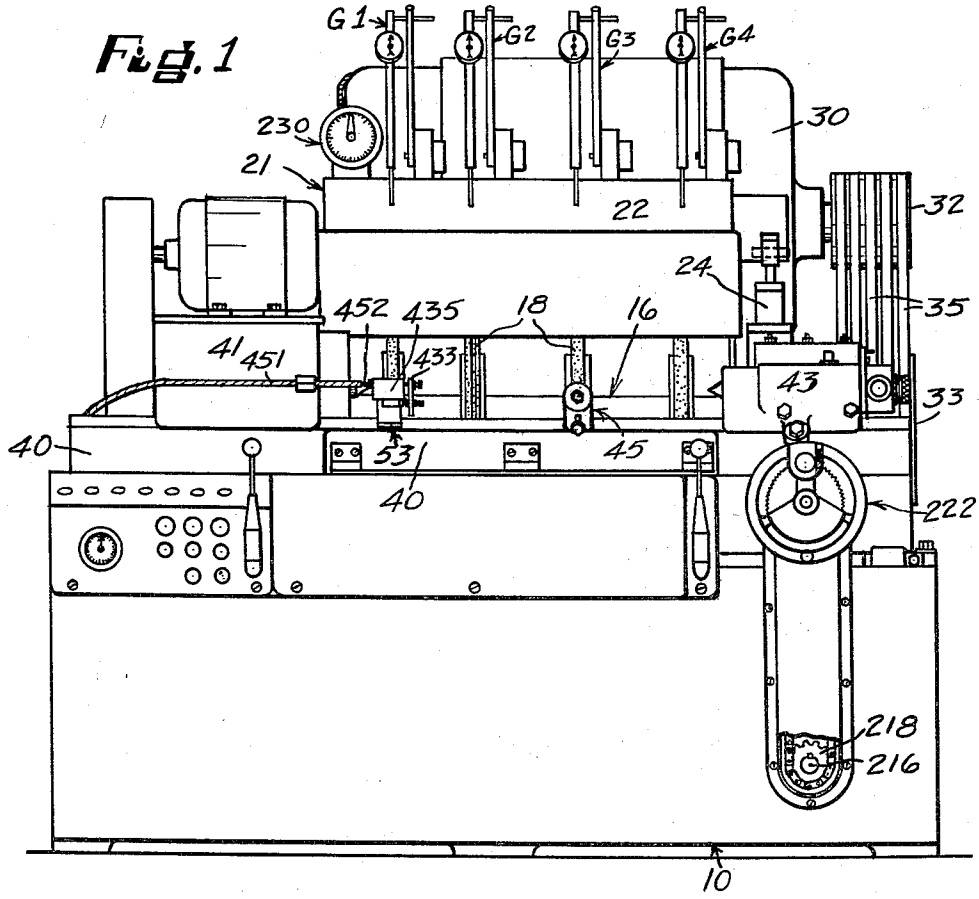
March 2, 1965 O. E. HILL 3,171,234

MULTIPLE WHEEL GRINDING MACHINE

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Fig. 1



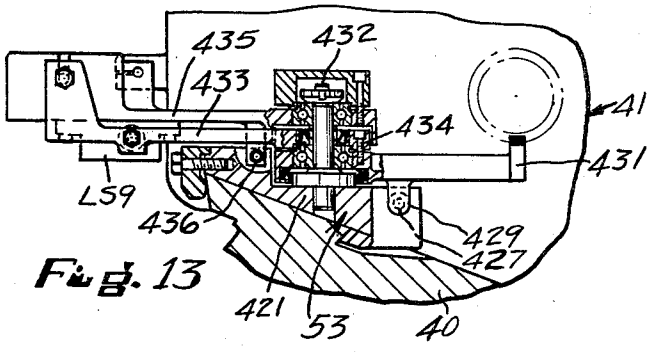


Fig. 13

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MULTIPLE WHEEL GRINDING MACHINE

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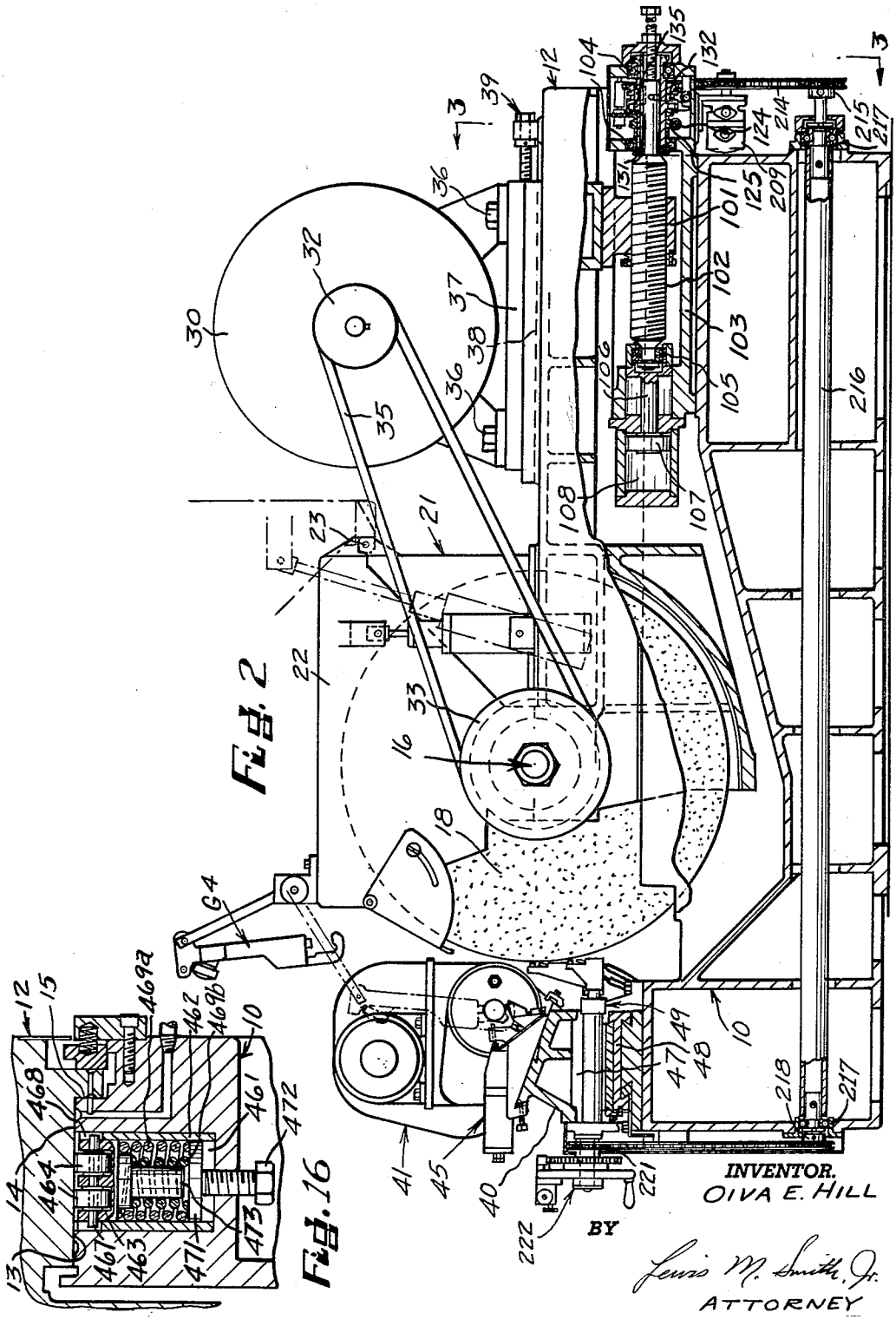


Fig. 2

Fig. 16

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MULTIPLE WHEEL GRINDING MACHINE

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Fig. 3

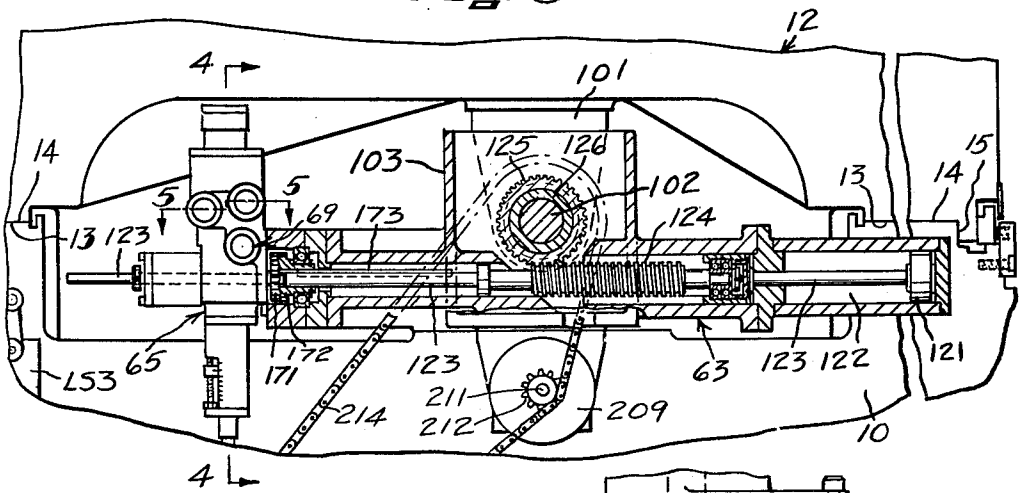


Fig. 4

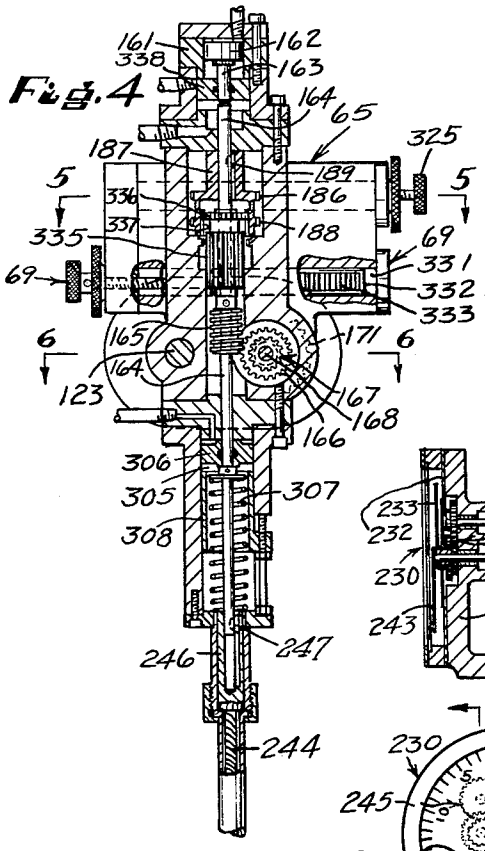


Fig. 6

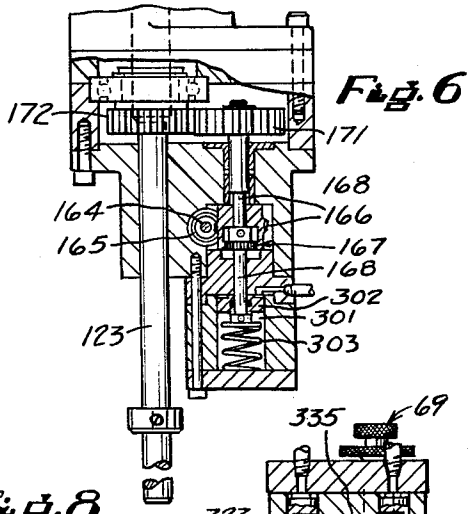


Fig. 8

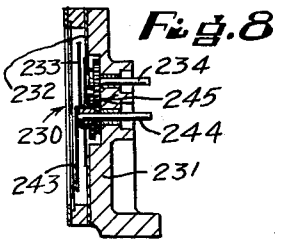


Fig. 7

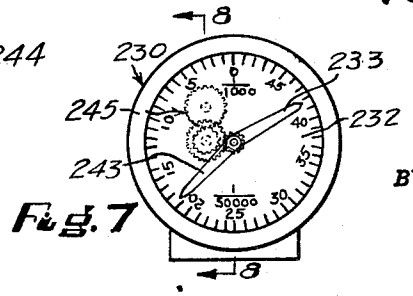
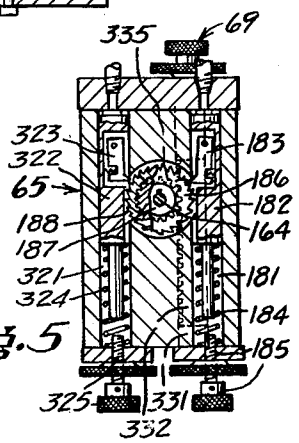


Fig. 5



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MULTIPLE WHEEL GRINDING MACHINE

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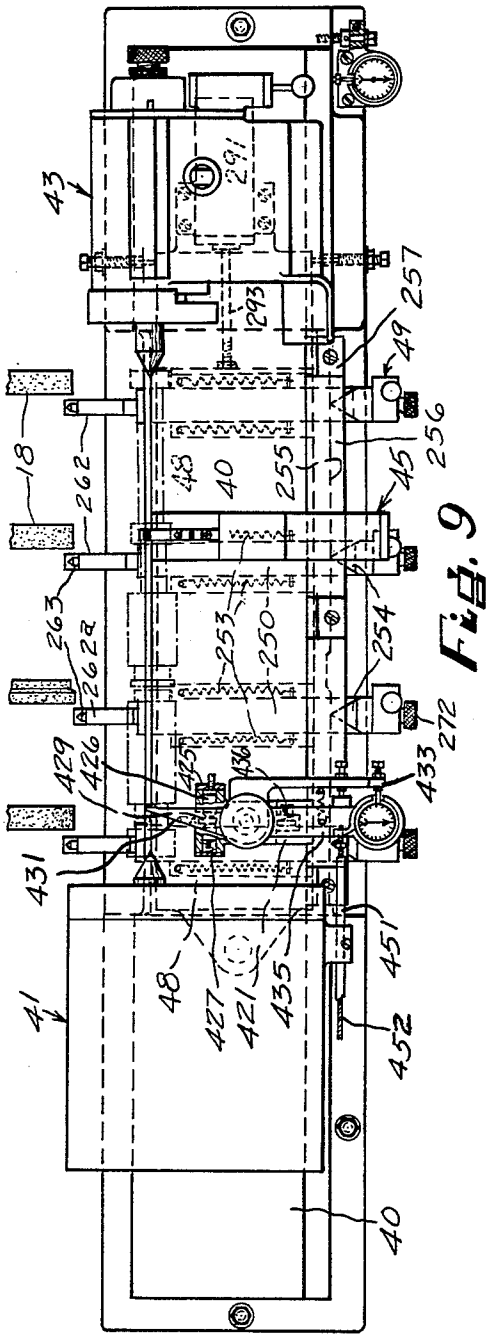


Fig. 9

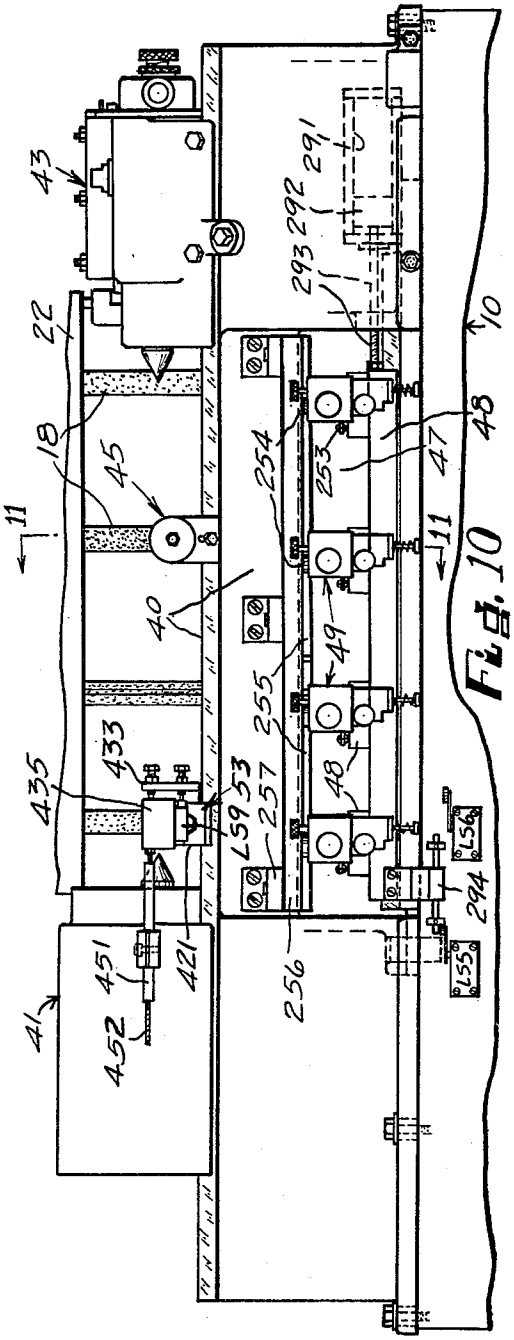


Fig. 10

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MULTIPLE WHEEL GRINDING MACHINE

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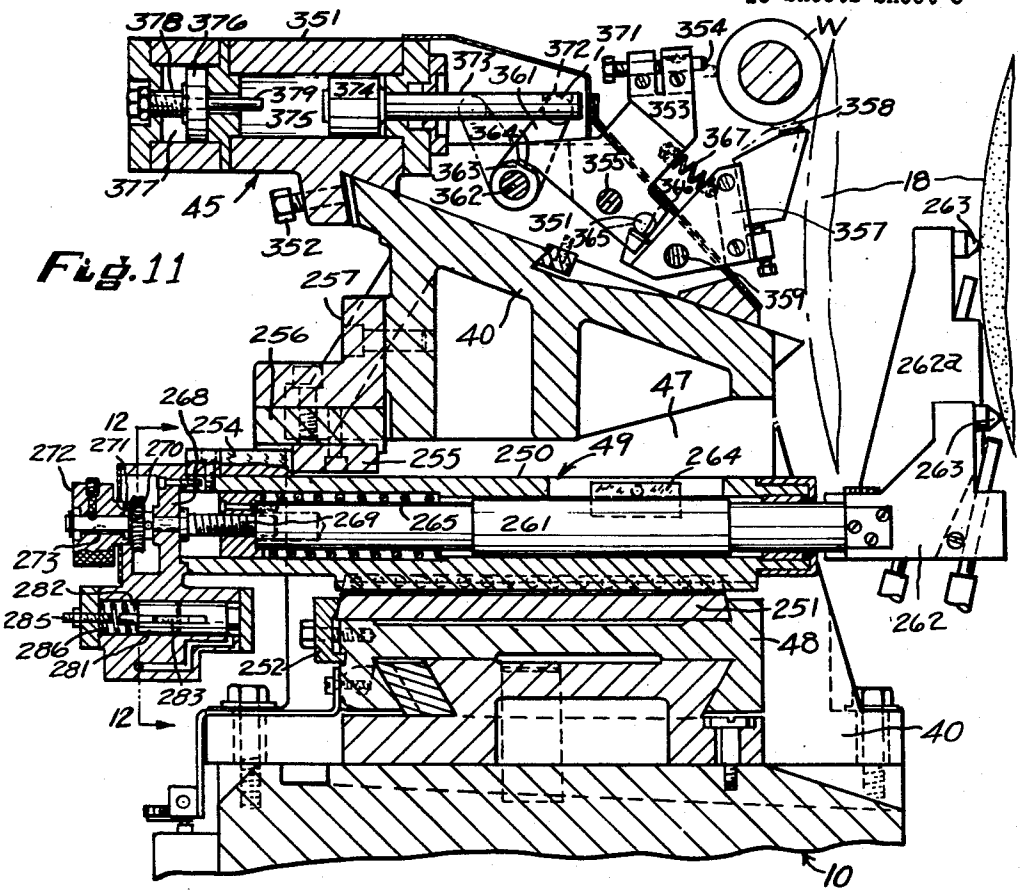


Fig. 11

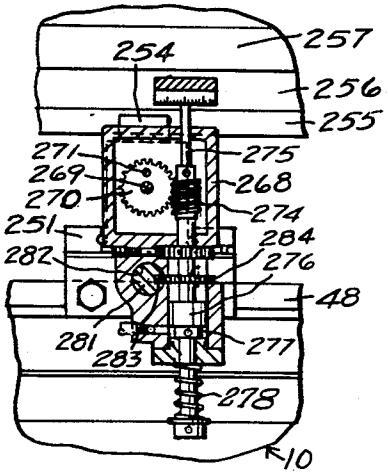


Fig. 12

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MULTIPLE WHEEL GRINDING MACHINE

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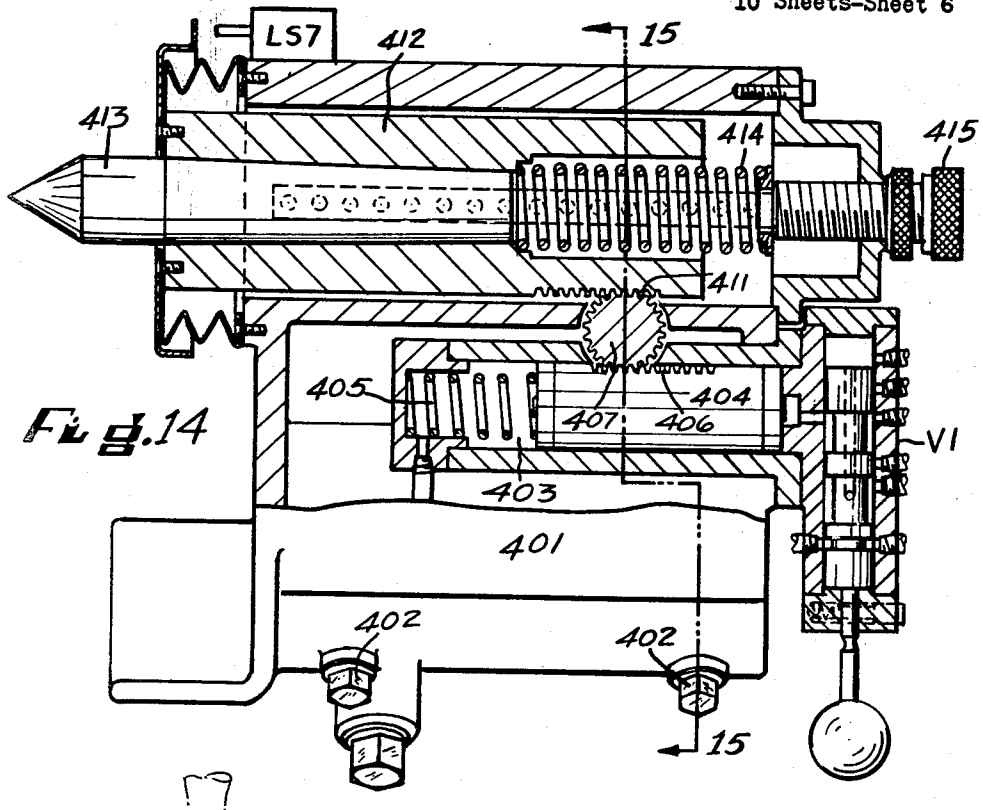


Fig. 14

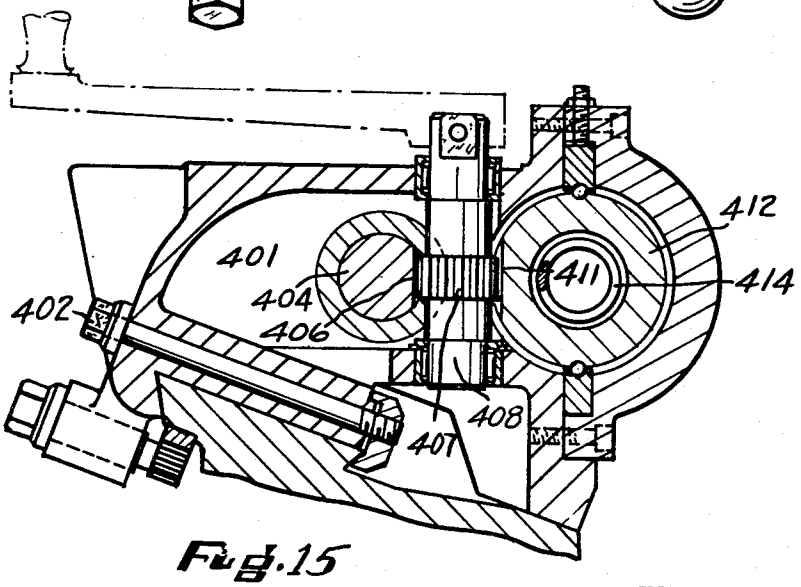


Fig. 15

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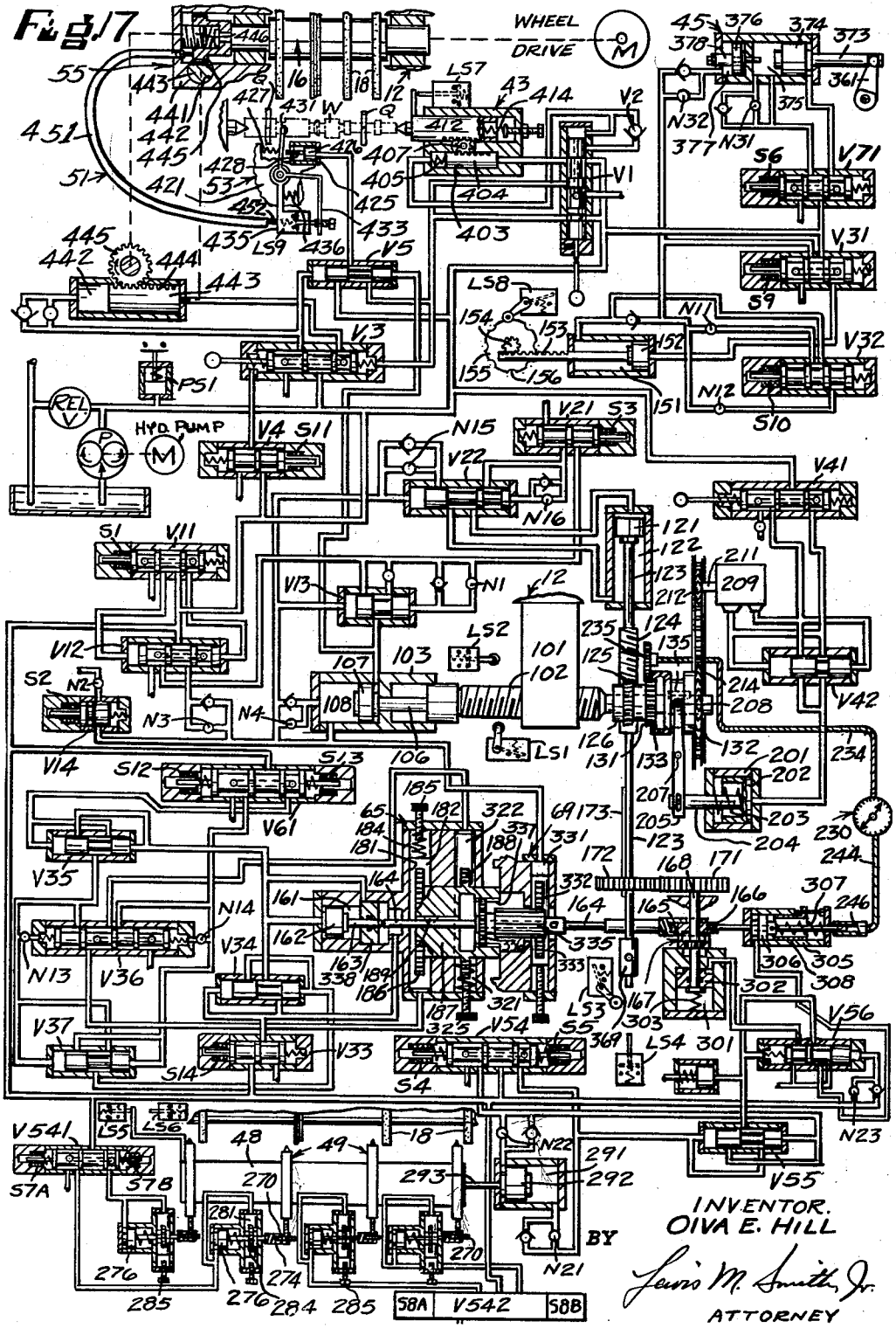
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MULTIPLE WHEEL GRINDING MACHINE

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Fig. 17



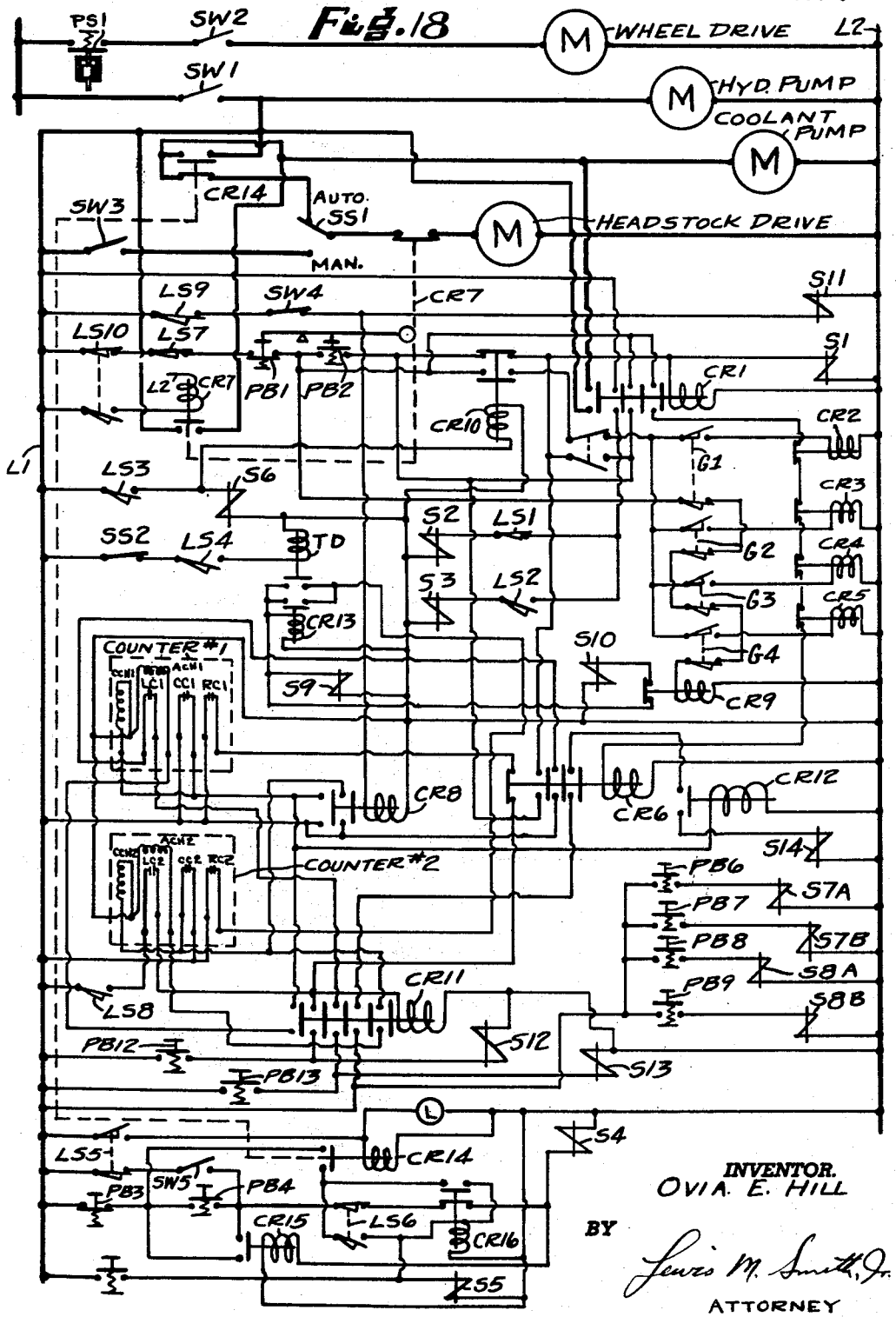
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MULTIPLE WHEEL GRINDING MACHINE

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Fig. 18



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MULTIPLE WHEEL GRINDING MACHINE

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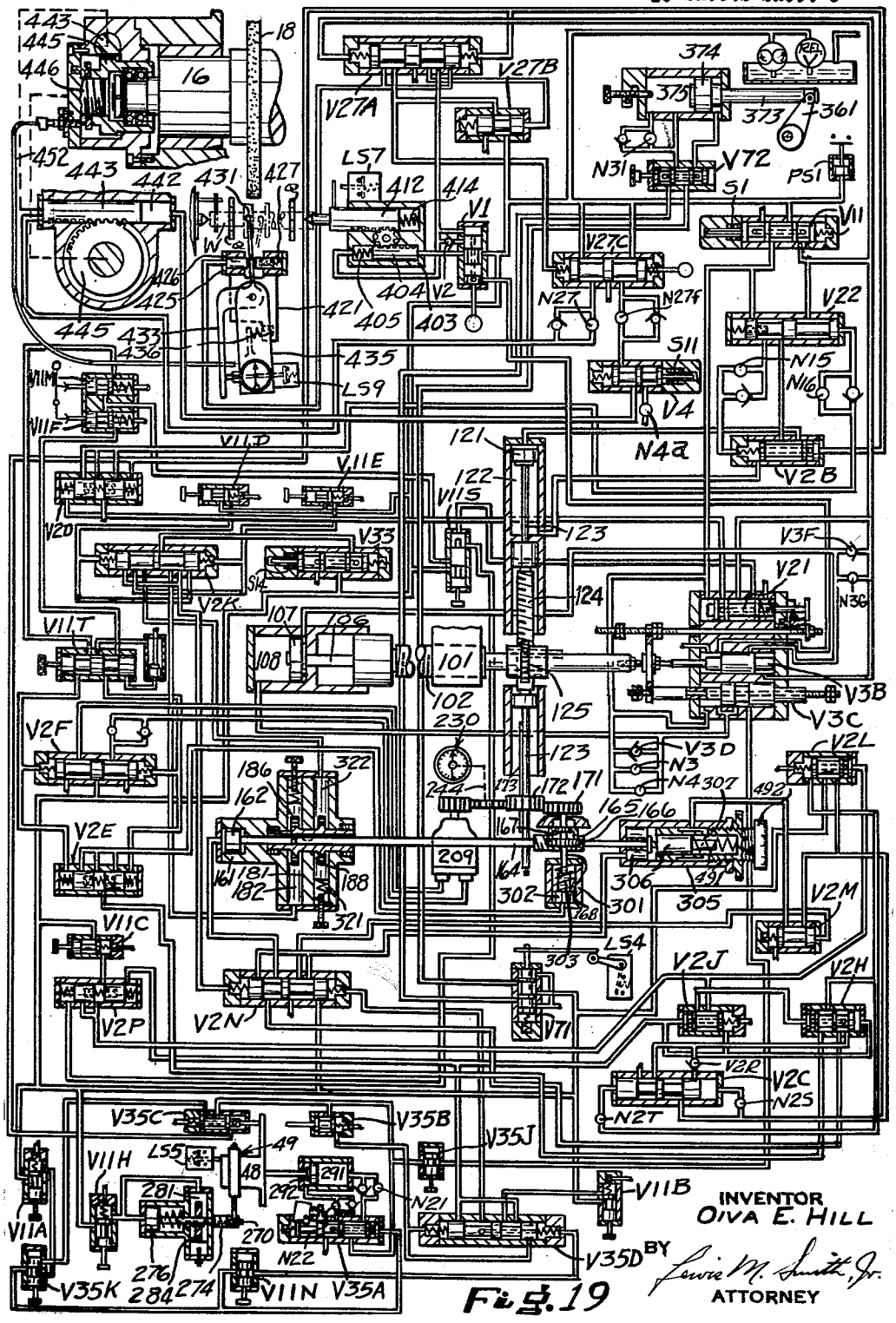


Fig. 19

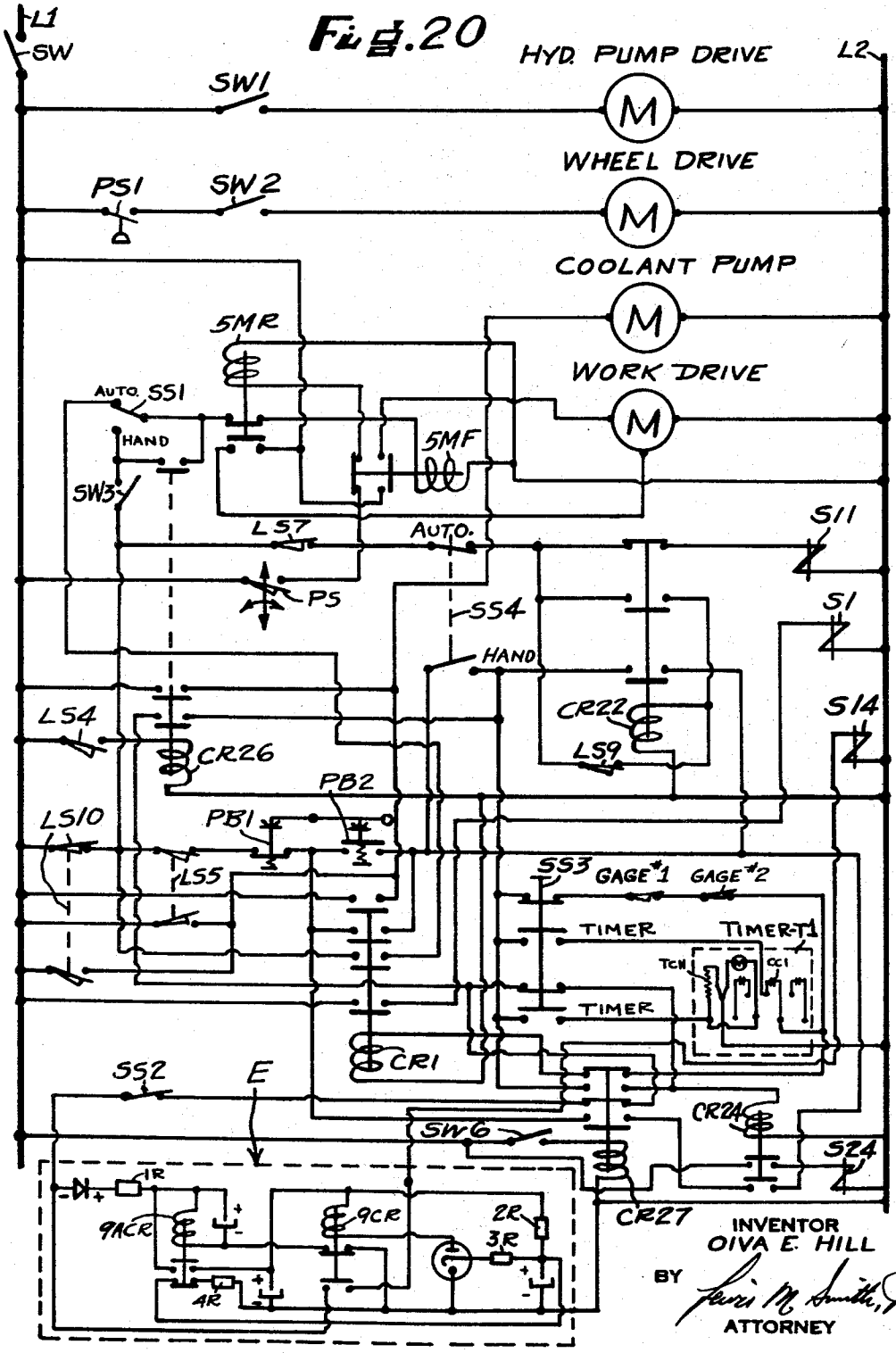
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MULTIPLE WHEEL GRINDING MACHINE

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United States Patent Office 3,171,234 Patented Mar. 2, 1965

3,171,234

MULTIPLE WHEEL GRINDING MACHINE

Oiva E. Hill, West Boylston, Mass., assignor to Norton Company, Worcester, Mass., a corporation of Massachusetts

Filed Sept. 5, 1961, Ser. No. 136,007
20 Claims. (Cl. 51—105)

This invention relates to grinding machines and more particularly to a multiple wheel grinding machine provided with a wheel feed mechanism controlled by in-process gaging and fully corrected as to set-up after each grinding cycle to produce work pieces continuously within the prescribed size range.

Precision grinding machines commonly include means for positioning and supporting a work piece accurately during a grinding operation and a grinding wheel feed mechanism for moving a grinding wheel into and out of engagement with a work piece according to a predetermined semi-automatic or automatic grinding cycle typically consisting of a series of different continuous and/or intermittent wheel feeds. Since the accuracy with which successive work pieces are ground is adversely affected by numerous variables such as those induced by truing the grinding wheel and by wheel wear, both reasonably predictable with respect to their magnitude and sense, and by other variables more difficult to predict such as truing diamond wear and transient thermal effects, many of these machines include wheel feed compensating mechanisms operable so that they tend to minimize the cumulative error in the wheel feed set-up introduced by one or more of these variables.

In their simplest form, wheel feed compensating means may be selectively manually operated as necessary by the operator when he detects an undesirable variation in the finished sizes of the work pieces. Alternatively, the compensating means may be automatically operable either cyclically or continuously and be arranged to produce wheel feed adjustments of a magnitude and in a sense to compensate for the reasonably anticipated errors which would otherwise accumulate in the wheel feed set-up of the machine due to variables such as those noted above. Even with such an arrangement, it is customary to check the finished size of the work pieces periodically and then to adjust the wheel feed set-up manually to eliminate any residual error remaining after automatic compensation at the pre-set rate. Finally, since gages are widely used in association with grinding machines to measure the size of the work pieces being ground, many such machines are provided with gages arranged to control a compensating mechanism automatically so that when the gage detects an oversize or an undersize condition on a work piece at its finished size, it initiates operation of the compensating mechanism by a predetermined amount in the proper sense to limit the drift of the wheel feed mechanism from the desired set-up in which the grinding machine produces properly sized work pieces most efficiently.

In the first instance the wheel feed set-up is fully corrected periodically at the discretion of the operator. In the second instance the wheel feed mechanism is held closer to the correct wheel feed set-up between manual adjustments at which time it may be fully corrected. In the third instance, the amount by which the wheel feed mechanism may deviate from the desired wheel feed set-up is limited.

Notwithstanding the frequent usage of such arrangements for refining the control of the wheel feed mechanism for a grinding machine, there remains a need for means automatically effective to fully correct the wheel feed set-up for the following cycle, when a given grinding cycle is completed. This need is fulfilled by the multiple wheel grinding machine characterizing the instant invention which incorporates means constituting a compensating mechanism actuated in response to a control system including work piece sizing gages and other elements operable in coordinated relation thereto to detect the sense and magnitude of drift from the desired wheel feed set-up and to operate the means comprising a compensating mechanism in the sense and by the amount necessary to fully correct the wheel feed set-up prior to the next grinding cycle, so that this control system not only assures that each work piece will be ground to a final size within the acceptable size range, but also so that the wheel feed set-up is fully corrected before each grinding cycle.

The multiple wheel grinding machine of the instant invention additionally includes an improved wheel feed mechanism incorporating a simplified precision feed so coupled with suitable compensating means as to constitute a compensating mechanism with the particular capability referred to above, and a truing means positioned and arranged to cooperate with this improved wheel feed mechanism. Moreover, since the precision and the consistency with which work pieces may be finished is necessarily dependent upon the ease with which the grinding wheels are displaced relative to the work piece being ground, the accurate establishment of the proper axial relationship between the work piece and the grinding wheels, and the rigidity with which the work piece is supported during the grinding operation, this multiple wheel grinding machine is also provided with adjustable means for facilitating movement of the wheel slide relative to the base, means automatically operable to position the grinding wheels axially relative to a work piece to be ground, and improved means for supporting a work piece during the grinding operation.

One object of the invention is to provide a simple and thoroughly practical multiple wheel grinding machine having a plurality of spaced grinding wheels which are arranged simultaneously to grind a plurality of spaced portions on a work piece.

Another object of the invention is to provide multiple grinding wheel feeding mechanisms including simplified means for producing a fine intermittent precision feed.

Another object of the invention is to provide a truing device which is easily accessible and adjustable from the front of the machine for simultaneously truing all of the grinding wheels either on or below the horizontal plane passing through the wheel center.

Another object of the invention is to provide a compensator and controls for adjusting the feeding mechanism and truing apparatus accordingly to compensate for wheel wear, diamond truing tool wear or drift due to thermal changes in the machine.

Another object of the invention is to provide an automatic work locator for positioning the grinding wheels in a predetermined relationship with the work piece longitudinally of the axis of rotation of the work piece.

Another object of the machine is to provide a two speed steadyrest for supporting a work piece being ground.

Yet another object of the invention is to provide a footstock for a grinding machine which eliminates the sticky spindle bearings and also reduces excessive end pressure on its spindle.

Other objects will be in part obvious or in part pointed out hereinafter and shown in the accompanying drawings in which:

FIG. 1 is a front elevation of the multiple wheel grinding machine of the instant invention,

FIG. 2 is an elevation of the grinding machine looking from the right hand side of FIG. 1, partly in section showing the grinding wheel feeding mechanism and truing apparatus,

FIG. 3 is a fragmentary sectional view of the cross feed and pick feed mechanism feeding the grinding wheel at a reduced rate, taken on line 3—3 of FIG. 2,

FIG. 4 is a vertical section through the pick feed and compensator mechanism taken on line 4—4 of FIG. 3,

FIG. 5 is a sectional view through the compensating mechanism taken on line 5—5 of FIGS. 3 and 4,

FIG. 6 is a sectional view showing a detaching mechanism so that the crossfeed mechanism may be disconnected from the pick feed and compensator mechanism taken on line 6—6 of FIG. 4,

FIG. 7 is a front elevation of a feed indicator activated by the feed mechanism,

FIG. 8 is a sectional view taken on line 8—8 of FIG. 7 through the feed indicator.

FIG. 9 is a partial plan view of the machine showing the multiple wheel truing aparatus, work locator, steadyrest, and footstock,

FIG. 10 is a partial front elevation of the machine showing the truing apparatus, work locator, steadyrest and footstock,

FIG. 11 is a partial vertical section of the machine through one of the truing devices and steadyrest mechanisms taken on line 11—11 of FIG. 10,

FIG. 12 is a vertical sectional view taken on line 12—12 of FIG. 11 showing the truing device adjusting mechanism,

FIG. 13 is a partial vertical sectional view through the work locator mechanism,

FIG. 14 is a partial sectional view through the footstock mechanism,

FIG. 15 is a vertical section through the footstock taken on line 15—15 of FIG. 14,

FIG. 16 is a partial vertical section through one of a plurality of adjustable friction reducing devices located in the ways of the grinding wheel slide support,

FIG. 17 is an hydraulic diagram of the preferred embodiment of the machine,

FIG. 18 is an electrical diagram of the preferred embodiment of the machine,

FIG. 19 is an hydraulic diagram showing modifications of some of the mechanisms and controls and the substitution of hydraulic controls for electrical in another embodiment of the machine, and

FIG. 20 is an electrical diagram showing a modified circuit used with the hydraulic system illustrated in FIG. 19.

GENERAL DESCRIPTION

Referring now to the drawings wherein like reference numerals refer to like or corresponding parts, the basic components of the apparatus comprising the instant invention as illustrated best in FIGS. 1 and 2 include a base assembly 10 supporting a wheel slide assembly 12 provided with flats 13 engaging slideways 14 on the upper surface of the base assembly 10 and maintained in alignment by a suitable guide such as shoulder 15 and the coacting spring biased elements such as those shown in FIG. 3 or in FIG. 16.

The wheel slide assembly 12 supports a wheel spindle assembly 16 in turn supporting a plurality of grinding wheels 18 enclosed by a wheel guard assembly 21 formed integrally with and/or supported on the wheel slide assembly 12 including a wheel guard portion 22 connected to the fixed portion of the wheel guard assembly 21 by means of a pivot 23 and arranged to be raised and lowered by means of an actuating cylinder 24 for changing the grinding wheels 18. The wheel slide assembly 12 also supports a wheel drive motor 30 connected to the wheel spindle assembly 16 through sheaves 32 and 33 and a set of drive belts 35. The wheel drive motor 30 may conveniently be mounted upon the wheel slide assembly 12 in the manner best illustrated in FIG. 2 by means of attachment bolts 36 upon a mounting plate 37 slidably positioned in a slideway 38 by means of a mounting plate positioning assembly 39 including a lead screw supported by a lug projecting from the wheel slide assembly 12.

The base assembly 10 also supports a work table 40 which may conveniently be mounted for angular adjustment about a vertical axis relative to the base assembly 10 by pivotal supporting means illustrated in FIGS. 9 and 10 well known in the art.

The work table 40 in turn supports a headstock assembly 41, a footstock essembly 43, and one or more steadyrest assemblies 45 all mounted for slidable adjustment lengthwise of the work table 40 and arranged to be secured in fixed relation to the work table 40 by suitable clamping means.

The work table 40 is provided with an elongated opening 47 extending longitudinally thereof midway of its ends as illustrated in FIG. 10 to accommodate an elongated truing device support 48 for reciprocation lengthwise of the table in slidable engagement with a suitable dovetail slide as illustrated in FIG. 11. A plurality of truing device assemblies 49 illustrated in detail in FIGS. 11 and 12 may be fixedly secured to the truing device support 48 as shown in FIGS. 9 and 10 for reciprocation therewith.

The apparatus characterizing the instant invention also includes an endwise locator assembly 51 including a probe portion 53, shown best in FIGS. 13 and 17 or FIG. 19, mounted upon the table 40 and a portion 55, shown best in FIG. 17 or FIG 19, mounted in the wheel slide assembly 12 coupled together by an interconnecting portion illustrated as comprising a flexible shaft 452 enclosed by a housing 451.

The wheel feed mechanism assembly, shown in FIGS. 2 and 17 and elsewhere, not only includes means for producing a fast feed described below but also includes a coarse or body feed assembly 63 as shown in detail in FIG. 3 to which is coupled a fine feed assembly 65 as shown in detail in FIG. 4. The wheel feed mechanism assembly additionally includes a compensator coacting with the wheel truing apparatus and a reset assembly 69 arranged to coact with the fine feed assembly 65 to provide compensation in the amount and in the sense necessary to fully correct the wheel feed set-up before each succeeding grinding operation.

Various assemblies referred to briefly above which embody novel features of the instant invention will be described further below under appropriate headings in relation to the various figures of the drawings best illustrating these assemblies.

WHEEL FEED MECHANISM

As illustrated in FIG. 2 and elsewhere, the wheel feed mechanism include a feed nut 101 dependent from and fixedly secured to the wheel slide assembly 12, an elongated horizontally disposed feed screw 102 threadably engaged by the feed nut 101, a housing 103 fixedly secured to the base assembly 10 by any suitable means such as attachment bolts not illustrated, a rear anti-friction bearing 104 supported by the housing 103 engaging an element described further below in turn slidably supporting a rearward extension of the feed screw 102 of reduced diameter, and a bearing assembly 105 including a cylindrical external bearing surface in slidable engagement with an internal bearing surface in the housing 103 and anti-friction bearing assemblies rotatably supporting an extension from the forward end of the feed screw 102 of reduced diameter.

The various principal portions of the wheel feed mechanism including the fast feed, the coarse or body feed, and

the fine feed are described below under appropriate subheadings in the sequence in which these feeds occur.

Fast feed mechanism

The fast feed portion of the wheel feed mechanism includes a piston rod **106** attached to and projecting from the bearing assembly **105** coaxially with the feed screw **102** to which the fast feed piston **107** is secured for movement within the fast feed cylinder **108** secured to the forward end of the housing **103**.

The movement of the fast feed piston **107** is controlled in the manner described further below by the portion of the hydraulic system best illustrated in FIG. 17 including valves V11, V12, V13 and V14, the needle valves N1, N2, N3 and N4, and the respective hydraulic conduits interconnecting these valves and the fast feed cylinder **108**. This portion of the hydraulic system is in turn controlled by various elements of the electrical system best illustrated in FIG. 18 including the solenoid S1 energized by closing the cycle start switch PB2 to displace the valve spool within the valve V11, and the solenoid S2 energized by means of limit switch LS1 to displace the valve spool within the valve V14, so that the fast feed is reduced to a relatively slower shoulder feed after the wheel slide assembly **12** has been advanced a predetermined distance determined by the position of limit switch LS1.

Body feed

The body feed portion of the wheel feed mechanism includes a body feed piston **121** movable within the body feed cylinder **122** and provided with an elongated piston rod **123** disposed transversely of the longitudinal axis of the feed screw **102**. An elongated worm **124** mounted concentrically of and fixedly secured to the piston rod **123** is disposed in engagement with a worm wheel **125** fixedly secured to or formed integrally with a sleeve **126** mounted concentrically of and freely rotatable relative to the elongated rearward extension of the feed screw **102**. An external gear **131** fixedly secured to the sleeve **126** forms one element of a clutch assembly having a second element comprising a sleeve **132** mounted concentrically of and slidable relative to the rearward extension of the feed screw **102**. The sleeve **132** is secured against rotation relative to the feed screw **102** by means of a key **135** so that rotation of the worm wheel **125** by axial displacement of the piston rod **123** is effected to produce rotation of the feed screw **102** when the gear **131** is engaged by the gear **133** on the sleeve **132**.

The movement of the body feed piston **121** is controlled by the portion of the hydraulic system including valves V21 and V22. Fluid pressure is admitted to valve V21 via valve V12 when solenoid S2 is energized by limit switch LS2 closed when the fast feed piston **107** reaches the end of its stroke.

Fine feed

The fine feed portion of the wheel feed mechanism includes a cylinder **151** enclosing a piston **152** provided with a piston rod having a rack **153** along its outer end engaging and rotating a pinion **154** as the piston **152** is displaced. Rotation of the pinion **154** productes concurrent rotation of the disc **155** fixedly secured to the pinion **154** and provided with a plurality of recesses **156** to receive the actuator of a limit switch LS8 so that normally open contacts of the limit switch are opened each time the actuator drops into a recess **156**. This arrangement of elements comprising a cyclic actuator is controlled by a portion of the hydraulic system including valves V31 and V32 and needle valves N11 and N12 in turn controlled by the solenoids S9 and S10. Solenoid S9 is energized when a limit switch LS4 is closed by predetermined movement of the piston rod **123** of the body feed mechanism and solenoid S10 is arranged to be energized as a work piece approaches the proper size by suitable means such as gages applied to the work as illustrated in the drawings to reduce the rate at which the cyclic actuator operates.

In order to permit the wheel feed mechanism to pick up the fine feed increments provided by the mechanism described below, the fine feed mechanism includes an unwind-wind mechanism including a cylinder **161** containing a piston **162** provided with a piston rod **163** projecting therefrom internally of the cylinder **161** and engaging a substantially elongated push rod **164** extending to the right therefrom as shown in FIG. 17. The push rod **164** is provided with a worm **165** fixedly secured thereto disposed in engagement with a worm gear **166** which may conveniently be formed integrally with one element of a clutch assembly **167** supported on a shaft **168** in turn supporting a spur gear **171**. The spur gear **171** engages a spur gear **172** slidably supported upon the piston rod **123** of the body feed mechanism and secured against rotation relative to the piston rod **123** by an elongated key **173** slidable relative to the spur gear **172** with piston rod **123** as the piston rod is displaced axially relative to the spur gear **172**. With this driving arrangement, the piston **162** is effective when it is displaced to unwind the feed mechanism including the piston rod **123** while the spur gear **172** may be constrained by any suitable means so that it is maintained in driving engagement with the spur gear **171**. When the fluid pressure applied to the left side of the piston **162** is released, the return spring **307** acts through the push rod **164** and piston rod **163** to wind the feed mechanism and to return the piston **162** to the position illustrated in FIG. 17.

The return spring **307** is referred to further below in connection with the wheel truing compensating mechanism of which it is also a part.

The fine feed is effected by apparatus including the cylinder **181** containing a piston **182** provided with a spring biased pawl **183**. The piston **182** is normally biased in one direction within the cylinder **181** in which the pawl **183** is inoperative by a return spring **184**. The travel of the piston in the opposite direction in response to the application of hydraulic pressure, limited by an adjustable stop **185**, moves the spring biased pawl **183** into operative engagement with a ratchet wheel **186** which may be formed integrally with a sleeve **187** also provided with a reversed ratchet wheel **188** spaced from the first ratchet wheel **186** for operative engagement with the pawl of a compensating feed mechanism to be described further below. The sleeve **187** is secured in slidable non-rotatable relation to the push rod **164** by means of a key **189** and a key way extending the length of the sleeve **187**.

The fine feed mechanism described above is controlled by a portion of the hydraulic system including valves V33, V34, V35, V36 and V37, needle valves N11 and N12, and the hydraulic conduits interconnecting these elements and cylinders **161** and **181**. The solenoid S14 is energized intermittently by the limit switch LS8 operated by the cyclic actuator described above to produce properly coordinated operation of the unwind-wind mechanism and the pick feed mechanism described above.

Auxiliary feed

The wheel feed mechanism of the instant invention is supplemented by an auxiliary feed mechanism including a cylinder **201** enclosing an actuating piston **202** normally biased to the right as seen in FIG. 17 by a return spring **203**. The piston **202** is provided with a piston rod **204** projecting from the cylinder **201** for connection to one end of a lever **205** by suitable means such as a pin and slot connection as illustrated in FIG. 17. The lever **205** is mounted for rotation about a pivot **207** to displace a roller **208** pivotally connected to the other end of the lever **205** and thereby disengage the clutch assembly including the sleeve **132** described above. It will be evident that the lever **205** may in fact be bifurcated at its upper end to form a yoke provided with a pair of rollers disposed on opposite sides of the clutch sleeve **132**.

With the clutch assembly including sleeve **132** disengaged, a suitable auxiliary power source such as a vane

type hydraulic motor 209 may be energized in either direction to advance or retract the wheel slide assembly 12 by means of a shaft 211 supporting a sprocket 212 connected to a sprocket secured to the sleeve 132 by a drive chain 214.

The clutch actuating piston 202 and the motor 209 may be controlled by a manual valve V41 normally biased into a center neutral position by a pair of opposing springs, by valve V42, and by the hydraulic conduits connecting these valves operatively to the cylinder 201 and the motor 209.

As illustrated in FIG. 2, the drive chain 214 may also be passed over a sprocket 215 secured to the rear end of a shaft 216 extending through the base assembly 10 from its rear face to its front face and supported upon suitable anti-friction bearings 217. A sprocket 218 secured to the forward end of the shaft 216 may be connected to a sprocket 221 secured to a shaft supporting a hand wheel assembly 222 upon the front face of the base assembly 10.

The auxiliary feed including the motor 209 operable with the body feed mechanism and the fine feed mechanism declutched from the feed screw 102 is useful primarily for periodic side truing operations when new grinding wheels have been installed on the machine. The manual wheel feed including the hand wheel assembly 222 is most useful for setting up the machine.

Wheel feed indicator

The wheel feed mechanism may be provided with an indicator assembly 230 as illustrated in FIGS. 7 and 8 comprising a housing 231 provided with a calibrated dial 232, a first hand 233 for indicating the feed in thousandths, and a second hand 243 for indicating the feed in 50 thousandths. The hand 233 is connected to the wheel feed mechanism as shown in FIG. 17 by means of a flexible shaft assembly 234 provided at its remote end with a spur gear 235 positioned in engagement with the external gear 131 secured to the sleeve 126 and forming one element of the clutch assembly including sleeve 132 and internal gear 133. The hand 233 may be coupled to the shaft assembly 234 through a suitable gear train 245 illustrated in FIGS. 7 and 8. The hand 243 is connected to the wheel feed mechanism by means of the flexible shaft assembly 244 provided at its remote end with a sleeve 246 secured in slidable non-rotatable engagement with one end of the push rod 164 by means of a key 247 as illustrated in FIG. 17 and in greater detail in FIGS. 4, 7 and 8.

TRUING APPARATUS

Truing apparatus as illustrated best in FIGS. 9 and 10 and schematically in FIG. 17 includes a plurality of truing device assemblies 49 a representative one of which is illustrated in detail in FIGS. 11 and 12.

Each truing device assembly 49 consists of a truing device barrel 250 mounted transversely of the truing device support 48 by means of an anti-friction slideway assembly 251 secured to the support 48 by a suitable clamp 252 as shown in FIG. 11 and biased toward the grinding wheels by a pair of springs 253 interconnecting the barrel 250 and the support 48 as shown in FIG. 9. The transverse position of the barrel 250 is controlled as the support 48 is reciprocated by means of a follower 254 secured to the barrel 250 as shown in FIGS. 9 and 11 so that a point thereof engages a form bar 255 secured to a supporting bar 256 and thence by brackets 257 to the table 40. The barrel 250 encloses a supporting rod 261 to the outer end of which a tool holder 262 or 262*a* is secured to support the truing tool 263 in the proper position relative to a grinding wheel 18. The supporting rod 261 is secured slidably and non-rotatably within the barrel 250 by a key 264 and biased to the left as seen in FIG. 11 by a biasing spring 265. A truing feed housing 268 secured to the left hand end of the barrel 250 as seen in FIG. 11 supports the reduced end portion of a feed screw 269 threadably engaged with the supporting rod 261 so that rotation of the feed screw 269 produces axial displacement of the rod 261. The worm wheel 270 supported on and freely rotatable relative to the feed screw 269 is provided wih a pin 271 normally engaged by a radial slot in a knob 272 slidably and non-rotatably connected to the feed screw 269 by a key 273 so that the knob 272 selectively serves as a coupling between the worm wheel 270 and the feed screw 269 and alternatively may be displaced to the left as seen in FIG. 11 to be disengaged from the pin 271 for manual rotation of the feed screw 269 to adjust the axial position of the rod 261 with the truing feed mechanism uncoupled.

The worm wheel 270 is engaged by a worm 274 pinned to a shaft 275 in turn pinned to a piston 276 enclosed in cylinder 277 and normally biased downwardly as seen in FIG. 12 by a spring 278. Piston 276 arranged to be displaced cyclically by application of hydraulic pressure thereby displaces the worm 274 axially to unwind and then wind the truing device feed mechanism so that feed increments may be applied to the feeding mechanism. A piston 281 contained in cylinder 282 is provided with a pawl 283 arranged to engage a spur gear 284 slidably keyed to the shaft 275. The movement of the piston 281 in response to the application of hydraulic pressure is limited by an adjustable stop 285 and the piston is returned by a spring 286 with the pawl 283 riding over a spur gear 284. With this arrangement, the worm 274 is rotated to feed the rod 261 when the pawl 283 engages the spur gear 284 during the pressure stroke of the piston 281.

The support 48 is reciprocated by a mechanism including a cylinder 291 enclosing a piston 292 connected to a piston rod 293 in turn connected to the support 48. The support 48 is fitted with a trip dog 294 cooperating with limit switches LS5 and LS6 as the support 48 is reciprocated in the manner described further below.

The truing apparatus is controlled by the portion of the hydraulic system including the valve V54 and needle valves N21 and N22 and the hydraulic conduits interconnecting these valves with the cylinder 291. Valve V54 is in turn actuated by the respective pull type solenoids S4 and S5 energized by push button PB4 and/or switch SW5 in a sequence controlled by limit switches LS5 and LS6.

The means for individually controlling the position of the tool 263 in each truing device assembly as illustrated in FIG. 17 consists of a pair of pull type solenoid valves V541 and V542 identical to the valve V54, the former arranged to be selectively actuated by energizing either solenoid S7A or solenoid S7B and the latter arranged to be selectively actuated by energizing either solenoid S8A or solenoid S8B.

WHEEL FEED COMPENSATION

The compensating means incorporated in the wheel feed mechanism of the instant invention includes a first compensating mechanism coupled to the fine feed mechanism and operable automatically in coordinated relation to each truing operation to compensate for the reduction in wheel size resulting from the truing operation. The wheel feed mechanism also includes a second compensating mechanism incorporated in the fine feed mechanism and operable in cordinated relation to the fine feed mechanism during each grinding cycle in the proper sense and by the amount necessary to fully correct the set-up of the wheel feed mechanism to reestablish the proper set-up for the predetermined desired wheel feed sequence prior to the next grinding operation. Each of these compensating mchanisms will be described briefly below under the proper heading and subsequently in greater detail in the description of the operation of the instant invention which appears further below.

Wheel truing compensation

The first compensating mechanism operable in coordinated relation to the wheel truing apparatus includes a cylinder **301** enclosing a piston **302** supported on the shaft **168** normally biased upwardly as seen in FIGS. 6 and 17 by the return spring **303** in order to maintain the respective elements of clutch assembly **167** in engagement to couple worm gear **166** to the shaft **168**. The first compensating mechanism also includes a cylinder **305** enclosing a piston **306** normally biased upwardly as seen in FIG. 4 or to the left as shown schematically in FIG. 17 by a spring **307** and limited in its travel in response to the application of hydraulic pressure by the adjustable sleeve **308**.

The actuation of the respective components of the first compensating mechanism in the proper sequence is controlled by the portion of the hydraulic system including the sequence valve V55, the valve V56, needle valve N23 and the hydraulic conduits interconnecting these valves and the cylinders **301** and **305** and coupling the sequence valve V55 to valve V54.

Fully correcting compensating mechanism

The second compensating mechanism includes a reverse pick feeding assembly including a cylinder **321** enclosing the reverse pick piston **322** provided with a spring biased pawl **323**. The piston **322** is normally biased in one direction within the cylinder **321** in which the pawl **323** is inoperative by a return spring **324**. The travel of the piston **322** in the opposite direction in response to the application of hydraulic pressure, limited by an adjustable stop **325**, moves the spring biased pawl **323** into operative engagement with the reverse ratchet wheel **188** referred to above which may be formed integrally with the sleeve **187**. The second compensating mechanism also includes a reset cylinder **331** enclosing a reset piston **332** provided with a rack **333** extending longitudinally thereof and disposed in engagement with a spur gear **335** rotatably mounted upon and fixedly secured axially in relation to the push rod **164**. The spur gear **335** is formed integrally with an external gear **336** selectively positioned in and out of engagement with an internal gear **337** formed integrally with the sleeve **187**. Gears **336** and **337** thus constitute the cooperating elements of a clutch assembly controlled by displacement of the piston **338** slidable on the piston rod **163** within the cylinder **161**, by means of which the reset assembly is selectively coupled to and uncoupled from the fine feed mechanism as described below in the description of the operation of the instant invention.

The second compensating mechanism is actuated as required by an electrical control circuit including the counter #1 and the electrical gages interconnected as illustrated in FIG. 18 with the counter set to count out after the desired number of fine incremental feeding movements and the gages connected to reverse the wheel feeding movement when the work piece reaches the desired final size.

When the gages operate before counter #1 times out, solenoid S12 is actuated to control the portion of the hydraulic system including a valve V61 and the valve V36 and the hydraulic conduits interconnecting these valves and the cylinders **161** and **321**, to declutch the reset assembly while the reverse pick piston **322** produces reverse incremental feeding movements until the counter #1 counts out.

When the counter #1 counts out before the gages operate, solenoid S13 is actuated to control a portion of the hydraulic system including the valves V61, V33, V34, V35 and V37 and the hydraulic conduits interconnecting these valves and cylinders **161**, and **181** to declutch the reset assembly while the piston **182** continues to produce incremental feeding movements until the gages operate.

As illustrated in FIG. **18**, the control circuit for the second compensating mechanism also includes counter #2 arranged to count out after a series of incremental feeding movements sufficient to reduce a work piece almost to its minimum acceptable final size and operable when it counts out to reverse the wheel feed in the event that the gages have not yet operated for any reason such as a failure of the gage circuit.

STEADYREST

The steadyrest assembly **45** illustrated in various views and in detail in FIG. 11 includes a housing **351** adjustably secured to the table **40** by clamping means including the bolt **352**. An upper steadyrest support **353** having an upper steadyrest shoe **354** adjustably secured thereto as illustrated in FIG. 11 is rotatably mounted upon housing **351** by means of a first pivot **355** and a lower steadyrest support **357** having a lower steadyrest shoe **358** adjustably secured thereto as illustrated in FIG. 11 is rotatably supported upon the housing **351** by a second pivot **359**. A steadyrest control lever **361** rotatably secured to the housing **351** by means of a third pivot **362** is provided with a camming block **363** disposed adjacent to its pivot point for engagement with a cam follower surface **364** formed on a projecting portion of the upper steadyrest support **353**. The upper steadyrest support **353** is provided with a projecting camming pin **365** disposed for engagement with a cam follower **366** secured to the lower steadyrest support **357**. By means of compression spring **367**, the upper steadyrest support **353** is biased counter-clockwise about pivot **355** into engagement with the camming block **363** and the lower steadyrest support **357** is biased clockwise about the pivot **359** so that cam follower **366** is maintained in engagement with the camming pin **365**. The control lever **361** is provided at its free end with a lug **371** disposed in interfitting engagement with a transverse slot **372** in the free end of a piston rod **373** connected at its other end to a first piston **374** enclosed within cylinder **375** formed in the housing **351**. The steadyrest assembly also includes a second piston **376** enclosed in a cylinder **377** supported by the housing **351** and provided with a hollow piston rod **378** supporting a stop **379** adjustably secured within the piston rod **378** as illustrated in FIG. 11.

The steadyrest assembly **45** is controlled by the portion of the hydraulic system including valve V71 and the needle valves N31 and N32 and the hydraulic conduits interconnecting these valves and the cylinders **375** and **377**. The valve V71 is actuated by solenoid S6 energized by limit switch LS3 when it is triggered by an adjustable sleeve **369** secured to piston rod **123**.

FOOTSTOCK

The footstock assembly **43** consists of a housing **401** adjustably secured to the table **40** by suitable clamping means including bolts **402** which supports a cylinder **403** containing a footstock center retracting piston **404** biased to the right as seen in FIGS. 14 and 17 by the backlash eliminating spring **405**. The piston **404** is provided with a rack **406** engaging a gear **407** which may be formed integrally with a shaft **408** rotatably supported in the housing **401** by means of suitable anti-friction bearings. The gear **407** engages a rack **411** formed in the footstock spindle **412** supporting the footstock center **413** and biased to the left as seen in FIGS. 14 and 17 by biasing spring **414** in which the compression may be adjusted by an adjustment screw **415** threadedly engaging the housing **401**.

The footstock assembly is actuated by manual operation of the hydraulic valve V1 and is secured in its operative position by means of the check valve V2 in the manner described further below in the description of the operation of the instant invention.

ENDWISE LOCATOR

The endwise locator assembly **51** includes a portion supported by the table **40** comprising a support **421** secured to the table **40** by suitable clamping means as illustrated

in FIG. 13 and provided with a cylinder 425 shown best in FIGS. 9 and 17 enclosing a piston 426 normally biased to the right by a compression spring 427 bearing against an ear 429 shown best in FIG. 13 dependent from the probe 431 and thence by means of a piston rod 428 secured to piston 426 at one end and disposed with its other end in engagement with the ear 429. A vertical pivot assembly 432 mounted fixedly in the support 421 supports the probe 431 on an anti-friction bearing assembly for rotation about a vertical axis and an elongated finger 433 coupled to the probe 431 by suitable attachment means such as bolt 434 for rotation with probe 431. The pivot assembly 432 also supports an elongated arm 435 on a suitable bearing assembly for rotation about a vertical axis independent of the probe 431 and finger 433. A tension spring 436 inter-connecting the arm 435 and the support 421 biases the arm 435 counter-clockwise as seen in FIGS. 9 and 17 to maintain an actuator of the limit switch LS9 mounted on the end of arm 435 in engagement with an adjustable stop adjacent the end of finger 433 normally biased clockwise about pivot assembly 432 with probe 431 by compression spring 427 which is selected to be stronger than tension spring 436.

The endwise locator assembly 51 also includes a portion 55 attached to the wheel slide assembly 12 as shown in FIG. 17 comprising a housing 441 including a cylinder 442 enclosing a piston 443 provided with a rack 444 engaging a pinion 445 threadably engaged with a stationary screw 446 supported upon the housing 441 and disposed coaxially with the spindle assembly 16.

The endwise locator assembly 51 additionally includes an inter-connecting portion between portions 53 and 55 comprising a flexible shaft housing 451 secured at its opposite ends respectively to the headstock assembly 41 as shown in FIGS. 9 and 10 so that it is maintained fixed relative to support 421 and to the housing 441 as illustrated schematically in FIG. 17 and in greater detail in FIG. 19, and a flexible shaft 452 within housing 451 disposed with one end in engagement with the arm 435 and the other end in engagement with the end face of pinion 445.

The operation of the endwise locator assembly 51 is controlled by the portion of the hydraulic system including a spring centered valve V3 selectively either manually or automatically operated, a valve V4 actuated by solenoid S11, a shuttle valve V5, and the hydraulic conduits interconnecting these valves and valve V1 referred to above and the cylinders 425 and 442. When valve V1 is operated manually as noted above, fluid pressure is admitted to and actuates valve V3 and solenoid S11 is energized by limit switch LS9 dependent upon the relative positions of finger 433 and arm 435.

WHEEL SLIDE FRICTION

Noting that the substantial mass of the wheel slide assembly 12 will inevitably result in substantial frictional resistance to the displacement of the flats 13 on the wheel slide assembly 12 relative to the slideways 14 on the base assembly 10, this frictional resistance may be substantially reduced by the incorporation of a plurality of roller support assemblies in the slideways 14 as illustrated in FIG. 16 for engagement with the respective flats 13.

A typical roller support assembly as illustrated in FIG. 16 includes a sleeve 462 pressed into a cylindrical recess 461 in a slideway 14 and enclosing a roller housing 463 supporting a plurality of rollers 464 mounted upon a shaft 467 projecting at both ends from the roller housing 463 for engagement in diametrically opposed slots 468 in the sleeve 462 in order to maintain the shaft 467 perpendicular to the direction in which the flats 13 move relative to the slideways 14. The rollers 464 are biased into engagement with a flat 13 by a spring assembly which includes springs 469*a* and 469*b* as illustrated in FIG. 16. The spring assembly is interposed between the lower surface of the roller housing 463 and the upper surface of an end plate 471 positioned vertically by an adjusting screw 472 threadably engaged in the base assembly 10. The compression of the spring assembly may be limited by a stop 473 depending from the roller housing 463.

CONTROL SYSTEM—FIRST EMBODIMENT

The machine electrical circuit illustrated in FIG. 18 is shown in an idle position with pressure switch PS1 open in the absence of hydraulic pressure. Switch SW1 is open cutting off power to the machine circuit and the coolant pump motor. Switch SW2 is open cutting off power to the wheel drive motor. Switch SW3 is open preventing manual control of the headstock motor. Selector switch SS1 is set for automatic control of the headstock motor. Switch SW4 is closed for automatic operation of the endwise locator. Selector switch SS2, shown closed, is opened manually for setting up the machine.

Push button PB1, the normally closed cycle stop switch, and push button PB2, the normally open cycle start switch, are operated by a single cycle control lever.

The normally open limit switch LS9, held closed by the spring biased endwise locator probe 431, energizes solenoid S1 and control relay CR8 when closed. The NC contacts of limit switch LS10, manually operated by a lever, are closed. These contacts cut off power to the starting cycle when they are opened. The NO contacts of limit switch LS10 are open. These contacts energize control relay CR7 when closed. NC limit switch LS7, shown closed, is opened by the footstock spindle 412 when it moves to the right into the unclamping loading position.

NO limit switch LS3, shown opened, is closed by movement of the piston rod 123 responsive to displacement of the piston 121 within the coarse or body feed cylinder 122 to energize control relay CR10 and solenoid S6. NO limit switch LS4, shown opened, is closed at the end of the coarse or body feed by the piston rod 123 connected to the piston 121 enclosed by cylinder 122 to energize the time delay relay TD delayed on energization for spark-out prior to the fine feed. After the time delay relay TD closes, solenoid S9 is energized to initiate the intermittent fine feed. NC limit switch LS1, shown closed, is opened by wheel slide assembly 12 during the fast wheel feed, thereby deenergizing solenoid S2 to cut off free exhaust from fast feed cylinder 108 to slow down the wheel feed for grinding shoulders on the work piece W. NO limit switch LS2, shown opened, is closed by the wheel slide assembly 12 at the end of the shoulder feed to energize the solenoid S3 and thereby initiate the coarse or body feed. NO limit switch LS8 is intermittently closed by a rotatable disc 155 provided with a plurality of peripheral recesses 156 to produce the fine intermittent or pick feed.

Counter #1 is set to count a predetermined number of intermittent feed increments equal to the desired number of feed increments for the proper fine feed. Counter #2 is set to count a predetermined number of intermittent feed increments necessary to reduce the work piece W to a final size approaching the minimum acceptable work piece size.

The switch SW1 is closed starting the hydraulic and coolant pumps. Hydraulic pressure now closes the pressure switch PS1 and retracts the footstock spindle 412 by moving piston 404 toward the left to a loading position opening the normally closed limit switch LS7, moves valve V3 to the left allowing fluid under pressure to hold the grinding wheel positioning piston 443 in cylinder 442 to the right, holds valve V5 to the right, moves piston 426 to the left in cylinder 425 as seen in FIG. 17 which moves the endwise locator probe 431 to the left, opening the normally open contacts of limit switch LS9. The hydraulic pressure also holds steadyrest pistons 374 and 376 to the right in cylinders 375 and 377, with shoes 354 and 358 retracted, holds piston 152 to the right in cylinder 151 with normally open limit switch LS8 open, holds valve V12 to the right through valve V11, holds piston 107 to the right in cylinder 103, holds valve V13 to the right,

holds valve V22 to the right, holds piston 182 against a stop 185 in a reset position in cylinder 181, moves and holds valve V56 to the left against spring pressure.

The switch SW2 is closed to start the wheel drive motor 30 through the now closed pressure switch PS1.

OPERATION—FIRST EMBODIMENT

A work piece is loaded into the machine and supported on V-blocks Q as indicated in FIG. 17 and the valve V1 is manually operated to move the valve spool inwardly. Fluid pressure goes to both sides of cylinder 403 and into hydraulic balance; but the spring 414 over-balances the pressure and moves the footstock spindle 412 to the left clamping the work piece between the headstock and footstock centers. The spring 405 takes up backlash between the rack 406, gear 407, and rack 411. Check valve V2 prevents the footstock spindle 412 from backing up under grinding pressure. Normally closed limit switch LS7 closes, and set up a circuit to energize control relay CR9 through the NO contacts of gages G1, G2, G3 and G4 when they are closed as the gages go on the work piece W.

Endwise locator

Valve V1 now allows exhaust of oil from the right hand end of valve V3 and cylinder 425. Valve V3 centers and piston 426 moves to the right under the pressure of spring 427 acting against the probe 431 of the endwise locator disposed in contact with the end of the piston rod 428 of the piston 426 in cylinder 425.

The spring moves the endwise locator probe 431 about pivot 432 against a locating surface on the work piece so finger 433 closes NO contacts of limit switch LS9 on arm 435 biased by spring 436 energizing solenoid S11 and control relay CR8. Control relay CR8 energizes control relay CR12 and clutch coils CCH1 and CCH2 of the counters #1 and #2 closing holding contacts CC1 and CC2, opening LC1, closing LC2, and closing RC1 and RC2. The counters are now ready to count. Control relay CR12 is energized by the closing of NO contacts of control relay CR8 closing the normally open contacts of control relay CR12 to ready a circuit. Energizing solenoid S11 moves valve V4 to the left under pressure to pass fluid under pressure to move valve V3 to the right. This allows fluid under pressure to move rack piston 443 in cylinder 442 to the left, rotating pinion 445, threaded onto stationary screw 446 clockwise, thereby moving the grinding wheel spindle assembly 16 toward the right. As the pinion 445 moves toward the right moving the wheel spindle assembly 16 with it, a flexible shaft 452 is spring biased against its left hand surface. The other end of flexible shaft 452 is in contact with an independently supported rotatable arm 435 biased clockwise as seen in FIGS. 9 and 17 by spring 436, which supports a limit switch LS9 fixedly mounted upon it. The above said spring 436 acting against the flexible shaft 452 by means of its connection to support 421 fixed to the machine table 40 causes the flexible shaft 452 and limit switch LS9 to move toward the left under the NO contacts of limit switch LS9 open, deenergizing solenoid S11 and control relay CR8 which allows the spring to move valve V4 to the right, thereby allowing valve V3 to center and stopping movement of rack piston 443. The grinding wheels and the work piece are now properly aligned. Limit switch LS10 is in its normal position with its NC contacts closed and its NO contacts open.

Wheel feed

The operator closes push button PB2 with the cycle control lever, and energizes control relay CR1 and solenoid S1 through the NC contacts of limit switch LS10, the now closed NC contacts of limit switch LS7, normally closed push button PB1 and the NC contacts of control relay CR10. Solenoid S1 shifts the valve V11 to the right allowing fluid under pressure to move the valve V12 to the left, allowing fluid under pressure through to move valve V13 to the left at a rate controlled by a needle valve N1 and through the valve V13 to the right side of cylinder 108 moving piston 107 rapidly to the left and also moving valve V5 allowing fluid under pressure through it into cylinder 425 to move the piston 426 to the left as seen in FIGS. 9 and 17, which moves the locating probe 431 out of engagement with the locating surface of the work piece W.

Energized control relay CR1 closes all its NO contacts, starting the coolant pump and headstock drive motors, and also energizes solenoid S2 through NC now closed limit switch LS1 to shift the valve V14 to the right which allows a fast exhaust from the left side of cylinder 108 controlled by needle valve N2. Control relay CR1 and solenoid S1 are held energized through a set of NO now closed contacts of control relay CR1 and through NC contacts of control relay CR10. Closing the normally open contacts of control relay CR1 also energizes control relay CR6 through normally closed series connected contacts of control relays CR2, CR3, CR4, CR5 the coils of which are connected in parallel. Energizing control relay CR6 also seals in control relay CR1 and solenoid S1 and also readies the circuits.

The wheel slide assembly 12 moves forward, to the left as seen in FIG. 2 and elsewhere, at a rapid rate until NC limit switch LS1 is opened deenergizing solenoid S2, allowing the valve V14 to return to the left and cut off exhaust of oil through it. Oil now exhausts at a slower or shoulder grinding rate controlled by a needle valve N3 and then through cushion needle valve N4. Piston 107 bottoms at the left end of cylinder 108 to terminate the shoulder grinding feed of the wheel slide assembly 12 and closes normally open limit switch LS2, energizing solenoid S3 shifting valve V21 to the left, allowing fluid under pressure from valve V12, now positioned to the left, to move valve V22 to the left and pass fluid under pressure through it into the upper end of cylinder 122 for a coarse or body grinding feed at a rate controlled by needle valve N15.

Sizing gages

The gages G1, G2, G3 and G4 are applied to the work piece which closes their NO contacts connected in series energizing control relay CR9 opening NC contacts to interrupt the circuit for solenoid S10. During the coarse grinding feed a sleeve 369 secured to the coarse grinding feed piston rod 123 closes the NO contacts of limit switch LS3 energizing solenoid S6 and relay CR10. The control relay CR10 NC contacts open and the NO contacts close allowing power to the now held open NC contacts of the four gages G1, G2, G3 and G4 which energize the gage relay coils CR2, CR3, CR4 and CR5 when closed. The gages are not described or illustrated in detail since they are commercially available items and since their specific features form no part of this invention. While the gages as illustrated in FIGS. 1 and 2 are mounted for manual engagement with the work piece, it is to be understood that they could alternatively be engaged automatically by means well-known in the art.

Steadyrests

Energizing solenoid S6 moves the valve V71 to the right allowing fluid under pressure to the right end of cylinder 375 to displace piston 374 to move the steadyrest shoes into engagement with the work piece W quickly. As the piston 374 moves to the left it first closes off an unrestricted exhaust port and then oil is exhausted at a rate controlled by a needle valve N31 for the remainder of the coarse grinding feed. At the end of the coarse grinding feed the piston rod 123 connected to feed piston 121 closes NO limit switch LS4. Steadyrest piston 374 bottoms against piston 376. Thereafter pistons 374 and 376 are displaced at a slower rate controlled by needle valve N32 during the fine feed.

Fine feed

Closing the normally open limit switch LS4 energizes time delay relay TD through closed selector switch SS2 which allows a predetermined dwell or time for the work piece to round up and spark out. After the time is up, the normally open contacts of the time delay relay TD, delayed after energization, close, energizing solenoid S9 and control relay CR13 through now closed NO contacts RC2 of counter #2. NO contacts of control relay CR13 close holding solenoid S9 and control relay CR13 energized. Since the work piece W is holding the series connected NO contacts of the gages G1, G2, G3 and G4 closed, control relay CR9 is energized holding its NC contacts open to keep solenoid S10 deenergized. The dwell thus provided can be eliminated by eliminating the time delay relay TD.

Solenoid S9 moves valve V31 to the right allowing fluid under pressure to cylinder 151 to move piston 152 and rack 153 to the left to rotate pinion 154 and the attached disc 155 which cyclically closes and opens the NO concontacts of limit switch LS8. Valve V31 allows oil to exhaust from cylinder 377 so that the steadyrest shoes move toward the work piece final size. Oil also exhausting from cylinder 151 through valve V32 and valve V31 is controlled by needle valve N11 at a fast intermittent or pick feed rate.

The intermittent closing of the contacts of limit switch LS8 energizes the relay CR11 intermittently through the now closed contacts LC2 of counter #2. A count signal is sent to each of the count coils ACH1 and ACH2 of the counters #1 and #2 each time the normally open contacts of relay CR11 close and open through now held closed contacts CC1 and CC2 of the counters #1 and #2. Intermittent energization of relay CR11 energizes solenoid S14 through NO contacts of relays CR6 and CR12 now closed. Energizing solenoid S14 moves valve V33 to the right allowing fluid to hold or shift if necessary the sequence valve V34 to the right, passing fluid to the right hand side of the cylinder 161 to hold piston 338 to the left on piston rod 163, and then through sequence valve V34 to the left side of cylinder 161. Piston 162 moves cyclically to the right in cylinder 161 through a stroke limited by piston 338, thereby partially rotating worm gear 166 and thence, through clutch assembly 167, a set of spur gears 171, 172 partially rotating the worm 124. Each time the fluid pressure is released the piston 162 is returned to the left by spring 307. This unwind-wind action reciprocates the wheel slide feed back and forth to permit the wheel feed mechanism to pick up the feed increments being fed.

Fluid under pressure also passing through the sequence valve V34 shifts the sequence valve V35 to the left allowing fluid under pressure through it to the left hand side of valves V36 and V37 and through valve V37 to the right hand side of valve V34 putting valve 34 in hydraulic balance. The spring centered valve V36 is also moved to the right allowing fluid under pressure to pass to cylinder 181 causing a pick-feed by displacement of piston 182 having a pawl which engages the ratchet wheel 186 which turns clutch gear 336 by means of clutch gear 337 and thence gear 335 displacing the reset piston 332 by a corresponding increment, and also rotating push rod 164, worm 165 and worm gear 166, and through clutch assembly 167 a set of spur gears 171 and 172 rotating piston rod 123 and thence worm 124 and worm gear 125, thereby rotating the feed screw 102 feeding the wheel slide assembly 12 a fine feed increment, intermittently at a fast rate, still controlled by the needle valve N11.

As stated before, the piston 162 in cylinder 161 is intermittently reciprocated to unwind and wind the feed mechanism to pick up the fine feed increment each time. When any one of the NO contacts of the gages G1, G2, G3 or G4, held closed by the work piece W senses a predetermined work piece size slightly greater than the

desired finished size of the work piece W, the relay CR9, held energized as long as all of these NO contacts of the gages are held closed, is deenergized, closing its NC contact thereby energizing solenoid S10 through the now closed contacts RC2 of counter #2 and the now closed NO contacts of relay CR13. Solenoid S10 moves the valve V32 to the right so that oil exhausting from cylinder 151 which actuated the limit switch LS8 of the cyclic actuator through needle valve N11 at a fast rate is now caused to exhaust through the needle valve N12 at a slower rate, causing a slower actuation of limit switch LS8 and consequently the reciprocation of the wheel slide and the picker feed piston 182 within the cylinder 181 above mentioned until final size is reached. This is determined by any one of the normally closed held open contacts of the gages G1 through G4 which energizes any one of relay coils CR2, CR3, CR4, CR5 which will deenergize relay CR6, solenoid S14, solenoid S1 and relay CR1.

As the wheel slide assembly 12 is advanced by the wheel feed mechanism, the indicator 230 registers the amount of feed on the dial 232 by means of hands 233 and 243.

Fully correcting compensation

As stated before, counter #1 is set to count the desired number of feed increments to bring the work piece to size near its high size limit and within the gage tolerances. Counter #2 is set to allow the maximum amount of feed required to grind the work piece to a size near its minimum acceptable size but beyond the low limit of the gages. This point is not ordinarily reached unless the gages fail.

More particularly, when for any reason such as wheel wear, truing tool wear, thermal effects, or some other variable factor the NO contacts of one of the gages G1, G2, G3, or G4, held open by the work piece W, close to terminate the normal grinding cycle before the predetermined preferred number of pick feed increments set on the counter #1 is reached, the wheel slide assembly 12 is withdrawn by reversing the wheel feed mechanism and the piston 332 is reset. Such operation of one of the gages deenergizes relay CR6 as described above so that NC contacts of the relay CR6 are closed to set up a circuit for energizing solenoid S12. At the same time, NO contacts of the relay CR6 are opened to deenergize solenoid S14 thereby allowing the valve V33 to move to the left to permit fluid to exhaust from the right hand end of cylinder 161. The solenoid S12 is thereafter energized intermittently through the NC contacts of relay CR6, through contacts RC1 of counter #1, through NO contacts of the relay CR11 which is intermittently energized by the limit switch LS8, and through contacts LC2 of counter #2, until counter #1 counts out, at which time contacts LC1 close and contacts CC1 and contacts RC1 open.

Each time solenoid S12 is energized the valve V61 is moved to the left allowing fluid under pressure to move the valve V37 to the left allowing fluid under pressure to pass through it into the right hand side of the valve V34 moving valve V34 to the left, thereby allowing fluid under pressure to pass through valve V34 into the left hand side of cylinder 161 and to the right hand side of valve V35 to move it to the left or to hold it in that position. Piston 162 in cylinder 161 moves toward the right pushing piston 338 in cylinder 161 with it all the way to the right as seen in FIG. 17 to disengage the gear 336 from the gear 337 and thence from the fine feed mechanism, thereby uncoupling the reset piston 332. Valve V61 shifted to the left by energization of solenoid S12 also passes fluid under pressure through a needle valve N14 moving the valve V36 to the left allowing fluid under pressure to pass through valve V36 into cylinder 321 to actuate the reverse pick feed piston 322 so that the pawl carried thereby engages and rotates the reverse ratchet wheel 188 without movement of the reset

piston 332 since the reset piston is disengaged from the fine feed mechanism. As noted above, this compensating movement is terminated when counter #1 counts out deenergizing solenoid S12. When the solenoid S12 is deenergized to terminate the compensating movement, the spring 307 acts through piston 306 and push rod 164 to reengage the clutch including gears 336 and 337 to reengage the reset mechanism for the next grinding operation.

On the other hand, if none of the sizing gages G1, G2, G3, or G4 operate to withdraw the wheel slide assembly 12 until the wheel feed mechanism has been advanced the number of fine feed increments for which the counter #1 is set, counter #1 will count out opening its contacts RC1 and CC1 to deenergize relay CR12 to deenergize solenoid S14 resetting valve V33 so that the fine pick feed is no longer effected through this valve and closing the normally closed contacts LC1 of counter #1 to set up a circuit for energizing solenoid S13 intermitently by means of limit switch LS8 through closed contacts of relay CR6 and relay CR11. Solenoid S13 when energized moves the valve V61 to the right allowing fluid under pressure through to the left hand side of valve V35 to move valve V35 to the right allowing fluid under pressure to pass through valve V35 to move valve V37 to the right and thereby allow fluid under pressure to pass through to the right side of valve V34 to move it to the left, so that fluid under pressure is allowed to pass through valve V34 into the left hand side of cylinder 161 to move both of the pistons 162 and 338 to the right to disengage gear 336 from gear 337 and thence from the fine feed mechanism as described above, since the right hand end of cylinder 161 is once again connected to exhaust through valve V33 with solenoid S14 deenergized.

Fluid under pressure also moves through a needle valve N13 into the left hand side of valve V36 moving it to the right to allow fluid under pressure through valve V36 to actuate the pick piston 182 in cylinder 181 each time solenoid S13 is energized to continue to feed the wheel slide assembly 12 forward until one of the gages G1, G2, G3, or G4 operates to send the wheel slide assembly 12 back. This operation is effective to reduce the amount of fine feed to the desired amount for the next grinding cycle, and the spring 307 is effective to reengage the gears 336 and 337 when solenoid S13 is deenergized for the last time so that the reset piston 332 uncoupled during the feed correcting operation described above is recoupled to the fine feed mechanism and reset when the wheel slide assembly 12 is sent back.

Counter #2 is set for the number of incremental feeding movements required to reduce the work piece W nearly to its minimum acceptable size so that counter #2 will operate to send the slide back before the minimum acceptable work piece size is reached if one of the gages G1, G2, G3 or G4 does not operate first to do so. During the fine feeding operation as limit switch LS8 is opend and closed intermittently to energize relay CR11, an impulse is sent to the count coil ACH2 of counter #2 operable to maintain relay CR11 deenergized when it counts out opening the contacts LC2, CC2 and RC2 to reset the counter #2 and to send the slide back.

With the circuit arranged as illustrated in FIG. 18, the open contacts LC2 interrupt the circuit for relay CR11 so that relay CR11 cannot be energized again even if limit switch LS8 is closed. Open contacts RC2 will deenergize relay CR13, solenoid S9 and solenoid S10, even if relay CR6 is still energized. With solenoid S9 deenergized, valve V31 resets and applies reverse pressure to pistons 376 and 374 and also moves piston 152 to the right to reset the cyclic actuator including limit switch LS8 which will be normally open again. The opening and closing of limit switch LS8 now has no effect, since contacts LC2 in counter #2 are open. When solenoid S10 is deenergized, valve V32 resets to the left.

Control cycle reset

When relay CR6 is deenergized by the energization of any one of the relay coils CR2, CR3, CR4 and CR5 by the closing of any one of the gages G1, G2, G3 or G4, it deenergizes solenoid S14, relay CR1, solenoid S1 and solenoid S3. Specifically, the NO contacts of relay CR6 break the holding circuit holding relay CR1 and solenoid S1. Deenergized solenoid S14 allows valve V33 to move to the left, piston 162 in cylinder 161 moves to the left under spring pressure, exhausting oil through valve V33, and reengaging gears 336 and 337 to recouple reset piston. When the NO contacts of relay CR1 open, it also deenergizes solenoid S3 as stated above so that valve V21 resets to the right and stops the headstock and coolant pump motors. Deenergized solenoid S1 allows valve V11 to reset to the left and pass fluid under pressure to move valve V12 to the right allowing fluid under pressure to pass through valve V12 to move the piston 107 to the right in cylinder 108 and thus move wheel slide assembly 12 rearwardly. Fluid under pressure also passes into cylinder 331 to reset piston 332 against the stop screw, into the left end of valve V13 moving it to the right so fluid may exhaust from cylinder 108 through valve V13 and valve V12, and through valve V22, now in a left hand position, thence into cylinder 122 moving piston 121 and wheel slide assembly 12 rearwardly by an additional amount.

During the exhausting of oil through valves V22 and V21, piston 121 is reset, pressure builds up and valve V22 is slowly moved to the right at a rate controlled by a needle valve N16 until the pressure port is covered stopping the movement of the piston 121 and interconnecting both ends of cylinder 122. As the piston 121 moves rearwardly, normally open limit switch LS4 opens deenergizing time delay relay TD. Then the normally open limit switch LS3 opens deenergizing solenoid S6 and relay CR10. Deenergized solenoid S6 allows valve V71 to move to the left under spring pressure, now allowing fluid to exhaust from cylinder 375 through valve V71 and allowing fluid under pressure into the left side of cylinder 375 in addition to pressure already present in cylinder 377 as noted above so that pistons 374 and 376 now move to the right retracting the steadyrest shoes. As the wheel slide assembly 12 moves rearwardly, the NO contacts of limit switch LS2 open and the NC contacts of limit switch LS1 close. When relay CR10 is deenergized closing its NC contacts and opening its NO contacts, power is removed from the gages G1, G2, G3 and G4. The work rotation and the flow of coolant is stopped by the deenergization of the relay CR1 which breaks the circuit to the headstock drive motor and the coolant pump motor. The hydraulic footstock valve V1 is manually pulled out passing fluid under pressure to retract the footstock center 412, opening limit switch LS7 and fluid under pressure also passes to the right side of valve V3 moving it to the left allowing fluid under pressure to move the wheel spindle positioning piston 443 to the right as shown in FIG. 17 into the reset position. Fluid pressure also moves valve V5 to the right, passing fluid through valve V5 and thereby holding piston 425 and the endwise work locating probe 431 away from the work piece W, and also holding the NO contacts of limit switch LS9 open. The work is now removed and the machine can be recycled again as described above.

Side truing

When it is desired to side true the grinding wheels, a manually operable valve V41 is pulled to the left by a handle allowing fluid under pressure to one side of the hydraulic motor 209 and to the right side of a valve V42 moving it to the left, allowing fluid under pressure to pass through valve V42 into the cylinder 201 to move its piston 202 to the left against spring 203 so as to declutch the gear 133 from the gear 131 by rotating the lever 205 clockwise as seen in FIG. 17, so that the hy-

draulic motor **209** can turn the feed screw **102** which feeds the wheel slide assembly **12** and grinding wheels **18** forward past fixed truing tools for side truing of the wheels **18** in the manner well known in the art.

Letting go of the handle centers the valve V41 so that the wheel slide assembly **12** remains stationary and lever **205** is rotated counterclockwise by spring **203** so that the clutch including gears **131** and **133** reengages. Pushing in the handle moves valve V41 to the right moving valve V42 to the right admitting pressure fluid to cylinder **201** to disengage the clutch again and to the hydraulic motor **209** in the opposite sense reversing its direction, thereby moving the wheel slide assembly **12** and the grinding wheels **18** rearwardly. This arrangement is also used to position the wheel slide assembly **12** for set-up purposes.

Truing

When the hydraulic system is activated by energizing the hydraulic pump motor, the valve V56 is held to the left initially by hydraulic pressure supplied directly from the pump. Closing push button PB4 energizes solenoid S4 and relay CR16. Hence, the now closed NO contacts of relay CR15 hold solenoid S4 energized, solenoid S4 shifts pull type valve V54 to the left passing fluid under pressure into the left side of the cylinder **291**, initiating movement of the truing slide or support **48** toward the right and also moving valve V55 to the left. Fluid under pressure then passes through the sequence valve V55 to move the piston in the coolant discharge control cylinder to the left, and also to enter the left hand side of valve V56. Valve V56 is now hydraulically stabilized but its spool is held to the left initially against the pressure exerted by a compressed spring opposed by fluid constrained by needle valve N23.

The fluid under pressure flows first into cylinder **301** to disengage the clutch assembly **167** and as the spool of valve V56 moves slowly to the right, as fluid escapes through needle valve N23 under spring pressure, it uncovers a port connected to cylinder **305** displacing the wheel truing compensator piston **306** to the right as seen in FIG. 17.

As the spool of valve V56 continues to move toward the right slowly, controlled by the needle valve N23, it first allows piston **302** to be displaced by spring **303** to re-engage the clutch assembly **167** and then it allows spring **307** to re-set piston **306** by exhausting oil from cylinder **305**. The operation of cylinders **305** and **301** in the sequence described above provides an idle stroke backward of the pick feed mechanism followed by a predetermined stroke advancing the wheel feed mechanism to position the grinding wheels for a truing operation and at the same time compensating the wheel feed mechanism for the truing operation.

As the truing slide **48** starts to move to the right, NC contacts of limit switch LS5 close and NO contacts open. The NC contacts of limit switch LS5 energize relay CR14 and light L. The NO contacts of relay CR14 close starting the coolant pump and the NC contacts of relay CR14 open preventing the headstock from rotating. Truing slide or support **48** continues to move to the right, truing the grinding wheels **18** and, when the slide reaches the extreme right hand end, NC contacts of the limit switch LS6 are opened deenergizing relay CR15 and thence solenoid S4 and the NO contacts of limit switch LS6 are closed energizing relay CR16 and solenoid S5 through the now closed NC contacts of relay CR14, moving the valve V54 to the right, thus allowing fluid under pressure to enter the right hand side of cylinder **291** to move the truing slide or support **48** toward the left, and also to pass through valves V55 and V56 into and then out of cylinders **301** and **305** and the coolant cylinder in the sequence described above.

As the truing slide **48** starts moving to the left, it opens the NO contacts of limit switch LS6 and closes the NC contacts of limit switch LS6, and when it reaches the extreme left hand position as shown in FIG. 17, it closes the NO contacts of limit switch LS5 and opens the NC contacts of limit switch LS5, deenergizing relay CR14, stopping the coolant pump and deenergizing relay CR16 and thence solenoid S5 so that valve V54 centers. Light L goes out indicating that the truing operation is completed.

If continuous truing is desired, switch SW5 may be closed so that the above truing cycle repeats automatically. To manually adjust for diamond tool wear, solenoids S7A, S7B, S8A and S8B are energized manually by push buttons PB6, PB7, PB8, and PB9 to supply oil under pressure to the respective pistons **276** and **281** to unwind and wind the truing tool feed mechanism for picking up the truing tool feed increment and to advance the truing tool.

CONTROL SYSTEM—SECOND EMBODIMENT

The alternative embodiment of the instant invention illustrated in FIG. 19 comprising a schematic diagram of the hydraulic system and in FIG. 20 comprising an electrical schematic diagram includes many components identical to or corresponding closely to many components of the preferred embodiment as indicated by the extensive use in FIGS. 19 and 20 of the same reference numerals used in FIGS. 17 and 18 and elsewhere in this application. However, the control system for the second embodiment of the instant invention depends to a greater extent upon hydraulic controls than the control system for the first embodiment does. This difference indicated by the inclusion of numerous additional hydraulic components in FIG. 19 has resulted in the elimination from the control system of various electrical limit switches, solenoids, control relays, and an electrical counter mechanism generally replaced by hydraulic components arranged to perform a corresponding function as indicated by the showing in FIG. 19. The most notable exception to this trend with respect to the design of the control system for the second embodiment is the inclusion of the electronic control E for controlling the fine incremental feed consisting of various electrical and electronic components.

There are two minor modifications of the machine characterizing the instant invention as illustrated in FIG. 19 as compared to the first embodiment of this machine. First, the endwise locator probe **431** and its associated components are shown in a reverse relationship to the work piece W as compared to the showing in FIG. 17 and elsewhere in order to illustrate the feasibility of this reversal of parts. Second, FIG. 19 illustrates a modified configuration of the steadyrest assembly and the control means therefor also suitable for use in combination with the other components of the grinding machine characterizing the instant invention.

The principal modification in the control system for the second embodiment of this invention as compared to the control system for the first embodiment constitutes a rearrangement of the hydraulic system so that the mechanism provided for effecting wheel truing compensation is also operable to effect the full correction of the wheel feed mechanism between successive grinding operations.

Since this mechanism, described immediately below in greater detail, has this added capability in the second embodiment of the control system, this embodiment omits the reset mechanism including the reset cylinder **331** and reset piston **332** as well as the clutch assembly including gears **336** and **337** and the piston **338** operable to disengage the gears **336** and **337** and thereby disengage the reset mechanism from the fine feed mechanism as required. Moreover, the reverse pick feed mechanism including the cylinder **321** and the piston **322** still present in the second embodiment is no longer actuated automatically during the wheel feeding operation since it is not required to function in coordinated relation to the reset mechanism. Instead, the reverse pick menchanism

as illustrated in FIG. 19 is simply manually operated by the operator as required other than during the wheel feeding operation.

The wheel feed compensating mechanism of the second embodiment selectively operable both to effect wheel turing compensation and to effect full correction of the wheel feed mechanism between successive grinding operations includes a cylinder **161** enclosing a piston **162** connected to a piston rod **163**, a compensating cylinder **305** enclosing a piston **306** biased to the left as seen in FIG. 19 by a spring **307**, a push rod **164** supporting a worm **165** for engagement with a worm wheel **166** selectively coupled to a shaft **168** by a clutch assembly **167** actuated by displacement of a piston **302** within a cylinder **301** also enclosing a biasing spring **303**, and a spur gear **171** secured to shaft **168** for engagement with a spur gear **172** slidably and non-rotatably coupled to a piston rod **123** by a key **173**. It will be noted that all of these parts are also illustrated in FIG. 17 and described above in regard to the first embodiment of this invention. In addition, the compensating cylinder **305** is provided with a modified stop **491** and a manual control knob **492** for adjusting the position of this stop to set the compensating mechanism for a single coarse reverse pick equal to the amount picked by the desired number of fine incremental feeding movements to be effected by reciprocation of the pick feed piston **182** in the cylinder **181** during each wheel feed cycle.

The operation of the compensating mechanism to effect full correction of the wheel feed mechanism between successive grinding operations is controlled by the portion of the hydraulic system including valves V21, V11, V11S, V2P, V2L, V2J, V2H, V2C, V2M, V2N, V2R, V2E, and V11C, the needle valves N2S and N2T, and the hydraulic conduits interconnecting these valves and cylinders **305** and **301**.

The operation of the compensating mechanism to effect truing compensation is controlled by the portion of the hydraulic system including the valves V35D, V35A, V2P, V2H, V2J, V2N, V2L, V2C, V2E, V2M, V2R, V11N, V11A, V11B and V11C and the hydraulic conduits interconnecting these valves and the cylinders **305** and **301**.

OPERATION—SECOND EMBODIMENT

Since the operation of the second embodiment generally corresponds to that of the first embodiment, the discussion of the operation of the second embodiment appearing below will be limited to that portion of the operation relating to compensation of the wheel feed mechanism.

To initiate a grinding cycle the operator closes the cycle start push button PB2 with the cycle lever and the wheel feeding sequence begins with the activation of the fast feeding portion of the wheel feeding mechanism and with retraction of the endwise locator probe **431** when hydraulic pressure is supplied to the system.

Fully correcting compensation

At the same time fluid under pressure also passes through a hydraulically reset valve **V21**, maintained in position by a spring pressed latch previously secured when valve **V11** was shifted removing pressure from the left hand side thereof, and passes through a selector valve **V11S** moving pistons in sequence valve **V2P** to the right, passing fluid under pressure to the right side of valve V2L shifting it to the left and through valve V2J to the left hand side of valve V2H moving it to the right. Fluid under pressure then passes through valve V2L through valve V2H and also bypasses valve V2H to the left side of valve V2C moving it to the right at a rate controlled by a fixed orifice N2S.

The purpose of this movement of valve V2C is first to allow the feed mechanism to be reset back a coarse increment while feeding in and thereafter to disengage clutch assembly **167** so that the feed mechanism will retain this coarse increment of back feed equal to the amount of fine feed desired during each grinding cycle, when the piston **306** in cylinder **305** returns to the left as seen in FIG. 19.

Fluid exhausts from the right side of valve V2C and cylinder **305** through valve V2M and valve V2L. Fluid under pressure passing through valve V2H goes through valve V2N to the left side of cylinder **161** moving piston **162** to the right and the feed mechanism moves the wheel slide assembly **12** back a coarse increment equal to the number of fine feed picks desired at the end of the wheel feed cycle. Just before the piston **107** in cylinder **108** bottoms at the end of the shoulder feed, a rod trips the spring pressed latch holding valve **V21** in the position shown in FIG. 19, allowing it to move to the left under spring pressure.

Fluid then exhausts from the left side of valve V2P through valves V11S and V21. Valve V2P centers allowing exhaust from valve V2L through valve V11C. Valve V2L shifts to the right allowing fluid under pressure to pass through valve V2M into cylinder **305** and through valves V2C, V2R, V2H, and V2E into cylinder **301** to disengage clutch assembly **167** by displacing piston **302** against spring **303**. Fluid under pressure is also passed through valve V2L to the right hand side of valve V2C, now shifted to the right, moving it to the left. Fluid in cylinder **161** exhausts through valves V2N, V2H and V2L.

The pick feed mechanism takes an idle stroke to the left into the starting position with the clutch assembly **167** disengaged. Thereafter as stated before, the sequence valve V2C is moved toward the left at a rate controlled by a fixed orifice N2T. Cylinder **301** now can exhaust fluid through valve V2E, and valve V2H, now in a right hand position, and valve V2C. Valve V2C exhausts through valve V2L now in the position shown in FIG. 19. The clutch assembly **167** thus reengages the pick feed mechanism to the rest of the wheel feed mechanism.

Truing compensation

Truing of the grinding wheels is compensated for by moving the grinding wheels toward the work piece by the amount the truing device is preset to remove from the grinding wheels during each of the truing tool passes over the face of the grinding wheel. The truing cycle can be initiated only when the wheel slide **12** is in the rear position where it actuates valve V3C allowing fluid pressure through the truing selector valve **35J** shown in the "On" position in FIG. 20. Valve **V11A** is actuated momentarily to allow pressure fluid through valves V35K and **V11N** to the right side of valves V35A and V35D. Valve V35A shifts to the left and is held by a spring pressed detent allowing pressure fluid from valve V35J into the left side of truing cylinder **291** moving the truing slide to the right. At the same time pressure fluid passes through a central passage in valve V35D from valve V11N to the right sides of valves V2N, V2H, and V2P moving them to the left and to the left side of valve V2J moving valve V2J to the right.

As truing slide **48** starts moving to the right valve **35C** is spring biased to the right allowing pressure fluid to enter the right side of valves V2D, V27A and V2B. Valve V2D allows pressure fluid to enter the right side of valve V22 moving it to the left. Valve V27A moves to the left, allowing valve V27B to return to the right. Valve V27B passes pressure fluid which moves valve V27C to the right and moves cylinder **425** resetting probe **431**. Valve V27C allows pressure through valve V4 to reset cylinder **442**, holding the grinding wheels in a fixed axial position for truing. Valve V22 allows pressure fluid to pass through the central passage through the spool of valve V2B into cylinder **122** to take up the backlash in the compensator mechanism and then to move the body feed piston **121** into the forward position for truing.

When the spool of valve V2P is moved to the left as described above, the other ports therein are blocked by the spool. Valve V2J allows pressure fluid to shift valve V2L to the left and pressure fluid from valve V2L to enter the left side of valve V2C and to pass through valve V2H and through valve V2E to disengage clutch assembly **167** controlled by piston **302** in cylinder **301**. Cylinder **305** exhausts through valves V2M and V2L. As valve V2C moves to the right, pressure fluid moves through valves V2R, V2H, V2N, moving piston **306** and the pick feed mechanism on an idle stroke to the right.

Releasing valve V11A allows valve V35D to center permitting the exhaust through valve V11B of fluid from valves V2P, V2N, V2J and V2C to reset them to the position shown in FIG. 19. Valve V2L exhausts through valve V2P and V11C. Piston **302** in cylinder **301** engages clutch assembly **167** and pressure fluid from valve V2L passes through reset valve V2M, moving piston **306** and the feed mechanism forward a first compensating stroke.

This sequence and the resulting compensation are repeated also for the return stroke of the truing slide **48** to its initial position. As truing slide **48** approaches the end of its movement to the right, the spring detent of valve V35A is tripped, reversing the application of fluid pressure to cylinder **291**. Valve V35B is also actuated by movement of the truing slide **48** to shift valve V35D to the right, which actuates valves V2P, V2J, V2H, V2L and V2C in the manner previously described to first disengage clutch assembly **167** controlled by the movement of piston **302** within cylinder **301**, but when valve V2C reaches its right hand position, it now allows pressure fluid to pass through valve V2N into cylinder **161**, instead of into cylinder **305** to provide the idle stroke of the pick feed mechanism by pushing shaft **164**, worm **165** and piston **306** to the right. When valve V35B resets to the left valve V35D centers to reset valves V2P, V2J, V2L, and V2C which causes piston **302** in cylinder **301** to engage clutch assembly **167** and the pressure fluid to move through valve V2M moving the pistons **306** and **162** to the left to produce a compensating stroke of the feed mechanism and the grinding wheels positioned thereby.

In the second embodiment of this invention, the incremental fine feeding movements continue to be effected by reciprocation of the fine pick feed piston **182** in the cylinder **181** until a gage operates to reverse the wheel feeding mechanism when the work piece has reached the desired final size, regardless of whether the gage operates after the desired number of incremental feeding movements, after less than the desired number of incremental feeding movements, or after a number of incremental feeding movements in excess of the desired number. Under any one of these conditions, the compensating mechanism provided in the second embodiment of the instant invention operated in the manner described above, is automatically inherently effective to fully correct the set up of the wheel feeding mechanism for the desired number of fine incremental feeding movements during the next grinding operation.

Unwind and wind sequence

The unwind and wind mechanism is actuated simultaneously with each fine increment of feed forward. Near the end of the body feed the limit switch LS4 is actuated which starts an adjustable electronic pick feed actuator operable automatically alternately to energize and to deenergize the solenoid S14.

Each time solenoid S14 is energized, valve V33 is shifted to the right allowing pressure fluid to pass through valve V2K to cylinder **181** for a predetermined increment of fine pick feed forward and also to the left side of valve V2N moving it to the right allowing pressure fluid into the left side of cylinder **305** and into the right side of valve V2M, moving piston **306** to the right as valve V2M allows fluid to exhaust from the right side of cylinder **305**. This movement causes the feed mechanism to unwind or retract a predetermined amount. Each time the solenoid is deenergized valve V33 moves to the right allowing fluid to exhaust from cylinder **181** and the left side of valve V2N. Piston **182** resets and valve V2N centers. Valve V2N allows fluid to exhaust from the left side of cylinder **305** and the right side of valve V2M, so that valve V2M shifts to the right, thus allowing pressure fluid to move piston **306** to the left to wind or advance the feed mechanism to pick up the fine movement of infeed.

CONCLUSION

In summary, the grinding machine characterizing the instant invention provides the numerous advantageous features enumerated below.

This invention provides a wheel feed mechanism for precision grinding machines operable to feed grinding wheels against a work piece according to a precisely controlled predetermined feeding sequence and incorporating compensating means operable between successive grinding operations to fully correct for any variation in the predetermined feeding sequence.

This invention also provides a grinding machine configuration enhanced by the fact that a work piece is supported for grinding with its axis of rotation disposed parallel to and a predetermined vertical distance above the axis of the rotation of the grinding wheels substantially equal to the vertical distance below the axis of rotation of the grinding wheels at which the truing tools engage the grinding wheels, with the result that truing errors introduced by the fact that each truing tool is offset a substantial vertical distance from the horizontal diameter of each grinding wheel tend to be compensated by the substantially equal vertical offset between the horizontal diameter of the grinding wheel and the level at which the grinding wheel engages the work piece. It will be obvious that this compensation of errors will be most effective in a typical application for the machine characterizing the instant invention such as grinding crankshaft bearings typically of the order of two or three inches in diameter with grinding wheels as large as forty-two inches in diameter so that the vertical distance between the axis of rotation of the work piece and the level at which the grinding wheel engages the work piece is very small.

The wheel truing means incorporated in this grinding machine offers an additional advantage in the fact that it is arranged to be reciprocated for a truing operation at the front of the machine at a location close to that at which the grinding operation is performed while the means for supporting a work piece to be ground remain fixedly secured to the base of the machine.

In addition, this invention provides a relatively simple precision wheel feed mechanism including a series of wheel feeding elements coacting as required to produce a fast and a shoulder feed, a coarse or body feed, and a fine incremental feed in sequence, each of predetermined magnitude, the respective wheel feeding elements being connected in effect in series by a plurality of worm wheels rotatable with the respective wheel feeding elements operatively engaging a plurality of worms secured to the respective wheel feeding elements selectively operable both axially and rotatably by means of various actuating means activated in the sequence necessary to produce the desired wheel feeding sequence.

The instant invention further provides a work piece steadyrest assembly having control means therefor of a configuration especially suited to use with a precision wheel feed mechanism fully corrected between successive grinding cycles.

Moreover, the instant invention provides an improved footstock assembly having a work piece supporting center arranged to be secured in fixed relation to a work piece supported thereby without reliance upon the force

exerted by the means provided for biasing the center into engagement with a work piece.

The instant invention additionally provides an endwise locator mechanism automatically operable to establish the desired axial relationship between a work piece to be ground and the grinding wheel spindle assembly dependent for its satisfactory operation upon a follow-up mechanism incorporating a minimum number of parts that is readily adjusted, easily serviced, and reliable in use.

Finally, this invention provides a precision wheel feed mechanism so interconnecting the base and the wheel slide assembly of a grinding machine that the portion of the wheel feed mechanism adjustably interconnecting the base and the wheel slide assembly is subjected to a tension load rather than a compression load under operating conditions. This result is achieved in the embodiments of the instant invention described and illustrated herein by so disposing the wheel feed screw **102** and the elements connecting the wheel feed screw **102** to the base **10** and to the wheel slide assembly **12** respectively are disposed as shown in FIG. 2 and elsewhere with the fast feed cylinder **108** and the fast feed piston **107** located at the front of the feed screw **102** and the feed nut disposed relatively more remote from the work piece grinding station.

It is to be understood that the respective embodiments of the instant invention illustrated herein are illustrative only and not to be construed in a limiting sense, since the modification of various details of the several components of this invention are considered to fall within the scope of the instant invention. Instead, it is the applicant's intention that the scope of this invention be limited solely by the scope of the claims appended hereto.

What is claimed is:

1. In a precision grinding machine for grinding a series of work pieces to a predetermined finished size, a grinding wheel feed mechanism including an incremental fine feeding mechanism set up and automatically cyclically operable to feed a rotating grinding wheel spindle assembly toward each work piece to be ground according to a preferred feeding sequence terminating in a predetermined number of incremental feeding movements produced by the fine feeding mechanism, gage means operatively connected to said wheel feeding mechanism and arranged to operate when each work piece reaches the desired final size to reverse said wheel feeding means, counting means operable to count out when said wheel feed mechanism is advanced the predetermined number of incremental feeding movements, reset means normally operable to reverse the fine feeding mechanism by movement equal to that produced by the predetermined number of incremental feeding movements, clutch means selectively interconnecting said reset means and said wheel feed mechanism, compensating means operable if said gage means operates before said counter counts out to declutch said reset means immediately, to reverse the fine feeding mechanism by incremental feeding movements until said counter counts out, to engage said clutch means, and to actuate said reset means, and compensating means operable if said counter counts out before said gage means operates to declutch said reset means immediately, to advance the fine feeding mechanism by the additional number of incremental movements necessary for the gage means to operate, to engage said clutch means, and to actuate said reset means.

2. A device as described in claim 1, and, in addition, an overriding counting means operable to count out when a work piece being ground approaches the minimum acceptable final size, and means operable when the overriding counting means counts out to reverse said wheel feeding means.

3. In a precision grinding machine for grinding a series of work pieces to a predetermined finished size, a grinding wheel feed mechanism including an incremental fine feeding mechanism set up and automatically cyclically operable to feed a rotating grinding wheel spindle assembly toward each work piece to be ground according to a preferred feeding sequence terminating in a predetermined number of incremental feeding movements produced by the fine feeding mechanism, gage means operatively connected to said wheel feeding mechanism and arranged to operate when each work piece reaches the desired final size to reverse said wheel feeding means, compensating means operable after said gage means operates to feed said fine feeding mechanism in reverse an amount equal to the feed produced by the predetermined number of incremental feeding movements necessary to terminate the preferred feeding sequence, whereby the set-up of the wheel feed mechanism is fully corrected to position the rotating grinding wheel spindle assembly prior to the next grinding operation for grinding the next work piece according to the preferred feeding sequence.

4. A precision grinding machine comprising a base, a wheel slide slidably mounted upon said base for feeding movement in a horizontal plane, a wheel spindle assembly mounted upon said wheel slide for rotation about a first horizontal axis, first drive means for rotating said wheel spindle about said first horizontal axis, wheel truing means mounted upon said base and arranged to support a truing tool for operative engagement with a grinding wheel mounted upon said wheel spindle assembly a predetermined vertical distance below said first axis, work piece supporting means mounted upon said base arranged to support a work piece for rotation about a second horizontal axis parallel to and spaced substantially the same predetermined vertical distance above said first horizontal axis, a second drive means for rotating a work piece, and a wheel feeding mechanism selectively operable to feed said wheel slide toward a work piece and to coact with said truing means to position said wheel slide for truing a grinding wheel mounted upon said wheel spindle assembly.

5. A device as described in claim 4, and, in addition, means for reciprocating said wheel truing means and the truing tool supported thereby in a horizontal plane transversely of a grinding wheel mounted upon said wheel spindle assembly with said work piece supporting means fixedly secured to said base.

6. A grinding machine comprising a base, a wheel slide slidably mounted upon said base, a grinding wheel spindle mounted upon said wheel slide for rotation about a predetermined axis, a first drive means for rotating said grinding wheel spindle assembly, a table assembly fixedly secured to said base, work piece supporting means fixedly secured to said table assembly and arranged to support a work piece for rotation about a fixed predetermined axis, a truing slide mounted upon said table assembly for reciprocating movement therealong transversely of a plurality of grinding wheels supported on said grinding wheel spindle assembly, a plurality of truing means fixedly secured to said truing slide each fixedly supporting a truing tool for operative engagement with a grinding wheel, and means for selectively maintaining or shifting the position of each truing tool relative to the associated grinding wheel as required and independent of the position of other truing tools as said truing slide is reciprocated.

7. A device as described in claim 6 wherein at least one truing tool is mounted upon a truing means by means of a vertical extension means so disposed that the truing tool is supported in operative engagement with a grinding wheel at its horizontal diameter.

8. A wheel feed mechanism inter-connecting the base and the wheel slide of a grinding machine comprising a first elongated element including a first threaded portion fixedly secured thereto and a first worm wheel fixedly secured thereto, a first linear actuator operable to displace said first elongated element axially to produce a fast feed, a second elongated element including a second threaded portion fixedly secured thereto and engaging

said first worm wheel to produce rotation of said first elongated element, a second linear actuator operable to displace said second elongated element axially to produce a coarse feed, a second worm wheel coupled to said second elongated element to produce rotation of said second elongated element, a third elongated element including a third threaded portion fixedly secured thereto and disposed in engagement with said second worm wheel, a third linear actuator operable to displace said third elongated element axially to produce an unwind-wind motion of the feed mechanism, a fourth linear actuator operable to produce axial displacement of said third elongated element for wheel truing compensation, a first pick feed mechanism cyclically operable to rotate said third elongated element to produce an incremental fine feed, a second pick feed mechanism operable to rotate said third elongated element in the opposite direction to produce a reverse incremental fine feed, and a reset mechanism operable to rotate said third elongated element in said opposite direction to reset said wheel feed mechanism.

9. A device as described in claim 8, and, in addition, a first clutch assembly interconnecting said second worm wheel and said second elongated element, means operable to declutch and clutch said first clutch mechanism in coordinated relation to the operation of said fourth linear actuator, a second clutch assembly interconnecting said third elongated element and said reset mechanism, and means operable to declutch and clutch said second clutch assembly in coordinated relation to the operation of said first pick mechanism and said second pick mechanism.

10. In a precision grinding machine, a grinding wheel feeding means set up and automatically operable to feed a rotating grinding wheel assembly toward a work piece to be ground according to a predetermined preferred feeding sequence including a coarse feeding portion followed by a fine feeding portion over a predetermined distance, means operable after each grinding operation to fully correct for deviation in the distance covered by the fine feeding portion of the predetermined feeding sequence, and a work piece steadyrest means, said steadyrest means including opposed support means with steadyrest shoes secured thereto, biasing means operable to bias said opposed support means away from a work piece, actuating means operable at a predetermined point in the coarse feeding portion of the feeding sequence to override said biasing means and move said opposed support means into engagement with a work piece, first limiting means operable as the steadyrest shoes engage the work piece to limit the rate of displacement of the actuating means to a rate commensurate with the coarse feeding portion of the feeding sequence, and second limiting means operable coincident with initiation of the fine feeding portion of the feeding sequence to limit the rate of displacement of the actuating means further to a rate commensurate with the fine feeding portion of the feeding sequence.

11. A steadyrest assembly for supporting a work piece in a grinding machine comprising a supporting member, steadyrest shoes reciprocably supported upon said supporting member, retracting means operable to maintain said steadyrest shoes out of engagement with a work piece, compound actuating means operable to override said retracting means including a first cylinder portion, a first piston enclosed by said first cylinder portion and operatively connected to said steadyrest shoes, a second cylinder portion, a second piston enclosed by said second cylinder portion and having an adjustable stop projecting into said first cylinder portion for engagement with said first piston, means operable to displace said first piston toward said second piston initially by unrestricted fluid pressure and then by relatively less restricted fluid pressure, and means operable when said first piston portion engages said adjustable stop to displace said first piston and said second piston by relatively more restricted fluid pressure.

12. A footstock assembly for supporting one end of a work piece rotatable in a machine tool in clamping relation to a headstock assembly arranged to rotatably support the other end of the work piece, said footstock assembly comprising a supporting means, a work piece supporting center mounted reciprocably upon said supporting means, center biasing means operable to bias said center toward a work piece, hydraulically actuated center retracting means selectively operable to retract said center, an hydraulic control means operable to actuate said center retracting means, a mechanical linkage operably interconnecting said center and said center retracting means, backlash eliminating means operable to eliminate backlash from said mechanical linkage, and center locking means in said hydraulic control means automatically operable when said center engages a work piece to secure said center in engagement with the work piece independent of the force exerted upon said center by said center biasing means.

13. A machine tool assembly comprising a base, a tool supporting means mounted upon said base, a cutting tool mounted upon said tool supporting means on a predetermined first axis, means for securing a work piece in fixed relation to said base on a predetermined second axis parallel to said first axis, means for actuating said machine tool support to perform a machining operation upon a work piece with said cutting tool, axial locating means movably mounted upon said base, biasing means interconnecting said axial locating means and said base operable to bias said axial locating means into engagement with a locating surface on a work piece secured to said base, tool positioning means activated by said axial locating means when said cutting tool is out of proper axial alignment with a work piece to be machined, and follow-up means consisting of a first element interconnecting said base and said tool supporting means and a second element interposed between said tool positioning means and said actuating means coacting with said first element to deactivate said actuating means when said cutting tool has been displaced into the proper axial alignment with a work piece to be machined.

14. A device as described in claim 13, and, in addition, retracting means for said axial locating means automatically operable when a work piece is secured in said machine tool assembly to release said axial locating means for engagement with a locating surface on the work piece and automatically operable when a machining operation is initiated on said machine tool assembly to retract said axial locating means from engagement with a locating surface on the work piece.

15. A precision grinding machine comprising a base, a wheel slide assembly supporting a grinding wheel for movement into and out of engagement with a work piece to be ground, and wheel feeding means interconnecting said base and said wheel slide assembly and operable to advance said wheel slide assembly across said base toward a work piece to be ground, said wheel slide assembly including an elongated wheel feeding element interconnecting said base and said wheel slide assembly disposed with its longitudinal axis parallel to the direction in which said wheel slide assembly is advanced along said base, first connecting means coupling said elongated wheel feeding element to said base, and second connecting means coupling said elongated wheel feeding element to said wheel slide assembly spaced from said first connecting means along said elongated wheel feeding element and so disposed relative to said first connecting means that the portion of said elongated wheel feeding element extending between said first connecting means and said second connecting means is maintained in tension when said wheel feeding means is actuated to advance said wheel slide assembly toward and against a work piece to be ground.

16. A grinding wheel feeding means adjusted and operable according to a preset wheel feeding sequence to feed a grinding wheel toward a work piece to be ground, gage means operable independent of said preset wheel feeding sequence when a work piece is ground to a desired final size to reverse the wheel feeding means, and means automatically operable between successive work piece grinding operations fully to correct the adjustment of the wheel feeding means for either foreshortening or protraction of the wheel feeding sequence actually completed relative to the preset wheel feeding sequence so as to position the grinding wheel to grind the next work piece to the desired final size upon completion of the preset wheel feeding sequence.

17. In a precision grinding machine, a grinding wheel feeding means set up and automatically operable according to a predetermined preferred feeding sequence to feed at least one grinding wheel toward a work piece to be ground, gage means operable independent of said preferred feeding sequence when a work piece is ground to a desired final size to reverse the wheel feeding means, and means automatically operable before the next work piece is ground fully to correct the set-up of the wheel feeding means so as to position the grinding wheel to grind the next work piece to the desired final size by completing the predetermined preferred feeding sequence, whether the wheel feeding sequence actually completed when the previous work piece reached final size was relatively shorter or relatively longer than the predetermined preferred feeding sequence.

18. In a precision grinding machine, a grinding wheel feeding means set up and automatically operable according to a predetermined preferred feeding sequence to feed a rotating grinding wheel assembly toward a work piece to be ground, gage means operable independent of said preferred feeding sequence when a work piece reaches a desired final size to withdraw the wheel feeding means, and means operable automatically between succeeding work piece grinding operations when the wheel feeding sequence actually completed is either foreshortened or protracted relative to the predetermined preferred feeding sequence fully to correct the set-up of the wheel feeding means by positioning the grinding wheel assembly to grind the next work piece to the desired final size coincident with the completion of the predetermined preferred feeding sequence.

19. In a precision grinding machine for grinding a series of work pieces to a predetermined finished size, a

grinding wheel feeding mechanism set up and automatically cyclically operable to feed at least one grinding wheel toward each work piece to be ground according to a predetermined preferred feeding sequence, gage means connected to said wheel feeding mechanism operable independent of the predetermined preferred feeding sequence when each work piece reaches the desired final size to reverse the wheel feeding means, and compensating means responsive to either foreshortening or protraction of the actual feeding sequence completed relative to the predetermined preferred feeding sequence and operable automatically when the wheel feeding means is reversed fully to correct the set-up of the wheel feeding means prior to the next grinding operation by positioning the face of the grinding wheel so as to grind the next work piece to the desired final size upon completion of the predetermined preferred feeding sequence.

20. In a precision grinding machine, a grinding wheel feeding means set up and automatically operable cyclically to feed a rotating grinding wheel assembly toward successive work pieces to be ground according to a preferred feeding sequence ending with a predetermined number of fine picks forward, gage means operable independent of said preferred feeding sequence when a given work piece reaches a desired final size to reverse the wheel feeding means, and means operable by means of a single coarse reverse pick during the feeding sequence for grinding the next work piece to retract the wheel feeding means an amount equal to the amount the wheel feeding means is advanced by said predetermined number of fine picks forward fully to correct the set-up of the wheel feeding means so that the grinding wheel assembly is positioned to grind the next work piece to the desired final size upon completion of the preferred feeding sequence.

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