process hereinafter described and shown in the drawings, and of which the scope of application will be indicated in the appended claims.

In the accompanying drawings, in which is shown one of the various possible embodiments of the invention,

FIG. 1 is a perspective, partially schematic, view of a gear grinder constructed in accordance with the present invention, some of the supporting structure being removed to facilitate explanation;

FIG. 2 is an enlarged fragmentary sectional view taken substantially along the line **2—2** of FIG. 1, and being illustrative of a detail of the mechanism for selectively varying the angular rate of rotation of a gear blank during a single pass;

FIG. 3 is an enlarged fragmentary sectional view through the grinding wheel and gear blank, the same being taken in a plane including the axis of rotation of the grinding wheel and perpendicular to the axis of rotation of the gear blank;

FIG. 4 is an enlarged fragmentary sectional view taken in a vertical plane including the axis of rotation of the gear blank; and

FIG. 5 is a schematic view of the hydraulic actuating system and electrical control circuit for the gear grinder.

Referring now in detail to the drawings, the reference numeral **10** denotes a gear grinder embodying the present invention and adapted to precisely grind a roughed gear blank **12** with the aid of a grinding wheel **14** and suitable mechanisms to rapidly reciprocate the wheel transversely across the blank, to slowly roll the blank in phase with the wheel, and to intermittently index the blank.

One important feature of the invention relates to the grinding of plural gear teeth at each single pass thereby to complete the grinding of the gear in one complete pass instead of several as heretofore. To this end the grinding wheel is formed to provide an edge profile constituting plural basic rack teeth spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear to be ground, the grinding teeth having a common axis of rotation. After each single pass the gear blank is indexed, optionally through an arc which subtends the number of teeth ground, but preferably through an arc subtending a lesser number of teeth so that there is an overlapping of the grinding operation and more accurate and better surface finishing of the gear teeth. Precision is improved by indexing the gear only a single tooth at a time so that the final finishing grind always will be performed by the same endmost grinding tooth. However great accuracy is comparatively difficult to attain by this method alone for adjacent teeth on the gear are subject to the errors of making the multiple tooth forms on the grinding wheel of identical shape and equal spacing to a very small tolerance.

Pursuant to a most important refinement of the foregoing feature of my invention these errors are materially diminished by the edge profiling of the grinding wheel which is best shown in FIG. 3. As there is plainly seen the grinding wheel **14** which is made from suitable abrasive material has its edge profiled to provide plural (as here illustrated three) basic rack tooth forms **16, 18, 20** spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear **12** and having a common axis of rotation. The tooth forms may constitute plural properly shaped grinding wheels placed adjacent one another or a single wheel with the plural basic rack teeth forms dressed on its periphery.

To diminish errors which would arise from nonidentity of the plural tooth forms, and the costs incident to obtaining and maintaining substantial identity, in accordance with the refinement hereinbefore referred to the multiple tooth forms **16, 18, 20** on the grinding wheel **14** are of stepped heights. The innermost tooth form **20** which last engages the gear blank is of minimum diameter, i.e. minimum effective height. The intermediate tooth form **18** is of slightly greater effective height, a typical increase in effective height being in the order of 0.0005 inch. The outermost tooth form **16** is of still greater effective height, a typical progressive increase being in the order of 0.0015 inch. Thus the tooth forms are progressively stepped up in stages for an overall increase in height of 0.002 inch. It is particularly to be noted that the increase in height is provided without altering the uniform pitch of the basic rack. These increases are grossly exaggerated in FIG. 3. As shown the tooth forms are of identical contour but their bases are at progressively increased radial distances from the axis of rotation of the grinding wheel. However it is within the purview of the invention to employ tooth forms with their bases at the same distance from said axis but of progressively greater height as indicated and progressively slightly greater width.

The gear blank **12** has been preliminarily roughed, e.g. by shaping or hobbing, to oversize dimensions while still comparatively soft and thereafter heat treated to a greater hardness whereby to increase its strength and surface endurance limit. Such treatment, if the gear were finished to its ultimate shape and dimensions, would distort the involute surfaces and thus materially reduce load carrying ability and efficiency. The gear grinder **10** brings the blank down to its desired accurate dimensions and shape.

The gear blank is securely clamped on a mandrel **22** which extends through the central opening in the gear. It will be observed that several gears can be mounted on the mandrel to be ground in the same operation; but for simplicity the grinder will be described as operating on but a single gear. A group of successive teeth **24, 26, 28, 30, 32** are shown on the gear blank **12** in FIG. 3, said teeth defining valleys **34, 36, 38, 40, 42.**

Pursuant to the present invention the grinding wheel is spun about an axis parallel to the plane of FIG. 3, and at the same time is rapidly reciprocated in a direction perpendicular to said plane, such direction being parallel to the longitudinal axis of the mandrel in the set up shown. While the grinding wheel is thus turning and reciprocating, the gear blank is given a compound movement. This consists of a slow rotation of the blank about the longitudinal axis of the mandrel as indicated by the arrow **44** (counterclockwise as seen in FIG. 3), and a slow translation of the blank toward the effectively shortest tooth form **20** as indicated by the arrow **46** (toward the right as seen in FIG. 3). The total effect of these two movements is to impart a rolling motion to the gear which is such that the pitch circle **48** of the blank rolls without slipping on the pitch line **50** of the basic rack form represented by the effectively longest tooth form **16.**

It will be seen that each of the grinding tooth forms will generate by grinding involute surfaces on the flanks of teeth defining the valley through which that form passes. As shown in FIG. 3, the tooth form **16** will grind the flanks of the teeth **28, 30** on opposite sides of the valley **40** early in the single pass represented by said figure. The tooth form **18** will grind the flanks of the teeth **26, 28** on opposite sides of the valley **38** later in the pass, the two grinding operations being overlapped. The tooth form **20** will grind the flanks of the teeth **24, 26** on opposite sides of the valley **36** still later in the pass, the second and third grinding operations likewise being overlapped.

The effectively shortest tooth form **20** will perform a rough grinding operation. The effectively medium height tooth form will perform a semi-finishing grinding operation and, as soon will be seen, it operates on flanks which previously have been rough ground. The effectively tallest tooth form will perform a finishing grinding operation and, as soon will be seen, it operates on flanks which previously have been semi-finished ground.

After a single pass the grinding wheel is shifted to an out-of-the way position where it remains while the gear blank experiences a reverse compound movement constituting a reverse translation indicated by the arrow **52** and a reverse rotation indicated by the arrow **54.** In other words the blank "rolls back," being thus moved to its original starting position which is clear of the path of the grinding wheel. Prior to the roll back the blank is indexed through an arc which subtends one gear tooth, the direction of indexing being opposite to the direction of rotation during roll back, i.e. as indicated by the arrow **44,** whereby to advance the blank one tooth.

The next single pass is now run whereupon the effectively shortest tooth form **20** will freshly rough grind the valley **34,** the middle tooth form **18** will semi-finish grind the previously rough ground valley **36** and the effectively tallest tooth form **16** will finish grind the previously semi-finished ground valley **38.** The previously finished ground valley **40** will have been indexed to the position formerly occupied, as shown in the first single pass of FIG. 3, by the valley **42** between the teeth **30, 32** where it is not touched by the grinding wheel.

Single passes, followed by idle positioning of the grinding wheel, roll back of the blank, and indexing of the blank, are repeated until the gear blank has been completely ground (a complete pass). Desirably the complete pass may include one or a few, preferably two, more single passes than are absolutely necessary to ensure accurate shaping of the two teeth of the blank which initially were subjected to semi-finishing without rough grinding, and to finishing without rough grinding or semi-finishing.

In accordance with a further feature of the present invention the gear grinder **10** is so constructed as to impart the above-described motions to the grinding wheel and gear blank with comparatively simple mechanism which can be easily and quickly reset to provide different desired angular indexing movements for different numbers of teeth on a blank and to provide different desired generating ratios between the rate of blank rotation and the rate of blank translation for different pitch diameters of a blank.

More specifically the grinder includes a suitably supported flat horizontal bed **56** the ends of which are provided with open-sided parallel ways **58, 60**, one of which, **60**, may be undercut. A table **62** is slidable on the bed, being guided by depending shoes **64** which are matched to and engage the ways. The table is reciprocated by any standard drive, for example a rod **65** driven by a piston (not shown) sliding in a stationary hydraulic cylinder **66**. For convenience, the direction of movement of the table denoted by the arrow **68** hereinafter will be referred to as "in" and the opposite direction of movement denoted by the arrow **70** as "out."

A tailstock **72** fixed to the table carries an axially shiftable dead center **74** which is locked in any set position through the medium of a handle **76**. Also secured to the table and in line with the dead center is a pedestal **78** in which a hollow shaft **80** is journalled by antifriction bearings such as a pair of ball bearings **82, 84**. The shaft is aligned with the dead center. A drive spindle **86** coaxial with and within the hollow shaft is journalled therein by anti-friction bearings such as ball bearings **88, 90**.

The tip **92** of the drive spindle facing the dead center protrudes from the hollow shaft to fixedly receive a lathe plate **94** having the usual radial slots **96**. Said tip is seated in one countersunk end **98** of the mandrel **22**, the other countersunk end **100** of the mandrel receiving the tip of the dead center **74**. A conventional lathe dog **102** secured to the mandrel has its crank arm **104** snugly engaged in one of the slots **96** of the lathe plate whereby the blank and drive spindle are securely interengaged for joint rotation.

The hollow shaft **80** is provided with a coaxial drum **106** on which an elongated flexible member such as a steel ribbon **108** rides. Said ribbon is not permitted to experience angular movement relative to the drum, being suitably fastened to the drum, as by an anchor pin **110**, at a portion of the ribbon which during the operation of the grinder as hereinafter described remains in contact with the drum. The ribbon is trained about reversing sheaves **112, 114** on the "in" and "out" sides of the pedestal at a level beneath the axis of the hollow shaft. In addition, idler sheaves **116, 118** engage the ribbon between the drum and reversing sheaves to increase the arc of contact between the ribbon and drum and to suitably tension the ribbon. The rotatable supports for all the sheaves are mounted on the table but have been omitted from the drawings for the sake of simplicity. The drive for the ribbon, and consequently for the drum, will be described later.

A shallow cylindrical housing **120** is carried by the drum in axial registery with the drive spindle. Said housing encloses the last gear **122** in an indexing train **124**. Said gear is fast on the drive spindle **86** and is in mesh with a pinion **126**. The pinion is secured on a jack shaft **128** which is journalled in the back cover plate **130** for the housing **120**. It will facilitate understanding of the operation of the grinder to interrupt the detailed description of the indexing train at this point in order to observe that if the jack shaft is held against rotation in its bearing while the drum is turned said shaft will act as a crank operating through the thus locked together pinion **126** and gear **122** to rotate the drive spindle.

The indexing train further includes a gear **132** fast on the jack shaft and meshing with a pinion **134** secured to a counter shaft **136** which for convenience may be aligned with the drive spindle. The bearing (not shown) for the counter shaft must be so arranged as to permit free revolution of jack shaft about the axis of the drive spindle. To this end the counter shaft bearing may be carried by the housing **120**, or, as just mentioned, may be aligned with the drive spindle and carried by the table **62**.

Fast on the counter shaft **136** is a first change gear **138** meshing with a second change gear **140**. The second change gear is secured to a back shaft **142** the bearing for which (not shown) is carried by the housing **120** to allow the aforementioned revolution of the jack shaft. A third change gear **144** is fixed to the back shaft and meshes with a drive pinion **146** secured to the drive shaft **148** of a hydraulic indexing motor **150**. The motor likewise must permit the free revolution of the jack shaft described above and for this purpose is carried by the housing **120** in the grinder shown.

The last change gear **144** carries a fixed abutment dog **152** arranged to be engaged by an anchoring latch **154**. The latter (see FIG. 1) constitutes one end of a latching lever **156** which rocks on a spindle **158** that moves with the housing **120**. The latch is biased by a spring **160** into engagement with the dog. The opposite end of the latching lever is connected by a pivot pin **162** to the movable core **164** of an indexing solenoid **166**. The spring is anchored to and the solenoid is mounted on a structural element (not shown) carried by the housing **120**.

It now will be appreciated that when the ribbon **108** is shifted to turn the drum, the ensuing angular movement of the housing **120** relative to the table **62** is followed by the jack shaft, the counter shaft and the back shaft (as well as the gear fixed thereto), the motor drive shaft, the latching lever, the biasing spring and the indexing solenoid, the elements of the indexing train being locked against relative movement by the dog **152** pressing against the latching lever.

The change gears are so selected that an integral number of revolutions of the drive pinion **146** will rotate the gear **122** through an arc which subtends the pitch distance of a single tooth on the gear being ground. It may be mentioned here that although highly satisfactory operation is secured by picking the change gears to secure the desired rotation of the gear **122** with but a single rvolution of the drive pinion, more precise operation is obtained by what is designated herein as "multiple indexing," pursuant to which the drive pinion turns through plural revolutions for each indexing operation and a high step down ratio is procured in the change gear train, thus reducing gear transmission error.

In accordance with the invention means is provided for shifting the ribbon **108** and thereby rotating the housing **120**, said means being variably settable to readily and quickly secure any desired rate of rotation of the drive spindle relative to the rate of movement of the table **62** across the bed **58**. Said means quite simply comprises a ratio slide bar **168** having three points thereon of which at least one is selectively variably positionable axially of the bar. One of said points is connected to the ribbon, a second point is connected to the table and a third point is connected to "ground," e.g. to the bed. The connections are such as to permit rocking of the bar as a lever about one point with the other two points moving in parallel paths and the ribbon point shifting in a proper direction to turn the housing **120** in the desired manner.

More specifically, and as shown in the drawings, the ribbon **108** is secured by an anchor pin **170** to a first slide block **172** that is axially self-shiftable along the ratio bar **168** adjacent an end thereof. The block is mounted for vertical rotation on a second slide block **174** that is captively reciprocable in a way **176** in the table parallel to the bed ways **58, 60**.

At a point intermediate its ends said bar is secured on a post **178** that is mounted for vertical rotation in a bearing **180** on the table **62**. Since the bearing is carried by the table it is movable therewith parallel to the first slide block as the table shifts back and forth across the bed.

The third point constitutes a second slide block **182** that is axially selectively shiftable and self-shiftable along the ratio bar. Said block **182** is secured to a vertical pin **184** that is journalled for rotation about a vertical axis in a follower **186**. The follower is formed with a female thread that meshes with a lead screw **188** extending perpendicular to the direction of reciprocation of the table **62**. Suitable bearings, such as the bearing **190**, mount the ends of the lead screw on the bed **56** for rotation about a horizontal axis. The follower **186** moves a dovetail shoe **192** slidable in a matching way **194** formed in the bed and extending parallel to the lead screw. Thus the position of the second slide block **182** along the bar with relation to the positions of the post **178** and the first slide block **172** can be varied by turning the lead screw **188**.

In order to precisely position the second slide block and thereby establish any involute form desired, rotation of the lead screw is placed under the control of a dial group **196** mounted on an end of the lead screw projecting from the gear grinder. As is well known one turn of the handle **198** of the dial group rotates the lead screw through one full turn. Fractions of a single revolution are indicated on a drum **200** and the number of revolutions from an extreme position is indicated on a drum **202**.

It now will be seen that reciprocation of the table and corresponding reciprocation of the ratio bar post **178** will rock the lever **168** about the slidable fulcrum provided by the second slide block **182** and cause a settable proportional reciprocation of the first slide block **172**, the actual proportion being determined by the location of the follower **186**. Obviously movement of the first slide block **172** shifts the ribbon **108** and turns the drum **106**. Since during in movement of the table **62**, as soon will be seen, the indexing train is locked and the jack shaft held against rotation, the drive spindle **86** will be slowly turned as it is reciprocated with the table **62**, the speed of turning being determined by the location of follower **186**. Inasmuch as the position of the follower **186** can be varied rapidly and precisely by turning the lead screw **188** it will be appreciated that the phase of setting up the grinder relating to the generating ratio requires no tools and little skill, and yet can be carried out exactly and speedily.

A single grinding pass during which the tooth flanks of three consecutive valleys of the gear blank are respectively finished ground, semi-finished ground and rough ground takes place on the "in" movement of the table. On the reverse, i.e. "out" movement of the table the gear blank is rolled back to its idle position clear of the grinding wheel. During "out" movement or at the end of "in" movement the solenoid **166** is energized to disengage the latch **154** from the dog **152**. This permits the indexing motor **150**, which constantly is energized as long as the grinder is in operation, to actuate the indexing train. The solenoid **166** is maintained energized by a conventional timing device until the change gear **144** has turned through the required number of revolutions (less a substantial fraction of a revolution) to advance the gear blank one tooth as described above. The solenoid is then deenergized, allowing the change gear **144** to stop when the dog **152** meets the latch **154**.

To prevent back lash in the driving connection between the pinion **126** and the gear **122** during the transition from indexing to roll "out" and from roll "out" to roll "in" means is included to fix the gear **122** to the housing **120** against any movement relative thereto except such as is brought about by the indexing motor. Said means includes an annular friction shoe **204** loaded by axially directed coil (helical) springs **206** from the cover **130** and strongly pressed by said springs against a face of the gear **122**. The ensuing friction slip coupling provides the connection between the housing and drive spindle during roll "out" and roll "in," being automatically reset at each indexing operation when the friction shoe takes on a new angular orientation with respect to the gear **122**.

The grinding wheel **14** is carried on a shaft **208** of an electric motor **210** secured to a head **211** which is suspended from a plate **212** by a dovetail tongue **214** on the frame slidable in a dovetail slot **216** in the underside of the plate **212**. A hydraulic cylinder **220** carried by the plate **212** reciprocates the grinding head **211** parallel to the slot **204** by means of a piston rod **218**.

The plate **212** is carried on a heavy vertical pin **222** journalled in a bracket **224** whereby to permit selection of any desired angular position of the grinding shaft **208** relative to the mandrel **22**. A perpendicular relationship is employed for the grinding of spur gears and various angular relationships for helical gears.

The bracket **224** is guided by conventional means (not shown) for vertical movement relative to a standard **226** and is adjustable along the same by a lead screw **228** in mesh with a vertical tapped opening in the bracket, said screw being under the control of a hand wheel **230**.

The foregoing description embraces the mechanical elements of the machine employed in obtaining the proper relative movements for gear grinding in accordance with the present invention. The machine as thus far described is fully capable under manual control of performing accurate and rapid grinding and simple and speedy set ups for different grinding operations. However, pursuant to an ancillary feature of the invention an electric circuit is provided which automatically will bring about the proper sequence of operations of the hydraulic cylinders **66, 220** for effecting a single grinding pass, and furthermore will bring about the proper operational sequence of said cylinders and of the indexing solenoid **166** for effecting successive single passes and proper indexing until a complete grinding pass has been performed.

The power for control and operation of the sundry drives is taken from a three phase four wire system consisting of three supply buses **232, 234, 236** and a neutral bus **238**. The three supply buses furnish driving power and the supply bus **232** and neutral bus furnish control power.

To start the grinder a push button **240** of a normally open switch **242** is depressed whereby to energize a drive relay **244/4**. For convenience, the reference numbers of all relays will be followed by a diagonal line and another number which indicates the number of contacts controlled by that relay; each contact will be denoted by the number of its controlling relay followed by a hyphen and the identifying number for that contact. Thus the relay **244/4** has four contacts **244—1, 244—2, 244—3** and **244—4**.

The circuit for the actuating coil of the drive relay runs from the supply bus **232** to the neutral bus through a normally closed contact **246—1** of a control power relay **246/3**, the normally open power starting switch **242**, a normally closed power cut-off switch **248** and the actuating coil of the drive relay. Actuation of the relay **244/4** closes its contacts, all of which are normally open. Three contacts **244—2, 244—3, 244—4** are power contacts in the energizing circuit for an electric motor **250** which drives a pump (not shown) that supplies liquid under pressure for operation of the hydraulic indexing motor **150** and the hydraulic cylinders **66, 220**. Thus when the button **240** is depressed the pump motor is started. The back contact **246—1** is included in the initial energizing circuit controlled by the pump start button to prevent the pump from being started except when all other elements are stationary, as they will be when no power is supplied to the control circuit. The purpose of the power cut out switch **248** is obvious.

Normally open contact **244—1** is a stick contact for maintaining relay **244/4** actuated after its initial energization so that button **240** can be released. Said contact shunts the series connected back contact **246—1** and switch **242.**

The next step is to depress a push button **252** which closes a normally open switch **254** and this supplies power to a grinder wheel relay **256/5** through said switch **254**, a normally closed power cut off switch **258** and a normally closed back contact **260—1** of a brake relay **260/4**. One normally open contact **256—1** is a stick contact which shunts the switch **254** to maintain the relay **256/5** energized after the push button **252** is released. Three normally open contacts **256—2, 256—3, 256—4** supply power to the grinder motor **210** when the relay **256/5** is energized. The fifth contact **256—5** is a normally closed, i.e. back, contact, and is in the circuit for the brake relay **260/4**. Thus momentary depression of the grinder start button will set the grinder motor in operation providing that the braking circuit for said motor is not effective so that back contact **260—1** is closed.

Although braking of the grinding wheel motor is not the next normal operation, it most conveniently is described at this point. Depressing a push button **262** closes a normally open braking switch **264** that energizes the braking relay **260/4** through back contact **256—5** (preventing energization of the braking relay unless the grinding motor power cut off switch **258** previously has been depressed to deenergize relay **256/5** and open contacts **256—2, 256—3, 256—4**). When the braking relay is actuated its normally open contacts **260—2, 260—3, 260—4** will be closed to feed power to drive the grinding wheel motor in reverse. Said power is fed through resistors **266** to cut the current thus supplied to the motor to approximately full load value and will bring the motor to a stop under visual control in about three to five seconds. It will be noted that no stick circuit is provided for the braking button so that the grinding wheel cannot inadvertently be operated in reverse.

The third step is to depress a push button **268** which closes a normally open control power switch **270** that energizes the relay **246/3** through a normally closed cut off switch **272**. The switch **270** needs to be closed only momentarily since the relay **246/3** is locked in operation by the normally open stick contact **246—2** which shunts said switch **270**. Actuation of the relay **246/3** completes the preparatory steps necessary to ready the gear grinder for production. When said relay is energized it closes normally open contact **246—3** which places power on a relay control bus **274** and a solenoid control bus **276**. Energization of bus **274** lights indicator lamps **278, 280** through branch circuits soon to be described, thereby denoting to the operator that a counter **282/3** which totalizes the number of single passes for a predetermined complete pass and a counter **284/3** which totalizes the number of single passes between wheel dressing operations have been deenergized. Energization of bus **274** also activates a solenoid **286** which speeds up any motion undertaken by the grinding head **211**. Energization of bus **276** shifts the grinder head to its extreme "in" position (sometimes hereinafter referred to as "dwell"). "Dwell" also denotes the extreme "out" position of the table.

The grinding head dwell position is to the right as seen in FIG. 1 and in this position the grinding wheel is clear of the gear blank. The extreme "in" position of the table **62** is at the end of the "in" travel denoted by the arrow **68**. For convenience, movement of either the grinding head or table away from extreme "in" position will be denoted hereinafter as "outward" movement and the limit of outward movement as the "out" position.

To better understand the operation of the control circuit, it is best now to interrupt the description thereof in order to refer to five switches that are operated by the table and grinding head, a single manually controlled switch, the two counters and the valve controls for the hydraulic cylinders **66, 220.**

There are three switches **288, 290, 292** operated by the table **62.**

The switch **288** is a flip-flop single pole double throw switch having an A and a B position, either of which it will maintain when so placed. Said switch is shown in FIG. 1 where it will be seen that it is mounted on the bed **56** and has an actuating element **294** adapted to be contacted by either of two adjustable cams **296, 298** on the table. The cam **296** throws the switch to B position to determine the limit of "out" travel of the table. The cam **298** throws said switch to A position to determine the limit of "in" travel of the table.

The switch **290** is a normally closed momentary switch mounted on the bed **56** and arranged to have its actuating element **300** operated by a cam **302** adjustably mounted on the table. Said cam is positioned to hold the switch open in "out" position of the table and to release it to closed position after the table has moved a short distance, e.g. ¼" inward.

The switch **292**, like the switch **288**, is a flip-flop single pole double throw switch having an A and a B position. Said switch is mounted on the bed **56** and has an actuating element **304** adapted to be contacted by either of two cams **306, 308** adjustably carried by the table. The cam **308** throws the switch **292** to A position a short time, e.g. one second, after the switch **288** is thrown to A position. The cam **306** throws the switch **292** to B position concurrently with the switch **288.**

It will be seen now that the switches **288, 292** are in A position during outward (idle, i.e. "roll back") movement of the table and in B position during inward (grinding) movement of the table, assuming A position as they reach the extreme inward limit of table travel.

There are two switches **310, 312** operated by the grinding head **211**. Both of these switches are of single pole double throw construction, being spring-loaded to one contact, herein called the C contact, and away from the other contact, herein called the D contact. Both said switches are snap and hence fast acting.

The switch **310** is mounted on the plate **212** and is shifted from C contact to D contact by engagement of its actuating element **318** with a cam **316** carried by the grinding head. This engagement determines the right hand (dwell) position of the grinding head during the reciprocating action. The other switch **312** also is mounted on the plate and is shifted from C contact to D contact by engagement of its actuating element **314** with a cam **317** to determine the outward position of the head. The actuating element of switch **312** also is engaged by cam **316** in dwell position of the head.

All the machine actuated switches **288, 290, 292, 310, 312** are shown in the circuit in the position they occupy when the table and head are in "dwell' position.

A flip-flop single pole double throw switch **320** is manually controlled by the operator and is positioned for automatic operation of the grinder against an E contact. The switch is thrown to close an F contact when selected movements of the machine are to be slowly run under manual control, an operation herein referred to as "inching."

The two counters **282/3** and **284/3** are of like construction. Each includes an actuating coil which controls two normally open contacts **282—1, 282—2** and **284—1, 284—2** as well as a normally closed contact **282—3, 284—3**. Each counter further includes a counting coil **282CL, 284CL**. Each counter has a conventional settable counting mechanism (not shown) which when a preset count has been reached deenergizes the associated actuating coil. The counting mechanism further comprises a standard arrangement for maintaining the actuating coil deenergized; however said arrangement permits reenergization of the actuating coil when the counting mechanism has been manually turned back to zero.

Each hydraulic cylinder **66, 220** is similarly governed. Accordingly only the controls for one of them, the grinding head cylinder, is shown in FIG. 1 and will be described.

A conduit **322** connects one end of the head cylinder **220** to a two position valve **324**. The valve is biased to one position. In said one position the conduit **322** is connected to a conduit **326** that runs to a valve **328** with a variably settable restricted opening. The valve **328** is connected to a drain **330**. In its other position the valve **324** connects the conduit **322** to a high pressure line **332** supplied by the pump (not shown) that is run by the motor **250**.

In like manner a conduit **334** connects the other end of the head cylinder to a valve **336** that selectively is connected either to the drain valve **328** or to the high pressure line **332**. The valve **336** is biased to its drain position.

To distinguish between the valves for the table and head, the table valves will be denoted by T and the head valves by H. If valve **324T** is actuated the table will slowly move toward its extreme "in" position. If valve **336T** is actuated the table will move toward its extreme out position. Similarly, actuation of the valve **324H** moves the head in and actuation of the valve **336H** moves the head out.

The hydraulic circuit only for the head cylinder includes a by-pass **338** shunting the restricted flow valve **328**. A valve **340** movable between fully open and fully closed positions is inserted in the by-pass so that when the valve is closed the grinding head only can move slowly and when it is open the head will move rapidly. The valve **340** is biased to closed position.

Resuming the description of the control circuit, it will be recalled that the last action mentioned was depression of the push button **268** to apply power to the relay control bus **274** and the solenoid control bus **276**.

When the relay bus **274** is live but the actuating coils of the counters **282/3, 284/3** still are deenergized the lamps **278, 280** will be energized through branch circuits including the normally closed counter back contacts **282—3, 284—3**, respectively, thus indicating that the counters are deenergized.

Applying power to the relay bus with the switch **320** in automatic position against the E contact energizes the solenoid **286** which actuates by-pass valve **340** so that any movement of the grinding head will be rapid.

Applying power to the solenoid control bus **276** energizes a solenoid **342** that controls head "in" valve **324H** and also energizes a solenoid **344** that controls table "out" valve **336T**. It will be noted that the branch circuits for these valves include two normally closed control relay contacts hereinafter described. At this moment in starting up the machine no control relays have been energized so that the table will move to its "out" (dwell) position and the head will move to its "in" (dwell) position, the head moving at high speed.

The next steps are to put gear blanks on the mandrel **22**, to place the proper grinding wheel on the shaft **208**; to manually phase the rack forms of the grinding wheel with the rough-preformed gear blanks; to set the grinding wheel to proper depth; and to set the shaft **208** at the desired angle to the mandrel. The counters are turned back to zero thus readying their actuating coils for energization and desired total counts are set into them. The total count for the counter **282/3** is the number of single passes in a complete pass and the total count for the counter **284/3** is the number of single passes before the grinding wheel needs to be dressed.

Now a "grind" push button **346** is depressed to start the automatic operation of the machine. Said push button closes an energizing circuit for a relay **348/3** from a motor terminal of the grinding motor **210** to the neutral bus. This live part of the circuit is chosen for the particular relay to ensure that translation of the grinding head and table is not commenced with the grinding wheel stationary.

The contacts **348—1, 348—2** of grind relay **348/3** are in the branch circuits for the counter actuating coils **282/3, 284/3**, respectively so that the counters thereupon are energized. Said contacts **348—1, 348—2** are shunted by normally open counter stick contacts **282—1, 284—1**, respectively, whereby when button **346** is released and relay **348/2** deenergized the counter actuating coils are maintained energized. The counter branch circuits also include normally closed push button reset switches **350, 352**.

Energizing the counters closes counter contacts **282—2, 284—2** to put power on automatic control sub-bus **354**.

At this time the table is in its "out" (dwell) position and the head is in its "dwell" (right hand) position so that switches **288, 292** are in B position, switch **290** is held open, and switches **310, 312** are held in D position. An inspection-dwell relay **356/2** whose function and operation are described hereinafter is idle so that its back contacts **356—1, 356—2** are closed.

The back contact **356—1** energizes a relay **358/3** through the B contact of table switch **292**. This opens a normally closed contact **358—2** in the energizing circuit for the table "out" (roll back) solenoid **344** and concurrently closes a normally open contact **358—1** in the energizing circuit for the table "in" (grind) solenoid **360** which controls valve **324T** and admits liquid under high pressure to the proper end of cylinder **66** to drive the table in, the other end of the cylinder now being connected to drain through restricted valve **328T**. Thus the table starts to move in slowly and will continue to so move until it shifts flip-flop switch **292** to A position, opening relay **358/3** and reversing actuation of the solenoids **344, 360** whereby to start the table moving slowly back to "out" position. This in and out movement of the table is repeated as long as power is on bus **354** and relay **356/2** is idle.

The back contact **356—2** brings power to table switch **288** which controls movement of the grinder head but since initially the switch **288** is in B position and the switch **290** is held in open position no action will occur. However after the table has moved (because of energization of relay **358/3**) about one-quarter of an inch inward, switch **290** is permitted to close. This enables the table to get under way before rapid reciprocation of the grinder head starts. Now power flows through **288B, 290, 312D** (which is actuated in the "in" position of the head) a relay **360/1** and **310D** (which is actuated because the head at the moment is in "in" position). Actuation of relay **360/1** closes normally open contact **360—1** to energize a relay **362—3** through **310D**. A normally closed back contact **362—3** in the energizing circuit for head "in" solenoid **342** thereupon opens and a normally open contact **362—2** closes in the energizing circuit for a solenoid **364** which controls head "out" valve **336H** thereby causing the head to move away from dwell position. It will be recalled that this movement of the head is rapid since bypass valve **340** is open. As the head moves away from dwell, switches **310, 312** spring back to C position opening the initial energizing circuit for relays **360/1, 362/3**; but a stick circuit for relay **362/3** is provided by the contact **362—1** which shunts switch **310** and the contact **312C** which shunts now open contact **360—1** so that the head continues to move out.

Eventually the head reaches the limit of outward travel and causes the switch **312** to be shifted to D position. This deenergizes **362/3** and opens the stick circuit through **362—1** for relay **362/3** so as to hold out relay **362/3** even when switch **312** returns to C position upon reversal of the head. When relay **362/3** opens, contact **362—2** will revert to its normally open position, deenergizing head "out" solenoid **364**, and contact **362—3** will revert to its normally closed position, energizing head "in" solenoid

344, thereby causing the grinder head to move in at high speed. Thus the head will rapidly shift "in" and "out" so long as switch 288 is in E position (the table is moving from extreme "out" to extreme "in" position) and switch 290 is closed (the table has moved a short distance away from extreme "out" position).

When the table nears its extreme "in" position (about a second before switch 292 is shifted from B to A position) switch 288 will be shifted from A to B position. This only affects movement of the grinder head. It opens the circuit for relays 360/1, 362/3, regardless of the position of the head whereby to energize head "in" solenoid 342 so that shortly before the table has reached its extreme "in" position and the gear blank is clear of the grinding wheel the grinding head will move to dwell and will stay there until the table has moved back to "out" position and then far enough "in" to release switch 290.

With the switch 288 in A position a make-ready indexing relay 366/1 is energized through contact 312D, relay 360/1 and contact 310D since the head is in dwell position. It may be noted that relay 366/1 is a high resistance relay so that it does not permit a sufficient flow of current to energize relay 360/1. Subsequently when the table reaches its extreme "in" position and starts the return "out" (roll back) movement switch 292 is shifted to A position and power flows through the previously closed normally open contact 366—1, through a normally closed back contact 368—1 of a time delay relay 368/1 and through an indexing relay 370/1 to energize the latter. A normally open contact 370—1 thereupon closes to actuate indexing solenoid 166 and thus release abutment dog 152 so that the indexing motor starts turning the last change gear 144.

At the same instant that the relay 370/1 is energized power starts to flow through a conventional adjustable time delay device 372 and the time delay relay 368/1. The device 372 is adjusted to permit sufficient power flow to take place after a predetermined time to energize the relay 368/1. This time is computed as sufficient to allow the gear 144 to make the requisite number of turns, less a fraction of a turn. When relay 368/1 energizes it opens its back contact 368—1 in the energizing circuit for the indexing relay 370/1 which upon deenergization cuts out the indexing solenoid and causes the anchoring latch 154 to arrest the dog 152 at the end of a full revolution of the gear 144. Thus the drive spindle 86 and gear blank are indexed while the grinder head is in dwell position and during "out" movement of the table (roll back of the gear blank).

When table actuated switch 292 is shifted to A position as the table reaches its extreme "in" position the branch circuits for counting coils 282CL, 284CL are actuated to advance the counters by one each toward their total counts.

It will be seen that the counting coils are not protected by the made-ready contact 366—1 since no damage will be done if the counting takes place before the grinder head is returned to dwell, although obviously the same does not hold true should the grinding head be shifting during indexing.

After a total count is reached on either counter, the associated actuating coil will be deenergized. This will open one of the contacts 282—2 or 284—2 to remove power from the automatic control sub bus 354 so that relays 362/3, 358/3 are deenergized causing solenoids 342, 344 to become actuated whereby the head and table will be moved to their "dwell" (table "out" and head "in") positions awaiting the operator. The operator by looking at the lamps 278, 280 can tell which total count has been reached and take appropriate action.

If the operator desires to inspect the work on the grinding wheel at any time except when the relay 348/3 is energized, he presses inspect-dwell push button 373 closing a circuit through a relay 374/2. The relay is kept energized upon release of the button by a by-pass

circuit through a normally open stick contact 374—1. Energization of the relay 374/2 also closes a normally open contact 374—2 to complete an energizing circuit for the inspection dwell relay 356/2. Actuation of the latter relay causes its normally closed contacts 356—1, 356—2 to open the circuits of switches 292, 288, respectively, whereby the solenoids 342, 344 are energized to shift the table and head to "dwell" positions. The back contact 348—3 opens the inspection-dwell circuit when the grind button 346 is pressed. An indicator lamp 376 tells the operator when the machine is in inspection-dwell condition.

Upon occasion it is desirable to "inch" the table or head "in" or "out." The grinder is readied for inching by throwing flip-flop switch 320 from its E (automatic) position to its F (inching) position. This deenergizes solenoid 286 and closes by-pass valve 340 so that further motion of the head will be slow. In its F position switch 320 energizes relay 378/8. Said relay has four normally closed contacts 378—1, 378—2, 378—3, 378—4 in the energizing circuits for the head and table "in" and "out" solenoids 342, 364, 344, 360, which circuits are under the control of the automatic reversing relays 358/3, 362/3. Hence the machine is taken out of automatic control when the switch 320 is moved to inching position. The relay 378/8 also has four normally open contacts 378—5, 378—6, 378—7, 378—8 providing alternate energizing circuits for the said solenoids 342, 364, 344, 360, respectively. These circuits further include inching push buttons 382, 384, 386, 388, respectively. Thus when an inching push button is depressed it will energize the associated valve control solenoid 342, 344, 360, or 364 to cause the table or the head slowly to move "in" or "out" as the case may be as long as the button is held depressed.

It thus will be seen that there has been provided a gear grinder which achieves the several objects of this invention and is well adapted to meet the conditions of practical use.

Since various possible embodiments might be made of the above invention, and since various possible changes might be made in the embodiment above set forth, it is to be understood that the foregoing description of the details of the grinder and the accompanying drawing have been presented only by way of illustration and are not to be construed as limitative.

Having thus described the invention there is claimed as new and desired to be secured by Letters Patent:

1. In a method of grinding a gear blank having teeth with valleys therebetween, that improvement comprising the steps of rotating a grinding wheel having an axial edge profile constituting plural basic rack tooth forms of successively different effective heights spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear blank being ground, reciprocating the grinding wheel perpendicularly to its axis of rotation, and rolling the gear blank toward and past the effectively highest tooth form in a manner such that the pitch circle of the gear blank rolls without slipping on the pitch line of the effectively highest basic rack tooth form whereby a plurality of consecutive valleys of successively different depths are progressively generatively ground in a single repetitively transversely shifting grinding pass.

2. In a method as set forth in claim 1 that further improvement including the steps of moving the grinding wheel to a position clear of the gear blank, while the wheel is there step indexing the gear blank one valley and rolling the gear blank back to a starting position and then repeating the steps set forth in claim 1.

3. An apparatus for grinding a gear blank, said apparatus including means rolling a gear blank without slipping on a line tangent to its pitch circle, a grinding wheel having an axial edge profile constituting plural basic rack tooth forms spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear blank, the tooth forms being of successively different effective heights and having their tips successively closer to the

axis of the wheel, means rapidly spinning the wheel about its axis, and means rapidly reciprocating the wheel in a direction transverse to the direction the gear blank is rolled and with the pitch line of an endmost tooth form tangent to the pitch circle of the gear blank.

4. An apparatus for grinding a gear blank, said apparatus including means rolling a gear blank without slipping on a line tangent to its pitch circle, a grinding wheel having an axial edge profile constituting plural basic rack tooth forms spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear blank, the tooth forms being of successively different effective heights and having their tips successively closer to the axis of the wheel, means rapidly spinning the wheel about its axis, means rapidly reciprocating the wheel in a direction transverse to the direction the gear blank is rolled and with the pitch line of an endmost tooth form tangent to the pitch circle of the gear blank so as to generatively grind the blank and means for step indexing the gear blank after each grinding movement thereof a number of teeth less than the number of tooth forms on the grinding wheel.

5. An apparatus as set forth in claim 4 wherein the indexing means step indexes the gear blank only a single tooth after each rolling movement.

6. An apparatus for grinding a gear blank, said apparatus including means rolling a gear blank back and forth between two extreme positions without slipping on a line tangent to its pitch circle, a grinding wheel having an axial edge profile constituting plural basic rack tooth forms spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear blank, the tooth forms being of successively different effective heights and having their tips successively closer to the axis of the wheel, means rapidly spinning the wheel about its axis, means rapidly reciprocating the wheel between two extreme positions in a direction transverse to the direction the gear blank is rolled and with the pitch line of an endmost tooth form tangent to the pitch circle of the gear blank whereby a plurality of consecutive valleys between the teeth of the gear blank are consecutively generatively ground in a single grinding pass of the gear blank, means step indexing the gear blank after each single grinding pass, means counting the number of single grinding passes, and means responsive to a predetermined number of single grinding passes to stop the rolling means adjacent an extreme position thereof.

7. An apparatus for grinding a gear blank, said apparatus including means rolling a gear blank back and forth between two extreme positions without slipping on a line tangent to its pitch circle, a grinding wheel having an axial edge profile constituting plural basic rack tooth forms spaced at intervals equal to the pitch of a basic rack of the same diametral pitch as the gear blank, the tooth forms being of successively different effective heights and having their tips successively closer to the axis of the wheel, means rapidly spinning the wheel about its axis, means rapidly reciprocating the wheel between two extreme positions in a direction transverse to the direction the gear blank is rolled and with the pitch line of an endmost tooth form tangent to the pitch circle of the gear blank whereby a plurality of the consecutive valleys between the teeth of the gear blank are consecutively generatively ground in a single grinding pass of the gear blank, means step indexing the gear blank after each single grinding pass, means counting the number of single grinding passes, and means responsive to a predetermined number of single grinding passes to stop the rolling means and the reciprocating means adjacent an extreme position of each.

8. In a machine, a bed, a table, means mounting the table for slidable movement across the bed, a shaft, means mounting the shaft for rotation relative to the table about an axis perpendicular to the direction of movement of the table, means including an indexing change gear train to index said shaft, means to lock said train, and means responsive to slidable movement of the table for rocking the locked train.

9. In a machine, a bed, a table, means mounting the table for slidable movement across the bed, a shaft, means mounting the shaft for rotation relative to the table about an axis perpendicular to the direction of movement of the table, a drum coaxial with said shaft and rotatable with respect thereto, an indexing change gear train for indexing said shaft, said train being mounted to turn with said drum, means to lock said train, and means responsive to slidable movement of the table for rocking said drum with the train locked whereby to rock said shaft through said train independently of indexing.

10. A gear grinder comprising a frame, a member reciprocally slidable on the frame between two extreme positions, means on said member mounting a gear blank for rotation about its axis with said axis extending transversely to the direction of sliding movement of said member, a grinding head including a rotatable grinding wheel having an axis of rotation transverse to the axis of rotation of the gear blank, means mounting the grinding head on the frame for reciprocal sliding movement in a direction perpendicular to the axis of rotation of the wheel from an extreme position to an opposite extreme position, generative means responsive to sliding movement of the member in one direction for rotating the blank to impart a rolling generative motion thereto, means for reciprocating said member, means for repeatedly reciprocating said grinding head as said blank is undergoing said rolling generative motion while said member is moving in said one direction, means for maintaining said grinding head adjacent one of said extreme positions thereof as said member is moving in a direction opposite said one direction, and means for step indexing said blank, said indexing means comprising a motor, means drivingly connecting said motor to the gear blank, locking means normally preventing rotation of the motor and releasable to permit said motor to rotate, and means for slidably releasing said locking means.

11. A gear grinder as set forth in claim 10 wherein the releasing means comprises a solenoid device connected to the locking means for releasing the latter when said device is energized, a limit switch actuable in response to the member reaching one of its extreme positions, and means for energizing said solenoid device in response to actuation of said limit switch.

12. A gear grinder as set forth in claim 11 wherein the locking means comprises a movable latch element, the means drivingly connecting the indexing motor to the gear blank comprises a rotatable element drivingly connected to said gear blank and said motor, a lug mounted on said rotatable element, and spring means normally biasing said latch element into a position in engagement with said lug to prevent rotation of said rotatable element and thereby prevent rotation of said blank by said motor, said solenoid device being connected to said latch element for moving the latter out of engagement with said lug when the solenoid device is energized.

13. A gear grinder as set forth in claim 12 comprising means for automatically de-energizing the solenoid device after a predetermined time interval to allow the spring means to urge the latch element back to lug-engaging position before the rotatable element is rotated by the motor through a complete revolution.

14. A gear grinder comprising a frame, a member reciprocally slidable on the frame between two extreme positions, means on said member mounting a gear blank for rotation about its axis with said axis extending transversely to the direction of sliding movement of said member, a grinding head including a rotatable grinding wheel having an axis of rotation transverse to the axis of rotation of the gear blank, means mounting the grinding head on the frame for reciprocal sliding movement in a direction perpendicular to the axis of rotation of the wheel from an extreme position to an opposite extreme position,

generative means responsive to sliding movement of the member in one direction for rotating the blank to impart a rolling generative motion thereto, means for reciprocating said member, means for repeatedly reciprocating said grinding head as said blank is undergoing said rolling generative motion while said member is moving in said one direction, means for maintaining said grinding head adjacent one of said extreme positions thereof as said member is moving in a direction opposite said one direction, and means for step indexing said blank, said blank mounting means comprising a rotatable spindle, means drivingly connecting the blank to said spindle, a sleeve element rotatably mounted on said spindle coaxially therewith, a gear fixed to said spindle, a shaft rotatably mounted on said sleeve element on an axis eccentric and parallel to the axis of the sleeve and spindle, a gear fixed to said shaft, said gears constituting the indexing means, the generative means comprising means for locking said gears and for rotating said sleeve element in response to movement of the member.

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