United States Patent

Hill

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[54] **TAPER COMPENSATING METHOD AND APPARATUS**

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[52] **U.S. Cl.**.....**51/165.91,** 51/105 SP, 51/281 R, 51/324

[51] **Int. Cl.** **B24b 49/04**

[58] **Field of Search**.....51/165 R, 165.77, 165.8, 165.82,51/165.83, 165.85, 165.9, 165.91, 165.92, 105 SP, 281 R

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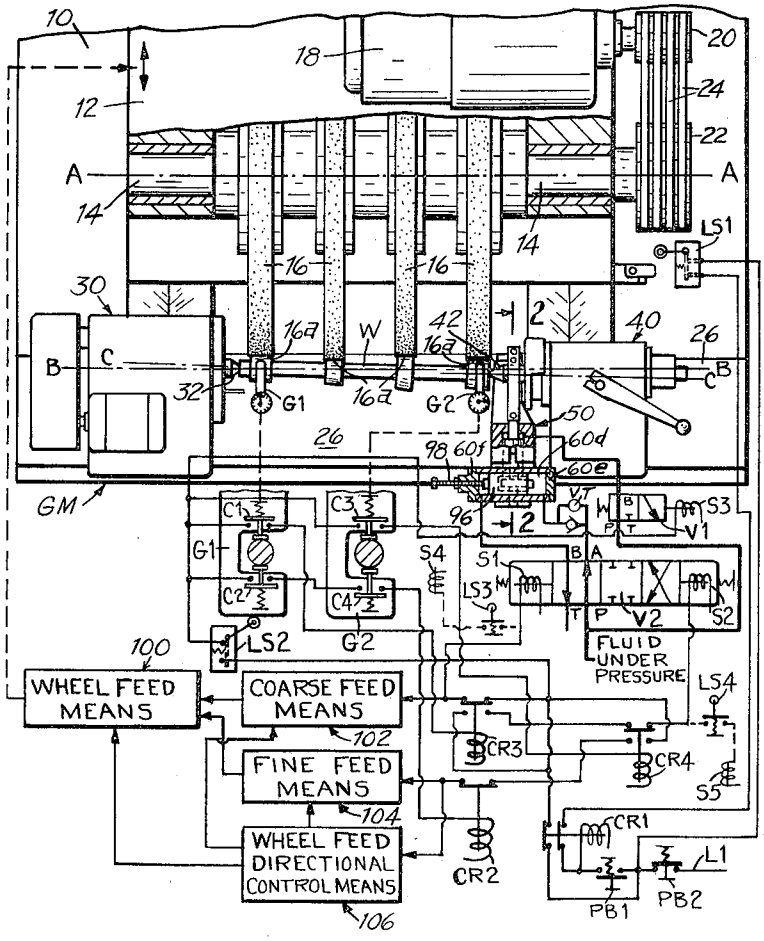
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[57] **ABSTRACT**

Taper compensating apparatus and method for elastically deforming a work support supporting one end of a workpiece being ground in a cylindrical grinding machine controlled by at least two in-process gages engaging opposite end portions of the workpiece. The apparatus distorts and forces the work support and hence the axis of the workpiece away from the grinding wheel to intentionally grind a taper in the same direction. When one end portion of the tapered workpiece furthest away from the deformed work support is ground to a predetermined oversize diameter an in-process gage thereon stops the infeed and actuates reversing means to relieve and allow the deformed work support to spring back and feed, without lost motion, the workpiece into the grinding wheel at a controlled precision fine feed rate until the end portion of the workpiece nearest the deformed work support is ground to exactly the same amount oversize as is the one end portion. Thereafter, the in-process gage thereon resumes the grinding feed at a fine rate until at least the end portions are ground to the final diameter at which time the gages stop and reverse the feed mechanism.

25 Claims, 7 Drawing Figures



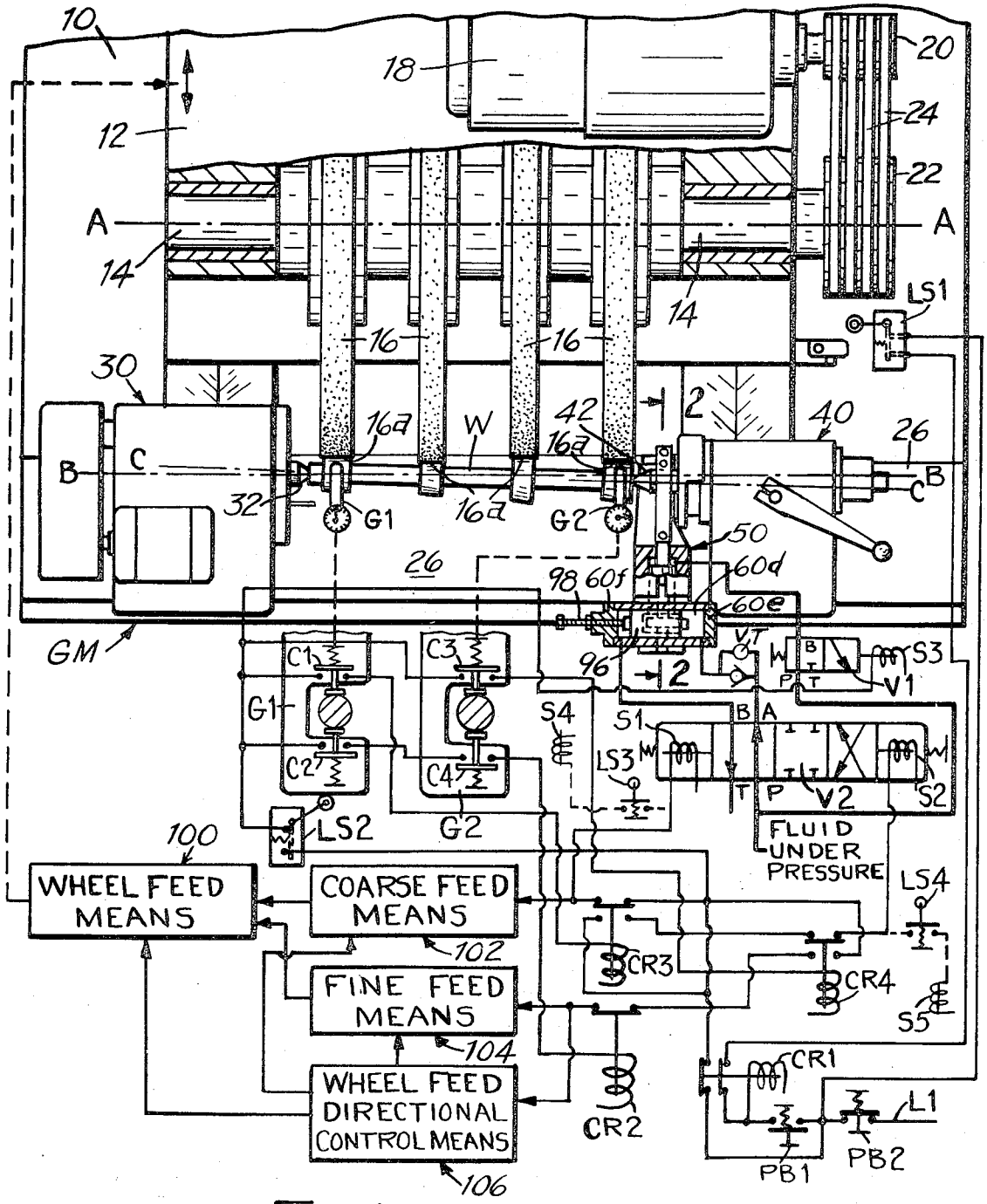


FIG. 1

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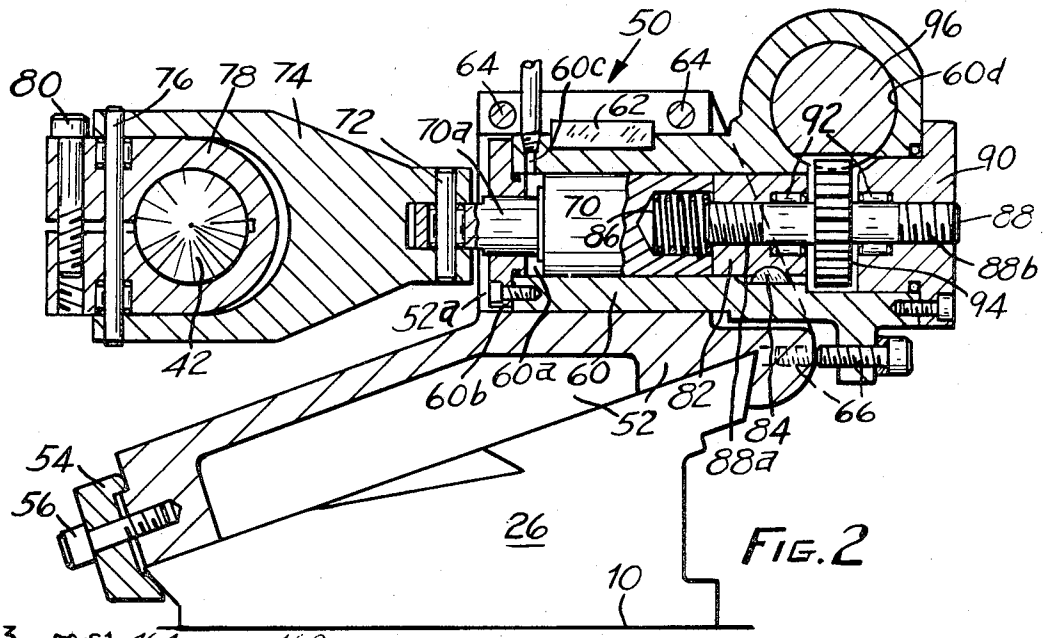


FIG. 2

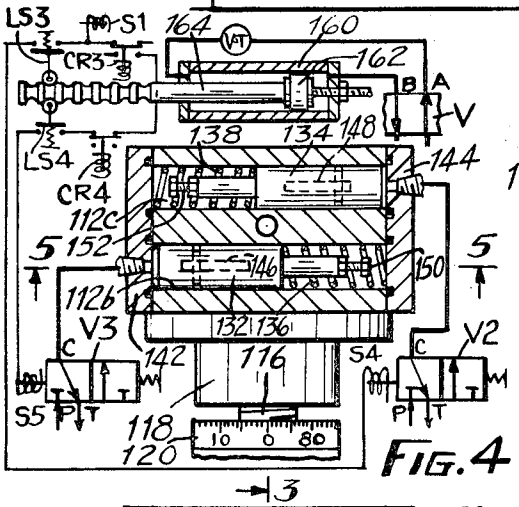


FIG. 4

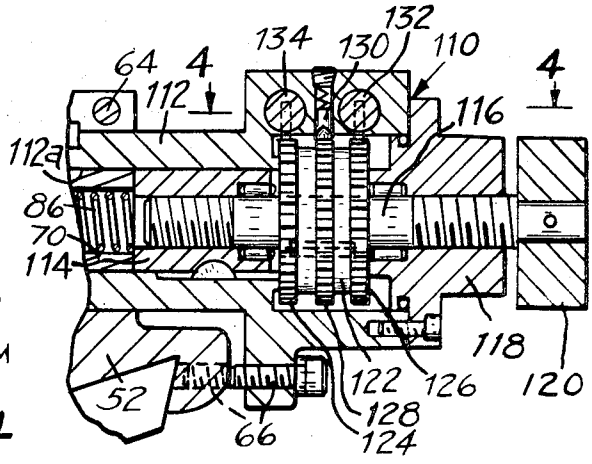


FIG. 3

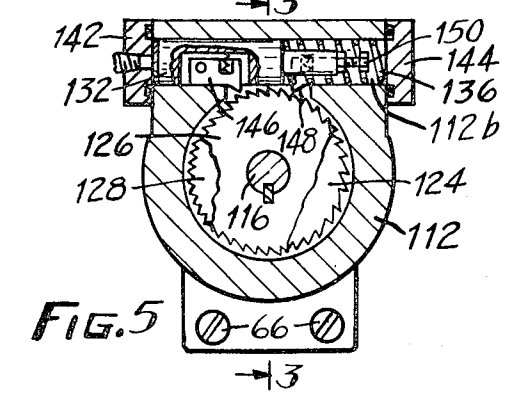


FIG. 5

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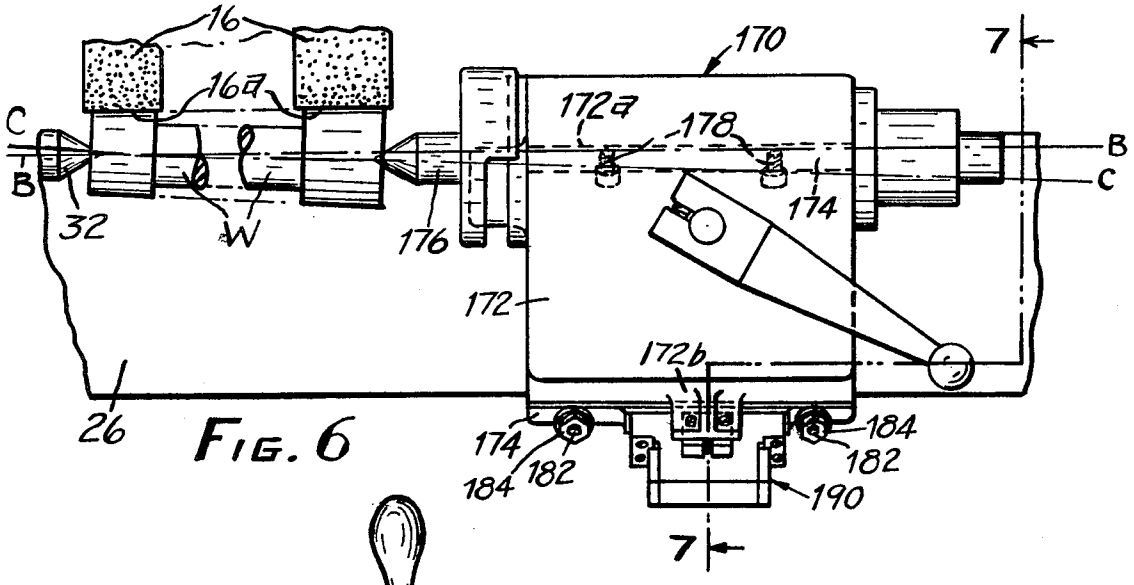


FIG. 6

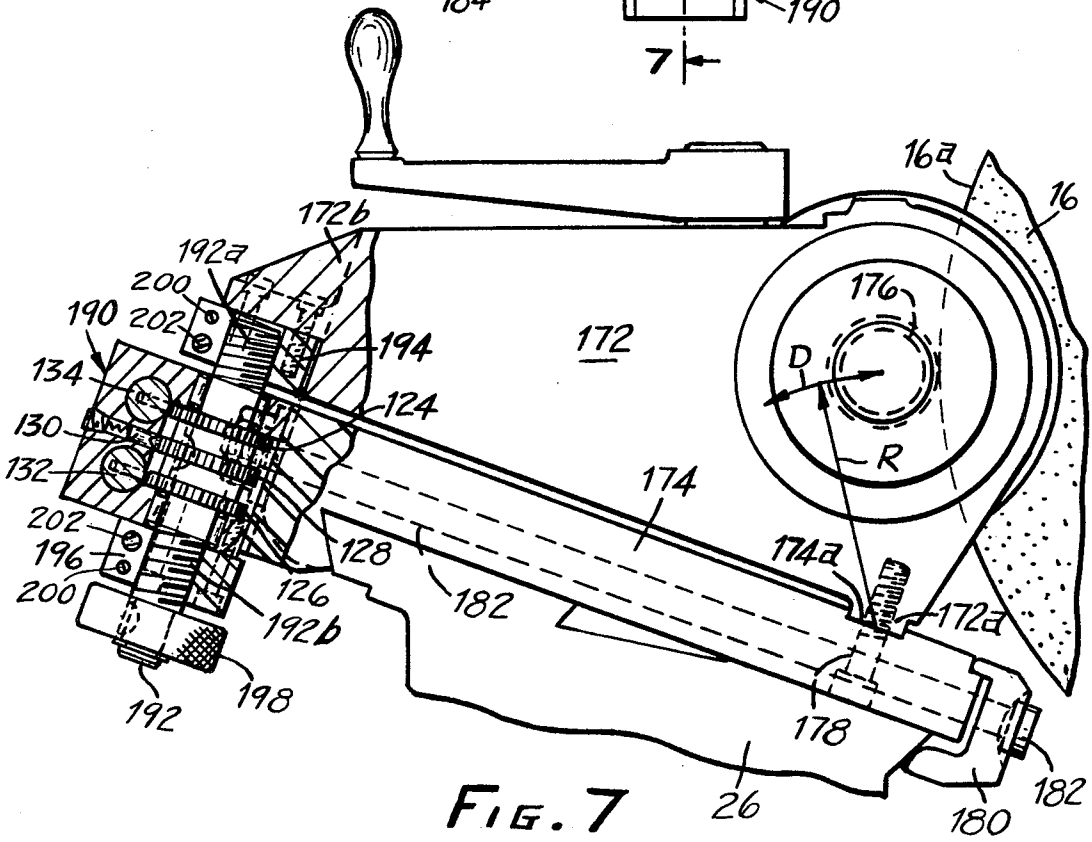


FIG. 7

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TAPER COMPENSATING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to cylindrical grinding machines and particularly to a taper compensating mechanism adapted to be mounted thereon and to stress and shift a work support at one end of the workpiece to correct for taper due to the changes which occur in the relationship between the grinding wheel and work support means.

2. Description of the Prior Art

When grinding workpieces having either one or a plurality of spaced portions of the same or different diameters rotatable about a common axis, it is often required that the diameter be constant or substantially constant within very close tolerances along the axis of the workpiece. The grinding machine must be able to produce a plurality of identical workpieces of the same diameter and with substantially precise cylindrical portions. However, it is known that many changes occur during the time the grinding machine is operating which affect the initial precision built into the components of the machine. For example, physical deflection or deformation of the components and the workpiece due to grinding feed pressure, grinding wheel wear, truing tool wear, dressing of wheels, and thermal drift due to changes in temperature of the machine components are all known to continually change the ideal relationship between the grinding wheel support means and the work support means to produce undesirable workpieces.

In the prior art are disclosed various methods and devices that automatically compensate for taper produced by machine drift. In U.S. Pat. No. 3,271,910 granted to Haisch there is disclosed an in-process gage system which detects taper and a compensating mechanism controlled thereby to exert a controlled amount of force, in the proper direction, against a work support at one end of the workpiece. The support is deflected and hence the end of the workpiece is shifted to compensate for taper detected by the in process gages. U.S. Pat. No. 2,599,922 granted to this applicant discloses a grinding machine wherein the swivel table is pivoted to correct for taper in response to in-process gaging. Also, an article appearing on page 701 of the Oct. 2, 1962 issue of Machinery Magazine discloses a Schaudt cylindrical grinder equipped with means for shifting either of the opposite ends of a footstock.

The applicants compensating means differs from the prior art in that the work support and hence one end of the workpiece is always deflected away from the grinding wheel by one force, an amount which exceeds the anticipated amount of machine change and deliberately grinds a taper on the workpiece. When the smaller opposite end reaches a predetermined oversize diameter the wheel feed is delayed and a second opposing overpowering force is applied through a differential screw at a controlled rate which eliminates all backlash or lost motion, and relieves the stress allowing the work support to spring back towards its undestorted position. Hence the workpiece is moved toward the wheel to correct for taper after which the wheel feed is resumed at a fine feed rate until final size is reached.

SUMMARY OF THE INVENTION

A taper compensating mechanism having a housing rigidly fixed relative to a cylindrical grinding machine base and adjacent means supporting one end of a workpiece to be ground cylindrically. A first fluid pressure operated piston is slidably mounted within the housing for transverse movement toward and away from the axis of the workpiece and has a piston rod at one end pivotally connected to a yoke pivotally connected to a clamp fixed to an axially movable work supporting center. An axially movable nut, engages the opposite end of the piston and is threaded onto one end of a differential feed screw rotatably mounted therein and a stationary nut fixed relative to the housing. At its opposite end the screw has a coarse thread of greater pitch threaded into the stationary nut.

A second fluid operated rack piston applies a greater force than said first piston to rotate a gear fixed to the differential feed screw. For each revolution of the screw the small piston moves axially an amount equal to the difference in the pitch of the threads at opposite ends of the screw. At the beginning of the grinding cycle the small piston is actuated to pull and distort the work support away from the grinding wheel which changes the relationship between the grinding wheel and the axis of the workpiece causing that end to be ground larger than the opposite end. Near the end of the grinding feed cycle the in-process gaging actuates the larger piston to rotate the differential screw at a controlled rate which inturn overpowers the opposing differential force of the small piston. Thus the work support is allowed to spring back toward its initial undistorted position to move the workpiece toward the grinding wheel until the in-process gages detect the absence of taper whereupon the grinding feed cycle is resumed at a reduced rate until gages determine final size, stop, and reverse the feed cycle.

Other embodiments of the invention disclose distorting and relieving the work support means to be deformed by rotating the differential screw in opposite directions. The differential screw having one end threaded into a movable nut fixed to the work support to be deformed and an opposite end threaded into a fixed nut on a base fixed to the machine adjacent to the work support means to be deformed. Also disclosed are means for rotating the differential screw either continuously or intermittently.

Another disclosed form of the invention provides a base onto which the work support means to be deformed is mounted and connected to a fixed base by a narrow elongated web or portion extending axially, a predetermined radical distance or radius from the common axis, between the base and the work support means thereon. A distorting and relieving mechanism including a differential screw and a fixed nut is mounted on a front portion of the base. A movable nut is fixed to an adjacent front portion of the work support thereon and connects to one end of the differential screw. Rotating the differential screw causes the work support and the common axis to move on an arc and pivot about a center of the radius at the narrow portion relative to the fixed base.

Therefore, it is the primary object of the invention to provide a precision taper compensating method and

apparatus for cylindrical grinding machines and having means to take up lost motion and elastically distort a work support in one direction only, away from the grinding wheel, to intentionally grind a taper and reversing means including a differential screw to relieve and allow the distorted work support to feed the workpiece into the grinding wheel at a precise controlled rate to eliminate taper.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic partial plan view of a cylindrical grinding machine and controls and on which the invention is mounted;

FIG. 2 is a vertical section through an embodiment of the taper compensating mechanism of the invention taken on line 2—2 of FIG. 1 with differential force applying means and a continuous feed mechanism for rotating a differential screw;

FIG. 3 is partial sectional view through a modified form of the invention with a constant reset pick feed mechanism for intermittently rotating the differential screw.

FIG. 4 is a horizontal sectional view through the pick feed mechanism taken approximately on line 4—4 of FIG. 3;

FIG. 5 is vertical sectional view through the pick feed mechanism approximately on line 5—5 of FIG. 4;

FIG. 6 is a partial plan view of another embodiment of the invention adapted to support and control the distortion of a work support mounted thereon; and

FIG. 7 is a side view partly in section of the embodiment shown in FIG. 6 showing the intermittent pick feed mechanism for rotating the differential screw and mounting for supporting the work support.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The invention will be described, by example only, in combination with a conventional multiple wheel cylindrical grinding machine having spaced work support means for supporting opposite ends of a workpiece, a reversible wheel feed mechanism, drive means for rotating the grinding wheels, means for feeding the wheel at a coarse feed rate and then a fine feed rate, and control means including at least one multiple contact in-process gage for continuously engaging each opposite end portion of the workpiece being ground. Also, the workpiece W shown may represent a plurality of spaced bearings of either the same or of different diameters on a precision camshaft or crankshaft. However, it is obvious that the invention may be utilized in combination with other types of cylindrical grinders with means for supporting opposite ends of a workpiece with either one or more portions to be ground to a cylinder without taper.

Referring to FIG. 1 wherein there is partially shown a multiple wheel grinding machine GM similar to those disclosed in U.S. Pat. Nos. Re 24,378; 2,851,827; 2,946,162 and 3,171,234 and to which reference may be had for details not disclosed herein. Normally, the grinding machine GM has a base 10 on which is slidably mounted a wheel slide 12 on which is rotatably journalled a grinding wheel spindle 14 supporting a plurality of spaced grinding wheels 16 for rotation about an axis A—A. A conventional drive motor 18, drive pulley 20, and driven pulley 22 connected by drive belts 24 provides means for rotating the spindle 14 and wheels 16.

Adjustably fixed to the base 10 is a table 26 to which is fixed an adjustable headstock 30 with a headstock center 32 supporting one end of a workpiece W. The workpiece W is rotatably driven by the headstock about its axis in the well known manner by drive means including a work drive dog, not shown in the interest of clarity.

Fixed relative to the table 26 and the base 10 is an adjustable footstock 40 of conventional design having an axially movable footstock center 42 biased into supporting engagement with the opposite ends of the workpiece W. The biased footstock center 42 forces the workpiece W tightly against the headstock center 32 and hence aligns the axis of workpiece W with the axis of the spaced centers 32 and 42.

Disregarding the effect of any outside forces, initially the headstock and footstock centers 32 and 42 are presumed to be in axial alignment and therefore coaxially align the axis of the workpiece W clamped therebetween to lie on a common axis B—B. In this instance the common axis B—B is parallel to the axis of rotation of the grinding wheels 16. We must also assume that the peripheral grinding faces of the grinding wheels have been trued and are precisely concentric and parallel with the axis of rotation A—A. Theoretically, then the grinding wheels 16 should grind each portion of the workpiece W to a perfect cylinder of constant diameter. However, this is not the case since it is known that the theoretical ideal relationship between the machine components change due to outside forces such as deflection, grinding wheel feed pressure, and expansion and contraction of the components due to changes in temperature therein. Therefore, the workpiece cannot be ground to a true cylinder without taper unless the operator continually checks the workpieces and readjusts the machine to maintain the theoretical ideal parallel relationship between the peripheral grinding faces 16a and the axis B—B.

Taper compensating means 50 has been provided by this invention for automatically compensating for the inherent movement caused by various forces which changes the preset ideal relationship between the grinding wheel faces 16*a* and the common axis B—B of the work support centers 32 and 42 and the workpiece W, necessary to produce a cylindrical workpiece without taper. The taper compensating means 50 comprises a base, a body, or housing 52 rigidly fixed by one or more clamps 54 and screws 56, to the work support table 26 and adjacent the footstock 40. The table 26 can be of any other type than that shown and well known in the art. In some instances the table 26 may be adjustable and adapted to be swiveled about a central pivot or made an integral part of the machine base 10.

The base, body, or housing 52 has inclined and dovetail surfaces which mate with the inclined surfaces of the table 26 and a central bore 52*a* extending horizontally along a central axis normal to the common axis B—B of the footstock center 42. Distorting means are provided comprising a cylinder body 60 adjustably mounted within the central bore 52*a* and fixed against relative rotational and axial movement respectively by a key 62, clamp screws 64, and opposing adjustable

thrust bolts 66. A distorting piston 70 is slideably mounted in a first cylinder bore 60*a* in the cylinder body 60 and is movable axially, toward and away from the footstock center 42, along the central axis normal to the common axis B—B. The piston 70 has a blind hole, at one end, in which is a biasing means, such as, a spring, continually applying a force tending to move the piston toward the footstock center 42. A piston rod 70*a* extends from the opposite end of piston 70 towards the footstock center 42 through an end portion or cap 60*b* fixed to the cylinder body 60 and is pivotally connected by a first pivot pin 72 at its end to one end of a link or yoke 74. The opposite spaced opposed ends of the yoke 74 are pivotally connected by a second pivot pin 76 to a clamp or collar 78 situated within the yoke and rigidly clamped about the footstock center 42 by a bolt 80.

It can be seen that when the work support or footstock center 42 is moved axially to remove or insert a workpiece the yoke can move freely, relative to the collar 78 and footstock center 42, and the piston rod 70*a*, in a horizontal plane about the parallel vertical axes of the pivot pins 72 and 76. Further, it is obvious that when fluid under-pressure is passed through a port 60*c* and into the cylinder bore 60*a*, that the piston 70, piston rod 70*a*, yoke 74, collar 78 and the footstock center are forced in a direction away from the grinding wheel faces 16a and the axis A—A of rotation. The force exerted hereby tends to deflect the preset position of the footstock center 42 so that the workpiece is moved about the headstock center 32 shifting the common axis B—B to a taper producing position C—C shown displaced at an angle to the axis A—A. Hence, all portions of the workpiece W being ground will taper from smaller and different diameters situated on the left or headstock side of each portion to larger and different diameters on the opposite right hand or footstock side of each portion being ground.

Reversing means are provided in the cylinder body 60 for overpowering the distorting force exerted by the relatively small area of the piston 70, and for relieving the stress and allowing the footstock to spring back at a precisely controlled rate, without lost motion, until the common axis B—B is parallel to the grinding faces 16*a* and/or the axis of rotation A—A of the wheels 16. The reversing means comprises a fine threaded movable nut 82 slideably axially in the bore 60a adjacent the end of the piston 70 of larger area. The fine threaded nut 82 is prevented for rotating relative to the cylinder body 60 by a key 84 slideable in a keyway in the body 60. Between the fine nut 82 and the end of the piston 70 is situated the biasing means such as a coil spring 86 compressed within a blind hole in the piston 70.

A differential screw 88 has threads of relatively fine pitch on one end portion 88a rotatably supported by and threaded into the axially movable nut 82. The opposite end portion 88*b* of the differential screw 88 has coarser threads 88*b*, of greater pitch than the finer threads on the other end portion described but which are of the same hand, rotatably supported and threaded into a stationary nut 90 fixed to the cylinder body 60. Bearing 92 may be provided in nuts 82 and 90 to support the differential screw during axial and rotational movements about the central axis.

Fixed to a central or intermediate portion of the differential screw 88 is rotatable gear 94 situated between the movable and stationary nuts 82 and 90. The gear 94 has peripheral teeth engaging the rack teeth of a rack piston 96 slideably mounted in a second bore 60*d* in the cylinder body 60. The axis of the bore 60*d*, along which the rack piston 96 moves, extends in a direction transverse to the central axis about which the gear 94 rotates. Fixed to the cylinder body 60 at one end of the bore 60*d* is an end cap 60*e* and fixed to the other end is an end cap 60*f* through which is threaded an adjustable reset or stop screw 98 which determines the initial starting position of the pistons 96, differential screw 88 and the movable nut 82 relative to the cylinder body 60. Hence, the axial position of the movable nut 82 determines the stroke of the piston 70 away from the center 42 and the amount of the center is deflected by the stress applied thereto by the fluid pressure operated piston 70

Referring to FIG. 1 and 2 it can be seen that when fluid under pressure is passed into the left hand end of the cylinder bore 60d the rack piston 96 is moved continuously toward the right, rotates the gear 94 and the differential screw clockwise, as viewed from the end of portion 88*b* in the stationary nut 90, causes the differential screw 88 to move axially relative to the nuts 82 and 90, and the gear 94 to shift relative to the rack teeth of the rack piston 96. If, for example, the threads on the end portion 88b and in the stationary nut bore twelve right hand threads per inch (12 pitch R. H.) one revolution of the gear 94 will advance the screw 88 one twelfth (1/12) or 0.0833 of an inch toward the footstock center 42, relative to the nut 90 and the rack piston 96. If the opposite end portion 88*a* and the nut 82 have fourteeen right hand threads per inch (14 pitch R. H.) one revolution of the screw 88 shifts the nut 82 axially relative to the screw 88 and the cylinder body 60 in a direction away from the footstock center toward the stationary nut one fourteenth (1/14) or 0.0713 of an inch. Therefore, the nut 82 has been fed or advanced toward the footstock center 42 a net or differential amount of 0.012 of an inch. Also, should the rack piston 96 have ten (10) teeth per inch (10P) and the gear 94 engaged thereby have twenty (20) ten pitch (10P) teeth, displacing the piston one (1) inch rotates the screw 88 one half (½) revolution. Thus, the nut 82 is advanced a corresponding amount equal to one half of 0.012 or 0.006 of an inch. The stroke of rack piston 96 can be varied to suit the particular requirements and this embodiment has a maximum stroke of approximately 1.5 inches to feed and retract the nut 820.018 of an inch.

In FIGS. 1 and 2 the taper compensating mechanism 50 is shown in an operating position at a point in the grinding cycle wherein fluid under pressure, supplied and controlled by conventional means not shown, is directed from the pressure port P to port B of a conventional solenoid operated spring return directional control valve V1 shifted to the left by solenoid S3 to the cylinder bore 60*a*. The fluid under a predetermined constant pressure acts against the relatively small exposed area of the piston 70 about the piston rod 70*a* and together produce sufficient force to deflect the footstock center until the piston 70 seats against the nut 82. The axis of rotation of the workpiece has been

shifted from B—B to C—C and the grinding wheel faces **16***a* are grinding a taper on each portion of the workpiece W contacted thereby. Two in-process gages G1 and G2 have been applied to opposite end portions of the workpiece being ground for controlling the wheel feed means and the taper compensating means when the gages determine that the portions measured thereby have been ground to a prescribed diameter. The in-process gages may be of a suitable conventional type each having multiple sets of contacts each of which can be adjusted to be actuated when the workpiece reaches a desired diameter to either actuate or deactuate means during the grinding cycle. Suitable in-process air-electric and electronic gages and gaging systems are readily available from various manufacturers such as Marposs Gage Corporation, North White Plains, New York; Moore Products, Spring House, Pennsylvania; and Federal Products, Providence, Rhode Island.

Preferably the in-process gages G1 has at least two sets of contacts C1 and C2 which are schematically shown and adjusted to close when the portion of the workpiece adjacent the headstock center **32** is ground to the diameter to which each has been preset. Similarly, gage G2 has two sets of contacts C3 and C4 which continuously measure the portion of the workpiece W adjacent the footstock center **32** and close when that portion attains the proper diameter for which they have been preset.

For the sake of clarity only those portions of the grinding machine, the control means, and of the grinding cycle have been or will be described which pertain to the operation of the taper compensating means of the invention. Therefore, assuming the workpiece W is being rotated abut the centers **32** and **42** by the headstock **30** and that the grinding wheel faces 16a have been trued parallel to and are rotating concentrically about the axis of rotation A—A of spindle **14**, and the wheel feed means **100** has been actuated. The wheel slide **12** is moving and feeding the grinding wheel faces **16***a* into the workpiece at a suitable body or coarse feed rate under the control of a coarse feed means **102**.

A normally closed one way operated limit switch LS1 was momentarily opened and closed during the previous rearward movement of the slide **12**. The switch LS1 in series with a normally closed push button PB2 and a set of normally open contacts of relay CR1 is holding relay CR1 energized after being energized by momentarily closing a conventional cycle start push button PB1. Another set of normally open contacts of relay CR1 are closed and supplying electrical power to normally closed contacts of relay CR3 and normally open now held closed contacts of relay CR3 and normally open now held closed contacts of a limit switch LS2 actuated by the application of the in-process gages G1 and G2 onto the workpiece W, to the contacts C1, C2, C3, and C4 and energized a solenoid S3 actuating the valve VI passing fluid under pressure into cylinder bore **60***a* and piston **70**. Also a solenoid S1 is energized shifting valve V2 to the left and the coarse feed means is actuated by power supplied through the closed set of normally closed contacts of CR3.

Fluid, under pressure is applied to the right side of the rack piston **96**, forcing it against the stop screw **98** and the differential screw **88** has been retracted. Fluid under pressure has forced the piston **70** against the fine threaded movable nut **82** and the work support center **42** with the workpiece W has been deflected away from the axis A—A and rotates about a distorted common axis indicated at C—C. The grinding wheel faces **16***a* are intentionally grinding a taper on the workpiece W, whereby due to the length of the workpiece the portion adjacent the footstock **40** is ground more oversize and will require more stock removal to bring it to the desired diameter than the portion adjacent the headstock **30**. In other words, the portion adjacent the headstock **30** will be closer to the desired diameter than the portion adjacent the footstock **40**. Therefore, to prevent grinding undersize the contacts C1 of gage G1 are preset to be closed when the diameter of the portion adjacent the headstock **30** is preferably oversize **.001** above the high limit of the desired final size whereupon CR3 is energized. Energization of CR3 opens the normally closed contacts deactuating the coarse feed means and stops the grinding wheel feed. Also, solenoid S1 is de-energized and solenoid S2 is energized, by closing of normally open contacts of CR3 and through normally closed contacts of CR4 to shift valve V2 to the right. Fluid under pressure is directed from port P to port B and the left hand side of the rack piston **96** and fluid exhausts from the opposite right side through a throttle valve VT and ports A and T of valve V2. The rack piston **96** with its greater area plus the leverage applied thereby through the gear **94** to the screw **88** and the nut **82** overpowers the force of the piston **70** and allows the deflected footstock center to spring back. The center **42** and the workpiece W supported thereby, move continuously at a rate controlled by the throttle valve VT from the axial position C—C toward the common axis position B-B until the contact C3 of gage G2, preset to close when the diameter is oversize 0.001 above the high limit of the desired final diameter, close energizing relay CR4. Normally closed contacts of CR4 open de-energizing S2 and valve V2 to the right. Fluid under pressure is directed from port P to port B and the left hand side of the rack piston **96** and fluid exhausts from the opposite right side through throttle valve VT and ports A and T of valve V2. The rack piston **96** with its greater area plus the leverage applied thereby through the gear **94** to the screw **88** and the nut **82** overpowers the force of the piston **70** and allows the deflected footstock center to spring back. The center **42** and the workpiece W supported thereby, move continuously at a rate controlled centers blocking all ports and normally open contacts of CR4 close and actuate the fine feed means **104** through the normally closed now closed contacts of relay CR2. Thus, the various amounts of taper which the machine would have produced, without taper compensating means, has been automatically compensated for and the workpiece W should be rotating about the common axis B—B substantially parallel to the grinding faces **16***a* and the axis A—A. Each ground portion of the workpiece W should be of substantially constant diameter without measurable taper. It must be realized that it is virtually impossible to eliminate all taper but it can be reduced to an acceptable amount that is hardly detectable by modern precision gages. Therefore, the precision and accuracy of the in-process gaging plays an important part and determines how much taper

remains. However, most precision in -process gages are quick acting and accurate enough to control taper to within an acceptable tolerance of 0.00050 of an inch difference between the small and large diameter of the workpiece.

Fine feed means **104** resumes and controls the wheel feed mechanism **100** to feed the grinding wheel faces **16a** at a reduced rate until both contacts C2 and C4 each preset to detect the allowable oversize high limit of the diameters desired. Closing of both contacts C2 and C4 energizes relay CR2 which opens its normally closed contacts to deactuate the fine feed means and stop the forward grinding wheel feed and actuate the wheel feed directional control means **106**. The wheel feed directional control means retracts the grinding wheels **16**, resets the fine and coarse feed means, and the grinding wheel feed means for the next grinding cycle.

Limit switch LS1 is momentarily opened as wheel slide retracts to break holding circuit and de-energizes relay CR1. Normally open contacts of CR1 open breaking its holding circuit and the circuit to LS2, solenoid S3 and to various contacts mentioned above to maintain wheel slide **12** in retracted position. Relays CR2, CR3 and CR4 are all de-energized and return to their normal positions shown. Valve V1 is deactuated allowing fluid to exhaust from cylinder bore **60*a***, by the spring biased piston **70**. Gages G1 and G2 are removed opening normally open limit switch LS2 to prevent actuation of the relays CR2, CR3, CR4 and solenoid S3 before gages are reapplied to a new workpiece.

The footstock center **42** is then retracted pivoting the yoke **74** which slightly shifts the piston **70** relative to the bore **60*a***. Workpiece W is removed, another workpiece may be inserted, and the grinding cycle repeated by momentarily closing push button PB1.

In FIGS. 3, 4, 5 there is shown a modified form of the invention wherein an intermittent or pick type differential screw feed mechanism **110** has been substituted for the continuous feed mechanism described above. Most of the components of the modified forms are substantially the same as described above and only those parts which are not interchangeable will be described. The pick feed type mechanism **110** comprises a cylinder body **112** substantially the same as cylinder body **60** which may be clamped into and fixed against rotary and axial motion in the base or housing **52** in the manner described above. Cylinder body **112** has a cylinder bore **112*a*** into which a piston **70** and spring **86** may be inserted for axial movement. A movable fine threaded nut **114** is movably axially in the bore **112*a***, engages the supports a fine threaded end of a rotatable differential screw **116**. The other end of the differential screw engages and is rotatably supported in a coarse threaded nut **118** bolted to the body **112** and has an adjusting graduated knob **120** fixed to its protruding end portion. By rotating the knob **120** the screw **116** is rotated to adjust the initial axial position of the movable nut **114** relative to the piston **70** and hence determines the extent which the piston can move and deform the work support. Intermediate the ends of the screw **116** is a center portion slidably keyed for axial movement within a hub **122** on which are fixed a pair of axially spaced ratchet wheels **124** and **126**. A detent gear **128** is also fixed to the hub between the ratchet wheels and has gear teeth engaged by a spring biased detent or plunger **120** for maintaining the position of the gear and hence the differential screw **116**. The detent or plunger **130** has a beveled end which is easily cammed out of the shallow mating V-shaped notches between the teeth in the gear **128** by forcefully rotating the gear **128**.

Adjacent each of the ratchet wheels **124** and **126** are ratchet pistons **132** and **134** slidably mounted for movement in opposite directions in bores **112*b*** and **112*c*** respectively in the body **112**. Biasing means such as the piston return springs **136** and **138** are placed between the pistons and the opposite end caps **142** and **144** fixed to the body **112** at opposite ends of the bores. In the pistons are slots in which are pivotally mounted spring biased pawls **146** and **148** for engaging the teeth and intermittently rotating of the ratchet wheels and the differential screw **116** in opposite directions. Adjustable bolts **150** and **152** are threaded into the ends of the pistons and locked in adjusted position by conventional lock-nuts for providing the desired equal feed stroke of the pistons and hence the axial displacement of the movable nut **114** by the differential screw **116**.

Referring to FIGS. 4 and 5, when fluid under pressure is directed intermittently into the left side of cylinder bore **112b** the feed ratchet piston **132** likewise intermittently moves toward the right and the pawl **146** engages and rotates the ratchet wheel **126**, the screw **116** clockwise and feeds the nut **114** toward the grinding wheels **16**. At the end of the grinding cycle fluid under pressure is intermittently directed into the bore **112*c*** to intermittently move the reset ratchet piston **134** the same number of times as was the piston **132**. Since the stroke of the pistons **132** and **134** are adjusted to be equal, then the differential screw and the nut **114** will be moved away from the grinding wheels the same amount it was previously fed toward the wheels **16**.

Conventional electrical and fluid directional control means well known in the art may be provided which are suitable for intermittently feeding and retracting the differential screw **116** and nut **114**. For example the conduit from port B of the valve V could be connected through a throttle valve VT to one side of a cylinder **160** having a piston **162**, and piston rod **164** with equally spaced cams intermittently actuating a normally open limit switch LS3 in series with the normally closed contacts of CR3 and a solenoid S4 of a two way directional control valve V2. Likewise a second tow way directional control valve V3 operated by solenoid S5 could be connected in series with the normally open contacts of the relay CR3, normally closed contacts of CR4, and a normally open limit switch LS4. Hence, the limit switches LS3 and LS4 would open and close de-energizing and energizing the solenoids S4 and S5 to shift the valves V2 and V3 and alternately connect their port C to the pressure port P and exhaust port T. The conduit from port A of valve V could be connected to the opposite end of the rack cylinder **160** to retract the piston to the adjustable fixed stop screw at the end of the cylinder **160** from which it began. The pressure port C of valve V3 would be connected to actuate the feed ratchet piston **132** and pressure port C of valve V2 would be connected to actuate the reset or retracting piston **134**. Instead of cams, the piston rod **164** could

have rack teeth engaging a small gear fixed to rotate a large disc with a greater number of equally spaced cams thereon.

Referring to FIGS. **6** and **7**, there is shown another modification of the invention wherein a work support **170** substantially the same as the footstock or, work support **40**, is split adjacent its lower side into two parts one of which is a body **172** connected by an elongated narrow portion or web to a base **174**. On its lower side the body has a narrow elongated integral portion, key, or tongue **172***a* extending, horizontally below, and substantially parallel to the axis of a work support center **176**. The long narrow key or tongue **172** has a narrow generally flat bottom surface and adjacent parallel side surfaces of greater depth than a narrow shallow mating slot, recess or keyway **174***a* extending substantially the entire axial length or width of the body **172** and the base **174**. A plurality of spaced bolts **178** extend through the base **174** and are threaded into the key or tongue **172***a* to fasten the key **172***a* securely within the closely fitting narrow keyway or recess **174***a*. Thus the rest of the body **172** is separated from the base **174** and has very little area of supporting contact with the base **174**.

The base **174** is substantially a plate having its lower surface machined to mate the dove detailed surface and top surfaces of the table **26**. A plurality of clamps **180** engage the dovetail surfaces on the backside of the table and clamping bolts **182** extending through the base **174**, with nuts **184** on the front side of the base maintains the base rigidly fixed to the table **26**.

An intermittent or pick type feed mechanism **190** substantially the same as the mechanism **110** described above is provided for rotating a differential screw **192** in opposite directions. Therefore, the same characters are used to indicate similar parts. The pick feed mechanism **190** is fixed by bolts to the central front portion of the base **174** so that the central axis of the differential screw **192** is substantially normal to a plane parallel to the inclined top and/or bottom surface of the base **174**. A fine threaded end portion **192***a* of the screw **190** projects upwardly and threadedly engages a split nut **194** fixed by bolts to and movable with a central forwardly projecting integral portion **172***b* of the body **172**. The opposite coarse threaded portion **192***b* engages the threaded split fixed nut **196** fixed by bolts to the body of the pick feed mechanism **190**. A hand knob **198** is fastened to the end of the differential screw for manually adjusting the axial displacement of the screw relative to the base **174**. As shown the differential screw **192** is keyed for rotation by the ratchet wheels in opposite directions and slideably keyed for axial movement only relative to the ratchet wheels actuated by individual feed and retracting ratchet piston in the manner described previously for the feed mechanism **110**.

In operation, rotation of the differential screw **190** with right hand threads counter-clockwise, as viewed from the knob **198**, will apply an axial pulling force to the end of the body, acting as a lever, when multiplied by the leverage distance between the axes of the differential screw and the key **172***a*, of sufficient magnitude to pull and deflect or distort the body **172** about the narrow elongated portion **172***a*. The center **176** will be deflected and moved away from the grinding wheels, counter-clockwise about an arc D whose radius R is substantially the distance from the center of the flat bottom surface of the key **172***a* to the axis of the center **176**. Hence, the end of the workpiece W is forced away so that the common axis B—B is shifted to the distorted position C—C as described above to produce an intentional taper. Conversely rotating the differential screw **192** clockwise provides an upward axial movement thereof at a controlled rate allowing the elasticity in the prestressed body to move the center and the workpiece clockwise along the arc D toward the grinding wheels to correct for taper.

It can be seen that when the body is distorted all backlash or lost motion between the threads of the screw **192** and the nuts **194** and **196** is eliminated and remains that way until all the stress in the body is relieved. Also, means including a conventional stop screws **200** and clamp bolts **202** may be provided for pre-adjusting the split nuts **194** and **196** so as to eliminate substantially all looseness between the engaging threads.

The differences between the taper compensating mechanism **50** and **170** is that there is no separate opposing force, such as, that applied by the piston **70** to overcome and reverse in order to relieve the stressed work support means without lost motion. Obviously a continuous compensating feed mechanism such as that described above in connection with the taper compensating mechanism **50** could be utilized instead of the pick or intermittent feed mechanisms **110** or **190** on the embodiment **170** shown in FIGS. **6** and **7**. The control means would be substantially the same as that shown and described for operating the continuous feed mechanism shown in FIG. **1** or as shown and described for operating the pick feed mechanism shown in FIGS. **3, 4,** and **5** except that the directional control valve V1 and control therefore would be unnecessary since piston **70** is not used.

As many modifications of the invention may be made without departing from the spirit and scope of the invention, it is to be understood that the embodiments shown in the drawings and described hereinabove are to be considered as illustrative and limited only by the scope of the appended claims.

What is claimed is:

1. In combination with a cylindrical grinding machine having at least one rotatably driven grinding wheel with a grinding face rotating about an axis of rotation; work support means axially spaced along a common axis spaced from the axis of rotation for engaging opposite end portions of a workpiece and supporting the workpiece for rotation about the common axis; grinding wheel feed means for feeding the grinding face into and out of engagement with the workpiece; gaging means for continuously measuring at least each of the opposite end portions of the workpiece and determining when the common axis is substantially parallel to the grinding face during a grinding cycle; and control means actuated by the gaging means for stopping the grinding wheel feed when one end portion of the workpiece is ground to a predetermined oversize diameter, resuming the wheel feed when the other end portion reaches a predetermined oversize diameter and the common axis is parallel to the grinding face, and retracting the grinding wheel when at least both end

portions of the workpiece are ground to final size; wherein the improvement comprises:

a taper compensating mechanism mounted on the grinding machine adjacent one of the work support means for engaging and supporting one of the opposite end portions of the workpiece including:

distorting means for elastically deforming one of the work support means and deflecting the common axis and the workpiece in one direction away from the grinding face a predetermined amount sufficient to compersate for lost motion and all movement continually occurring between components of the grinding machine during operation thereof that changes a preset parallel relationship between the grinding face and the common axis, and for deliberately grinding a taper on the workpiece so that the other end portion of the workpiece nearest the deformed work support means is always ground oversize a greater amount than the one end portion further away is ground oversize during the grinding cycle;

reversing means, actuated by the gaging means after the one end portion has been ground to the predetermined oversize diameter and the grinding wheel feed has been stopped for reversing the distorting means, to relieve and allow the elastically deformed work support means to spring back and feed the workpiece toward the grinding face at a fine precision controlled rate without lost motion until the gaging means detects the diameter of the end portion engaged by the deformed work support means is oversize by the same amount as the one end portion, the common axis is substantially parallel to the grinding face, the workpiece is substantially without taper, the reversing means is stopped, the grinding wheel feed resumed by the gaging means until at least both end portions of the workpiece are ground to the final size, and the gaging means actuates the control means to retract the grinding wheel and reset the grinding wheel feed means, the control means and the taper compensating mechanism for a subsequent grinding cycle.

2. The combination according to claim 1 wherein the distorting means comprises:

a base rigidly fixed relative to the work support means to be deformed having a bore therein;

a distorting piston slidably mounted within the bore for movement relative to the base;

a piston rod, extending from the piston and one end of the bore, operatively connected to the work support means to be deformed; and

means for directing a source of fluid under pressure against the piston for shifting the distorting piston and piston rod, taking up the lost motion, and continually applying a distorting force to deform and maintain the work support means deformed while grinding the taper and for opposing the reversing means while the workpiece is fed toward the grinding face without lost motion to remove the taper during the grinding cycle.

3. The combination according to claim 1 wherein the distorting means comprises:

a base rigidly fixed to the grinding machine and connected to the work support means to be deformed by a narrow elongated portion extending axially between the base and the work support means to be deformed at a predetermined radius from the common axis, there being a space between base and the work support means to be deformed extending from the narrow elongated portion to adjacent front portions of the base and the work support means to be deformed;

a movable threaded nut fixed to and movable with a front portion of the work support means to be deformed;

a fixed threaded nut fixed to the front portion of the base and having threads of different pitch than the movable nut;

a differential screw rotatably supported in the front portion of the base and having

a threaded end portion threaded into the movable nut, and

an opposite threaded end portion threaded into and mating with the threads of different pitch in the fixed nut; and

power means, operatively connected to and for rotating the screw in one direction to move the movable nut and the work support means toward the base and elastically deform the elongated narrow portion to deflect the common axis away from the grinding face on an arc whose radius originates from a center in the elongated narrow portion connecting the base to the work support means.

4. The combination according to claim 2 wherein the reversing means comprises:

an axially movable nut slidably mounted within the bore adjacent the distorting piston for engaging an opposite end face of the distorting piston and having a threaded hole therein;

a fixed nut, at an opposite end of the bore, fixed relative to the base and having a threaded hole therein;

a differential screw having a threaded end portion threaded into and rotatably supported in the movable nut and an opposite threaded end portion with threads of different pitch thereon threaded into the fixed nut; and

power means operatively connected to and for rotating the differential screw in one direction to overpower the distorting force and axially move the movable nut and the distorting piston against the distorting force to relieve the deformed work support means at the fine precision controlled rate and for rotating the differential screw in an opposite direction to return the movable nut to a predetermined reset position which determines a distorting stroke of the distorting piston and amount the support means is deformed away from the grinding face.

5. The combination according to claim 3 wherein the power means comprises:

a first ratchet wheel with ratchet teeth thereon operatively connected to rotate the differential screw in the one direction which deforms and moves the work support means to be deformed and the common axis away from the grinding face;

first ratchet means, slideably mounted in a first bore in the front portion of the base, adjacent the first ratchet wheel for intermittently engaging the ratchet teeth and rotating the first ratchet wheel and the differential screw in the one direction;

means for directing fluid under pressure intermittently into one end of the first bore to actuate the first ratchet means; and

means for biasing the first ratchet means toward the one end of the first bore and to ride idly over the ratchet teeth to a deactuated position.

6. The combination according to claim 4 wherein the power means comprises:

a gear operatively connected to rotate the differential screw;

a housing fixed relative to the base and having a second bore adjacent the gear;

a reversible rack piston slideable in the second bore and having rack teeth meshing with the gear; and

means for directing fluid under pressure into opposite ends of the second bore for shifting the rack piston, and rotating the gear and the differential screw, respectively, in opposite directions.

7. The combination according to claim 4 further comprising:

an axially adjustable housing fixed against axial and rotational movement relative to the base and having

a forward portion clamped within the bore in the base;

a first bore in the forward portion in which the distorting piston, the movable nut, and the differential screw are located and which extends between one end of the housing through which the piston rod extends and the fixed nut fixed to the housing at an opposite end of the first bore; and

a rear portion adjacent the opposite end and the fixed nut within which is situated the power means operatively connected to the differential screw.

8. The combination according to claim 4 wherein the reversing means further comprises:

resilient means compressable between the axially movable nut and the distorting piston for biasing the distorting piston away from the movable nut and taking up lost motion between the differential screw and the movable and fixed nuts.

9. The combination according to claim 4 wherein the power means comprises:

first ratchet and pawl means operatively connected to and for intermittently rotating the differential screw in one direction, overpowering the distorting means, and relieving the deformed work support means at the fine precision controlled rate; and

second ratchet and pawl means operatively connected to and for intermittently rotating the differential screw in an opposite direction for returning the movable nut to the predetermined reset position.

10. The combination according to claim 4 wherein the distorting means further comprises:

means for pivotally connecting the piston rod to the work support means to be deformed and allowing axial movement of a work support center thereon for supportingly engaging and disengaging the workpiece.

11. The combination according to claim 5 wherein the reversing means comprises:

a second ratchet wheel with ratchet teeth thereon operatively connected to intermittently rotate the differential screw in an opposite direction to relieve and allow the elastically deformed work support means to spring back and move the common axis and the tapered workpiece toward the grinding face;

second ratchet means slideably mounted in a second bore in the front portion of the base adjacent the second ratchet wheel for intermittently engaging and rotating the second ratchet wheel and the differential screw in the opposite direction;

means for directing fluid under pressure intermittently into one end of the second bore to actuate the second ratchet means; and

means for biasing the second ratchet means toward the one end of the second bore and to ride idly over the ratchet teeth of the second ratchet wheel to a deactuated position.

12. The combination according to claim 6 further comprising:

adjustable means, on the housing at one end of the second bore, for engaging and varying a return and reset stroke of the reversible piston, whereby rotation of the gear and the differential screw can be varied to change the reset position of the movable nut, the stroke of the distorting piston, and the amount the work support means is deformed.

13. The combination according to claim 9 wherein the first and second ratchet and pawl means comprises:

a first ratchet wheel with ratchet teeth thereon operatively connected to rotate the differential screw in one direction for overpowering the distorting means and to relieve the deformed work support means;

a second ratchet wheel with ratchet teeth thereon operatively connected to rotate the differential screw in an opposite direction for returning the movable stop nut to the predetermined reset position;

a housing fixed relative to the base and having

a first bore adjacent the ratchet teeth of the first ratchet wheel, and

a second bore adjacent the ratchet teeth on the second ratchet wheel;

ratchet means including a ratchet piston, slideably mounted in each of the first and second bores, for engaging the ratchet teeth and intermittently rotating the ratchet wheels and the differential screw in opposite directions;

means for directing fluid under pressure intermittently into one end of each of the first and second bores to actuate the ratchet means; and

means for biasing each of the ratchet means toward the one end of each of the first and second bores and to ride idly over the ratchet teeth to a deactuated position.

14. The combination according to claim 10 wherein the means for pivotally connecting the piston rod to the work support center comprises:

a clamp fixed to the work support center; and connected

a yoke having one end pivotally connected to the clamp and an opposite end pivotally connected to the piston rod.

15. The combination according to claim 11 further comprising:

a detent gear having, a plurality of equally spaced teeth and notches between the teeth, connected to rotate with the differential screw;

a detent movable within the front portion of the base and having a beveled end portion adapted to protrude into the notches and engage the teeth on the detent gear and to be cammed out of the notches by the teeth upon rotation of the detent gear by the differential screw; and

resilient means for biasing the detent and the beveled end portion into the notches and engagement with the teeth on the detent gear to prevent rotation of the detent gear and the differential screw during an idle movement of the ratchet means over the ratchet teeth toward the deactuated position.

16. A method of grinding a workpiece substantially without taper and compensating for taper in a cylindrical grinding machine having at least one rotatably driven grinding wheel with a grinding face rotating about an axis of rotation; work support means axially spaced along a common axis spaced from the axis of rotation, for engaging opposite end portions of the workpiece and supporting the workpiece for rotation about the common axis; grinding wheel feed means for feeding the grinding face into and out of engagement with the workpiece; gaging means for continuously measuring at least each of the opposite end portions of the workpiece, determining when the common axis is substantially parallel to the grinding face, and to actuate control means when each of the end portions have been ground to a predetermined oversize diameter and to final size during a grinding cycle; and control means actuated by the gaging means for arresting the grinding wheel feed when the gaging means detects one portion of the workpiece is ground to a predetermined oversize diameter, resuming the grinding wheel feed when the other end portion is ground to a predetermined oversize diameter and the common axis is substantially parallel to the grinding face, and retracting the grinding wheel when at least the end portions of the workpiece are ground to final size, the method comprising the steps of:

elastically deforming one of the work support means and deflecting the common axis and the workpiece in one direction away from the grinding face a predetermined amount sufficient to compensate for lost motion and all movement continually occurring between components of the grinding machine during operation thereof that changes a preset parallel relationship between the grinding face and the common axis, and to deliberately grind a taper on the workpiece os that the other end portion of the workpiece nearest the deformed work support means is always ground oversize a greater amount than the one end portion furthest away is ground oversize during the grinding cycle; and

relieving and allowing the elastically deformed work support means to spring back and feed the workpiece toward the grinding face at a fine precision controlled rate without lost motion, after the gaging means detects that the one end portion has been ground to the predetermined oversize diameter and actuated the control means to stop the grinding wheel feed, until the gaging means detects that the other portion engaged by the deformed work support means has been ground to a diameter that is oversize by the same amount as the one portion, the common axis is substantially parallel to the grinding face, the workpiece is substantially without taper and the gaging means actuates the control means to stop the relieving the deformed work support means and resumes the grinding wheel feed until at least both ends of the workpiece are ground to the final size.

17. The method according to claim **16** further comprising the steps of:

continuously applying a distorting force sufficient to elastically deform the work support means to be deformed the predetermined sufficient amount during the grinding cycle; and

applying an overpowering force, continually opposed by the distorting force, in an opposite direction at the predetermined fine precision controlled rate to relieve and allow the deformed work support means to spring back and feed the workpiece, without lost motion, into the grinding face.

18. The method according to claim **17** wherein the step of applying the distorting force further comprises:

directing fluid under pressure against one side of a piston slideably mounted within a bore of a base fixed adjacent the work support means to be deformed which is connected to the piston and move the piston relative to the base to deform the work support means; and

stopping and limiting the movement of the piston when the work support means has been deformed the predetermined sufficient amount by engaging the piston with an axially movable threaded nut, adjacent the piston in the bore, threaded onto one threaded end portion of a rotatable differential screw having an opposite threaded end portion with different pitch threads threaded into a fixed threaded nut fixed to the base at an opposite end of the bore.

19. The method according to claim **18** wherein the relieving step further comprises:

rotating the differential screw in one direction at a rate and with sufficient force to overpower the opposing distorting force and shift the axially movable nut together with the distorting piston at the fine precision controlled rate.

20. The method according to claim **19** further comprising the step of:

rotating the differential screw in the opposite direction sufficiently to shift the axially movable nut away from the distorting piston, to a reset position at the end of the grinding cycle, an amount which limits and provides sufficient movement of the distorting piston to deform the work support means the predetermined sufficient amount.

21. The method according to claim **20** wherein the relieving step further comprises:

directing fluid under pressure into a second bore of a housing fixed relative to the base and against one side of a reversible rack piston therein engaging a gear operatively connected to rotate the differential screw, shift the axially movable nut, reverse and overpower the opposing distorting piston with an overpowering force to relieve the

work support means at the predetermined fine precision controlled rate.

22. The method according to claim 16 wherein the deforming step further comprises:

rotating a differential screw, having one end portion threaded into an axially movable threaded nut attached to and movable with the work support means to be deformed and an opposite threaded end portion of different pitch threads threaded into a fixed nut fixed relative to the grinding machine adjacent the work support means to be deformed, in one direction sufficient to elastically deform the work support means the predetermined sufficient amount away from the grinding face.

23. The method according to claim 22 wherein the relieving step further comprises:

rotating the differential screw in an opposite direction at the predetermined fine precision controlled rate.

24. The method according to claim 23 wherein the rotating steps further comprises:

intermittently rotating the differential screw in each of the directions.

25. The method according to claim 23 further comprising the steps of:

mounting and connecting the work support means to be deformed onto a base fixed relative to the grinding machine so that it is connected to the base by an elongated narrow portion, extending axially between the base and the work support means, a predetermined radius from the common axis and the differential screw being connected to the movable nut fixed to a front portion of the work support means to be deformed and the fixed nut fixed to an adjacent front portion of the base; and

pivoting the work support means and the common axis about a center of the radius at the narrow portion by rotating the differential screw in one direction with sufficient force to deform and deflect the work support means to be deformed and the common axis on an arc away from the grinding face the predetermined sufficient amount and in an opposite direction on the arc at the fine precision controlled rate to relieve the deformed work support means.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,690,071 Dated September 12, 1972

Inventor(s) Oiva E. Hill

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 16, lines 61 and 62, delete "connected".
Column 17, line 52, for "os" read -- so --.

Signed and sealed this 10th day of April 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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