

May 15, 1956

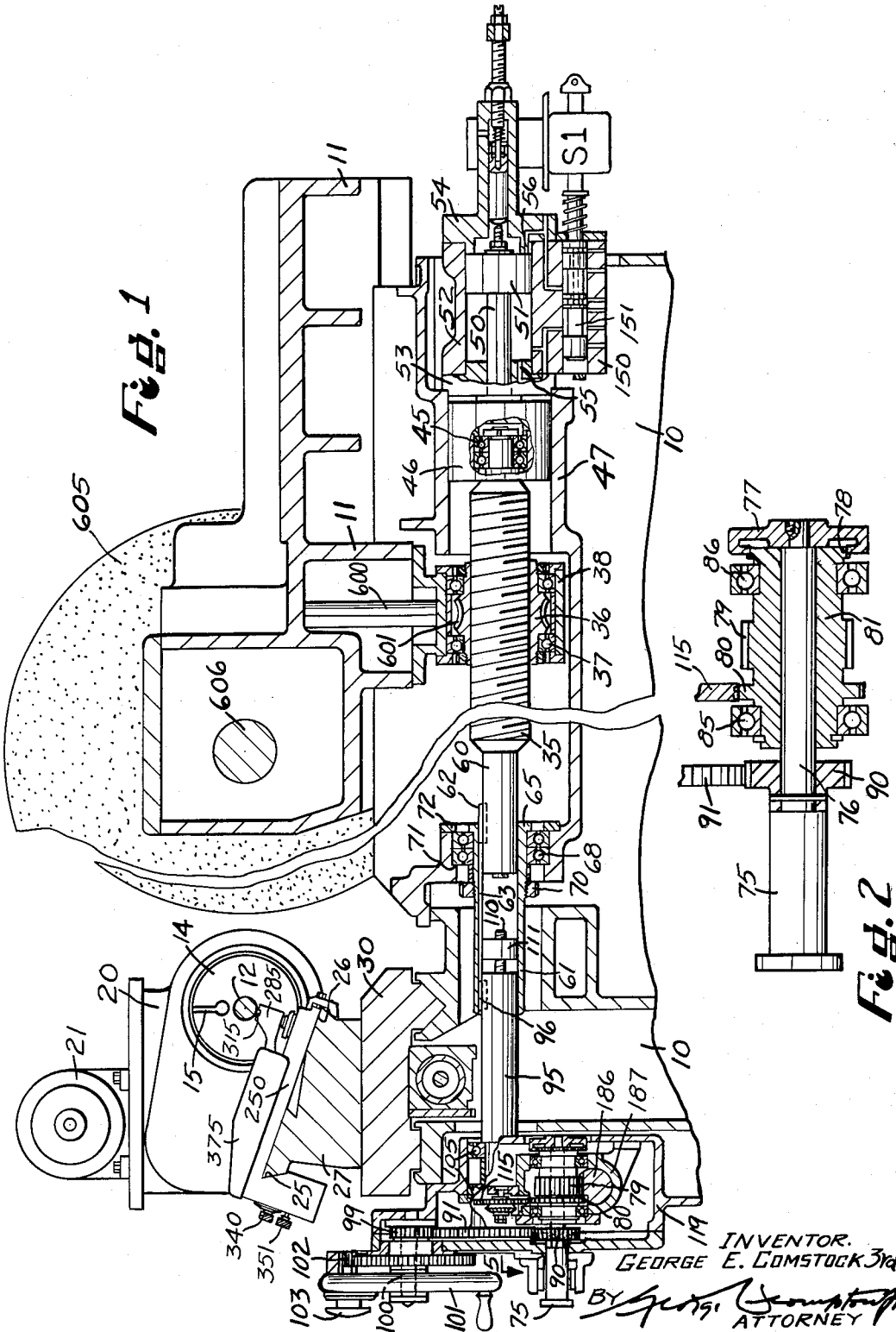
G. E. COMSTOCK, 3D

2,745,221

INFEED CONTROL

Filed Nov. 16, 1954

3 Sheets-Sheet 1



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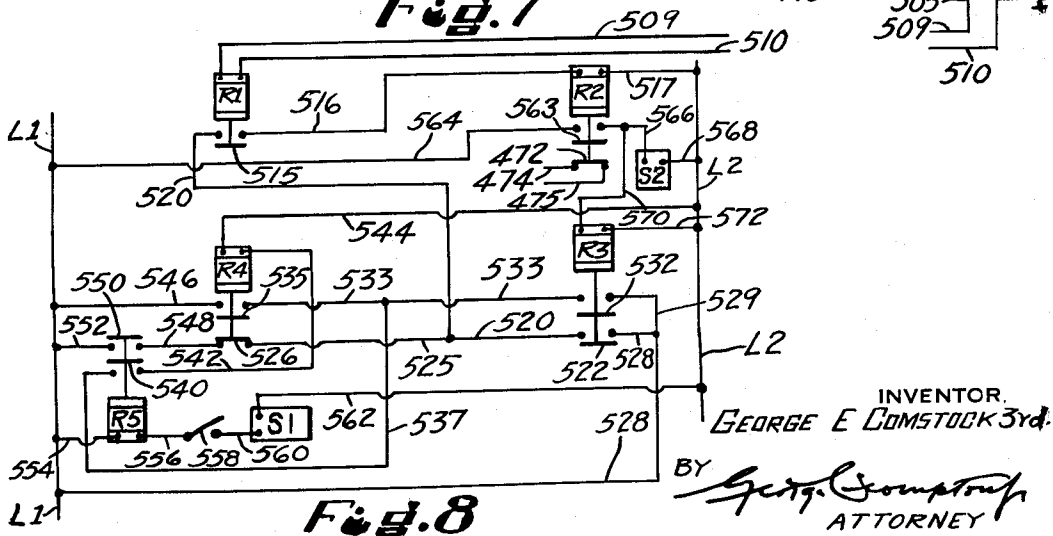
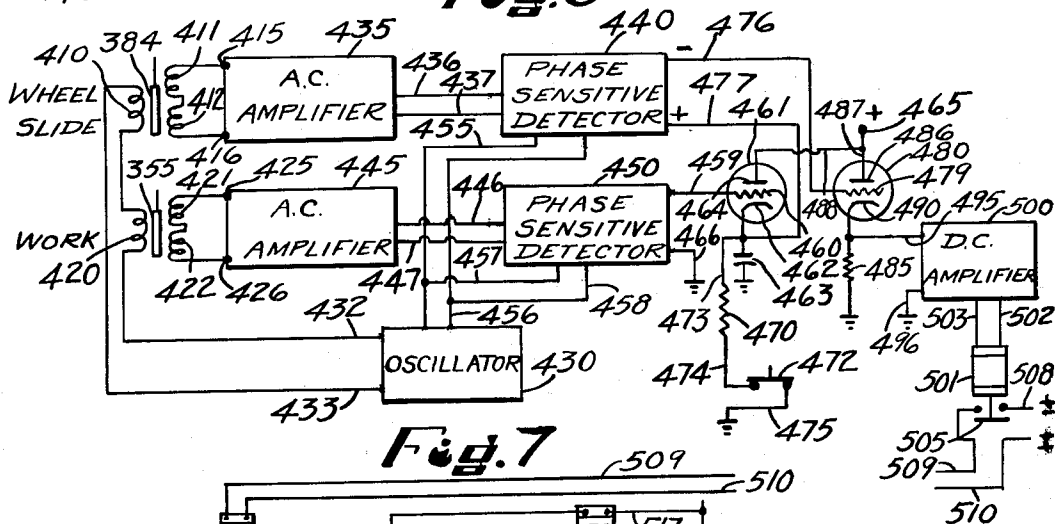
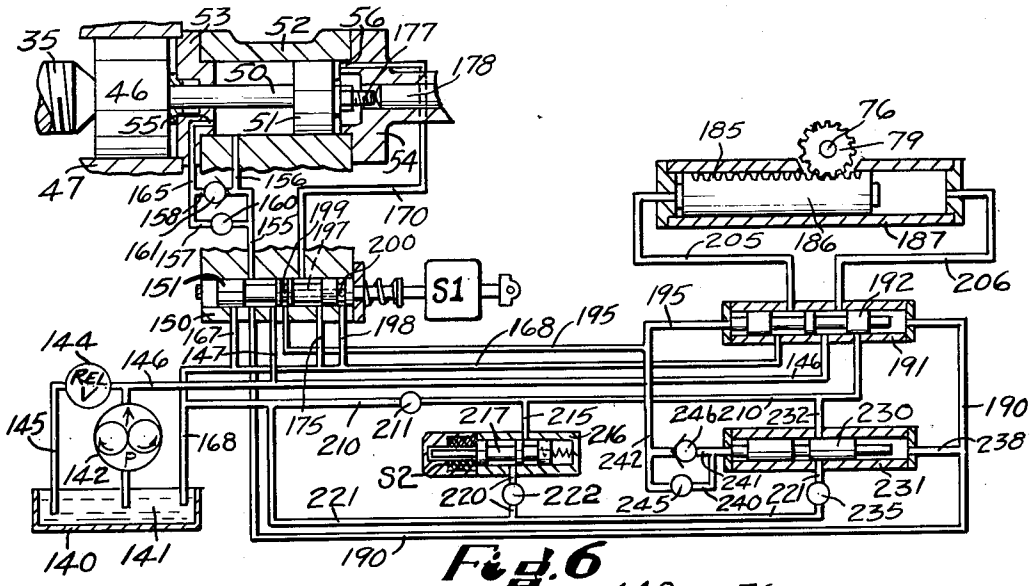
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3 Sheets-Sheet 3



INVENTOR,
GEORGE E COMSTOCK 3rd.

BY *Geo. G. Thompson*
ATTORNEY

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2,745,221

INFEED CONTROL

George E. Comstock 3d, Holden, Mass., assignor to Norton Company, Worcester, Mass., a corporation of Massachusetts

Application November 16, 1954, Serial No. 469,200

13 Claims. (Cl. 51—165)

The invention relates to infeed controls.

One object of the invention is to provide an infeed control especially for grinding machines to bring the wheel rapidly to bare contact or incipient contact with the workpiece. Another object of the invention is to provide a control of the type indicated susceptible of wide adjustments to meet varying conditions in actual use. Another object of the invention is to increase the production of various kinds of grinding machines and other machine tools. Another object of the invention is to provide an infeed control to bring the wheel to incipient contact with the work which shall operate effectively whether the workpiece is a true cylinder within close tolerances or is a very rough casting, forging or other shape that as yet is far from its final form. Another object of the invention is to provide an infeed control especially useful for rapidly positioning the wheel into incipient contact with the high point of eccentric workpieces.

Another object of the invention is to save time in every grinding operation especially in those cases where the workpiece is out of round to an unknown extent. Another object of the invention is to relieve the workman from the necessity of careful measurement of the workpiece before grinding each piece. Another object of the invention is to permit a general setting of the grinding machine or other machine tool for a large number of workpieces of the general type of classification without necessitating resetting for individual workpieces especially where the dimensions of successive workpieces vary widely, as in the case where a succession of castings all supposed to be derived from the same pattern or set of patterns actually differ a good deal in actual size because of differences of shrink and the roughness of the casting operation.

Another object of the invention is to provide an infeed control of the type indicated which functions effectively regardless of the varying size of the grinding wheel due to wheel wear. Another object of the invention is to provide a control of the type indicated which can be readily applied to cylindrical grinders of widely approved type. Another object of the invention is to provide an infeed control of the type indicated having a feeler element which is so located that it doesn't interfere with other machine elements and doesn't get in the way of replacement of workpieces. Another object of the invention is to provide a feeler control for machine tools having a memory capacity for controlling the machine so that it is the high point on the workpiece which is interpreted in the control of the machine.

Other objects will be in part obvious or in part pointed out hereinafter.

In the accompanying drawings illustrating this invention as applied to a particular type of cylindrical grinding machine, and illustrating a particular embodiment of the mechanical features of this invention, and illustrating a particular embodiment of the electrical features of this invention,

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Figure 1 is a vertical sectional view of a cross feed actuating mechanism of a cylindrical grinder,

Figure 2 is a sectional view on an enlarged scale of the feed gearing which is also shown in Figure 1,

5 Figure 3 is a vertical sectional view on an enlarged scale as compared with Figure 1 of the feeler mechanism having a contact block which contacts the workpiece,

Figure 4 is a sectional view on the same scale as Figure 2 and taken along the line 4—4 of Figure 3,

10 Figure 5 is a sectional view on an enlarged scale taken along a plane indicated by the line numbered 5 in Figure 1,

Figure 6 is an hydraulic diagram illustrating the hydraulic mechanism of the grinding machine,

15 Figure 7 is a block diagram of the electrical apparatus,

Figure 8 is a diagram of the electrical relay system.

Referring now to Figure 1, the infeed control is illustrated as applied to a grinding machine wherein the base 10 has conventional slideways, not shown, mounting a wheel slide 11 for rectilinear movement towards and from a workpiece 12 supported and rotated by a face plate 14 having a T-slot 15 by means of which the usual driving pin in the form of a bolt may be secured to the face plate to drive the clamping dog, not shown, secured to the workpiece 12. The face plate 14 is journaled in and rotated by a headstock 20 having a driving motor 21. The face plate 14 rotates, of course, at such speeds as are suitable for driving workpieces in a cylindrical grinder; the headstock 20 has reduction gearing connecting the face plate 14 to the armature shaft of the motor 21. As such mechanism is well known and has many forms and is not a part of the present invention, no further description thereof is required. The headstock 20 is clamped to the ways 25 and 26 of the machine table 27 to which a tailstock, not shown, is also clamped. The table 27 is secured in any suitable manner to a work carriage 30.

A screw shaft 35 passes through a nut 36 mounted in ball bearings 37 in a casing 38 attached to the under side of the wheel slide 11. Except for compensation, with which this invention deals indirectly, the nut 36 is stationary, so therefore whenever the screw shaft 35 is rotated, the slide 11 is moved in one direction or the other, and the shaft 35 can also be rectilinearly moved as will now be described.

Referring also to Figure 6, the screw shaft 35 is journaled in ball bearings 45 mounted in a piston 46 in a cylinder 47 whereby to guide the screw shaft in its rectilinear motion, the cylinder 47 being a part of the machine base 10. The piston 46 is connected by a piston rod 50 to a piston 51 in an hydraulic cylinder 52 which is secured to the machine base 10. This cylinder 52 has heads 53 and 54 having ports 55 and 56 for operation of the piston 51 by hydraulic fluid.

Referring to Figure 1, the left hand end 60 of the screw shaft 35 is of reduced size and fits in a hollow shaft 61 to which it is angularly secured by means of a key 62 in a spline 63 in the inside of the shaft 61. This shaft 61 has a flange 65 and the inner races of ball bearings 68 are secured to the hollow shaft 61 by means of the flange 65 and a nut 70; the outer races of the ball bearings 68 are held to the machine base 10 by means of a shoulder 71 and a ring 72. Thus is the hollow shaft 61 held in the machine base by thrust bearings so that it can rotate but not move rectilinearly.

Referring now to Figure 2, a plunger 75 has a reduced shaft portion 76 secured to which is an internal gear 77 acting as a clutch member which, when the plunger is to the left or out, is in mesh with an external gear 78 which is integral with a gear 79 and a gear 80 on a long hub 81 which is journaled in ball bearings 85 and 86. Secured to the shaft portion 76 is a gear 90 which meshes with a large gear 91 shown also in Figure 1, which see, and

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which is secured to the left hand or front end of a shaft 95 which is connected by a key 96 located in the spline 63 of the hollow shaft 61.

Going back to Figure 2, when the plunger 75 is pushed in or to the right the clutch gear 77 is disengaged from the clutch gear 78 so that rotation of the unit comprising gears 78, 79 and 80 will not drive the gear 90 and therefore will not rotate the gear 91, the shaft 95, the hollow shaft 61, and the screw 35. But, referring to Figure 1, the gear 91 is always in mesh with a small gear 99 on a hand wheel shaft 100 secured to which is a hand wheel 101 having a micrometer or inching pinion 102 operated by a knob 103, this inching micrometer device being well known to the art. Thus whenever the hand wheel 101 is turned as may be preset by the knob 103 or otherwise, the feed screw 35 is turned. The shaft 95 is journaled in ball bearings 105 and has extending through it a screw 110 and a stationary nut 111 press fitted in the inside of the hollow shaft 63 to act as an adjustable stop for the end 60 of the screw shaft 35. The screw shaft 110 extends through to the front of the machine but such is not shown here in order not to confuse the drawings. Much of this mechanism will be found to be described in U. S. Letters Patent 2,572,529 to H. A. Silven of October 23, 1951, but there are changes for the purposes of this invention, for example the gear 80 is additional and performs a function in this invention.

This gear 80 meshes with a gear 115 (refer now to Figure 5) which is journaled on ball bearings 116 on a stud 117 extending through a panel 118 which is part of a box 119 (Figure 1) enclosing a good part of the gearing just described. Going back to Figure 5, attached to the gear 115 is a bevel gear 125 which meshes with another bevel gear 126 on the end of a shaft 127 journaled in ball bearings 128 and a block 129 attached to the panel 118. At the right hand end of the shaft 127 is a screw end 132 which extends into a nut 133 located in a hollow cylindrical casing 134 and keyed to it so that it cannot rotate. The casing 134 has a flange 136 and bolts 137 attach it to the block 129. Of course when the gear 80 turns, it turns the gear 115 which turns the bevel gear 125 which turns the bevel gear 126 which rotates the shaft 127 and its screw 132 which moves the nut 133 and the purpose of this will be hereinafter described.

Referring now to Figure 6, a sump 140 which may be in the machine base has a supply of hydraulic fluid 141 which is pumped by a pump 142 to provide power for the movement and control of the wheel slide 11 (as well as for other functions of the machine which are not a part of the present invention). The pressure of the hydraulic fluid is maintained close to the desired pressure by means of a relief valve 144, which is adjustable, and which exhausts through a pipe 145 to the sump 140.

For short in the description which immediately follows as well as elsewhere in the specification, pipes and their connections conveying the hydraulic fluid will be referred to as lines. The pump 142 is connected by a line 146 to a line 147 which leads to a valve casing 150 in which is slidably mounted a plunger valve 151. With the plunger valve in the position shown in Figure 6, fluid is admitted to a line 155 which is connected by a line 156 to the cylinder 52. There are two more lines 157 and 158 in parallel with the line 56; in the former is a needle valve 160, in the latter is a check valve 161. These two lines 157 and 158 are connected to a line 165 which leads to the port 55 at the left hand end of the cylinder 52.

With the plunger valve to the left, the line 155 is connected to line 167 which is connected to line 168 leading to the sump 140. When the piston 51 moves to the left it can move fast unimpeded by any throttle until the line 156 is covered after which the fluid being unable to pass through the check valve 157 has to go through the needle valve 160 and therefore from that time on the piston 51 must move at an adjustable slow rate. When the piston

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51 moves to the right the check valve 158 is open and nothing at the left hand end of the cylinder impedes its progress.

With the plunger valve 151 to the left hydraulic fluid is admitted from the line 147 to a line 170 which is connected to the port 56 and this line is unrestricted. With the plunger valve 151 to the right as shown fluid can exhaust through the line 170 and then through the valve casing 150 to a line 175 to the exhaust line 168. At the end of a stroke to the right a screw 177 projecting from the piston 51 strikes a cushioning plunger 178 to cushion its stop. This cushioning plunger 178 is operated and controlled in a manner not germane to this invention.

Referring to the right hand side of Figure 6, a rack 185 on a piston 186 meshes with the gear 79 of Figure 2 and movement of the piston 186 revolves the gear 79 to rotate the gear 80 and, when the clutch 77—78 is engaged, to rotate the gear 90 and the gear 91 and through the connections already described to rotate the screw shaft 35. The piston 186 is located in a cylinder valve casing 187. A line 190 from the valve casing 150 is connected to the right hand end of a pilot valve casing 191 having a plunger valve 192. A line 195 connects the valve casing 150 with the left hand end of the pilot valve casing 191. With the plunger valve 151 to the right as shown in Figure 6, the line 195 is connected through a bore 197 in the plunger valve 151 to a line 198, the bore 197 having lateral ports 199 and 200. The line 198 is connected to the line 168 which leads to the sump. As the line 147 is at that time connected to the line 196, the right hand end of the casing 191 is connected to pressure and the left hand end is connected to exhaust.

At that time the exhaust line 168 is connected to a line 205 leading to the left hand end of the valve casing 187 and the right hand end of the valve casing 187 is connected to pressure through a line 206 and the line 146. It will readily be seen that when the plunger valve 151 is moved to the left, the pilot plunger valve 192 will be moved to the right, and the piston 186 will also be moved to the right, the exhaust from the right hand end of the casing 187 going by way of line 206 through the casing 191, through a line 210 connected through a needle valve 211 to the exhaust line 168.

But this exhaust path is maintained only when a solenoid S2 is deenergized as indicated in Figure 6 which solenoid is energized by an electrical signal resulting from the action of electronic controlling apparatus and relay mechanism to be described. With the solenoid S2 energized the exhaust from line 210 is shunted through a shunt line 215 to a valve casing 216 having a plunger valve 217 controlled by the solenoid S2 and then by way of a line 220 to an exhaust line 221 leading back to the exhaust line 210 beyond the needle valve 211. There is, however, a needle valve 222 in the line 220 but the needle valves 211 and 222 will be differently set to pass fluid at different rates.

There may also be incorporated a backlash eliminator in the form of a plunger valve 230 in a valve casing 231 connecting the line 221 to a shunt line 232 to the line 210 momentarily when the plunger valve 230 passes the lines 221 and 232 which are opposite each other as will be seen from Figure 6. There is another needle valve 235 in the line 221 next to the valve casing 231. This plunger valve 230 which acts as a shuttle is operated by pressure at the reversal of the feed as the right hand side of the casing 231 is connected by a line 238 to the line 190 and the left hand side is connected by parallel lines 240 and 241 to a line 242 to line 195. In the line 240 is a needle valve 245 and in the line 241 is a check valve 246. Thus the shuttle plunger valve 230 moves fast to the right but slowly to the left.

Referring now to Figures 3 and 4, I provide feeler mechanism which is supported by a casing 250 shaped to fit on the ways 25 and having a clamp 260 engaging the ways 26 and tightened in position by means of a screw

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261 extending through the clamp 260 into a block 262 secured to the casing 250. Mounted on and secured to the casing 250 by means of screws 263 is another block 264 to which is secured cruciform flat crossed springs 265 the other ends of which are secured to a lever arm 270. At their upper ends the crossed flat springs 265 can be secured to the block 264 and to the lever arm 270 by means of plates with screws 272 and at the lower ends they can extend into slots in the block and the lever arm respectively.

A feeler arm 275 is secured to the lever arm 270 by means of screws 276. Comparing Figures 3 and 4, it will be seen that the lever arm 270 has a deep slot 280 which is, when the screws 276 are loosened, just slightly wider than the width of the feeler arm 275 which is flat and fits with a snug but sliding fit within the slot 280. However, when the screws 276 are tightened the feeler arm 275 is locked in position. I provide a number of feeler arms 275 the left hand ends of which are all the same and are adapted to fit in the slot 280 and the right hand ends 285 of which are of different sizes for contact with workpieces of different sizes.

Pivotaly mounted in the casing 250 on the ball bearings 289 is an actuating lever 290 having a pad 291 with a stud 292 around which fits a spring 293 which fits over a stud 294 projecting from a pad 295 on a plate 296 which is secured to the casing 250 and completes the enclosure for the lever 290 and some other parts. The right hand end of the lever 290 has an enlarged portion 300 into which extends the lower small diameter end 301 of a stud 302 having a screw threaded upper portion 304 and a shoulder 305. The portion 301 is firmly secured to the portion 300 of the lever 290 by means of a screw 307. A rubber diaphragm 308 is engaged by a flaring washer 310 welded to the top of the plate 297 and is also secured to the shoulder 305 by means of a nut 311 on the screw threaded portion 304 which nut 311 likewise holds in position a protective cap 312. As clearly shown in Figure 3 the upper side of the portion 304 of the stud 302 engages the under side of the portion 285 of the lever 275, and the spring 293 continually urges the portion 285 and a wear resistant contact pad 315 thereon into engagement with the workpiece 12. Through reaction, downward movement of the portion 285 moves the lever 290 clockwise and conversely when the workpiece allows the spring 293 on the stud 292 to move the pad 315 etc. upwardly the lever 290 is moved counterclockwise. It will be seen that with an irregular workpiece the lever 290 is continually oscillating as the workpiece 12 revolves. Its extreme clockwise position represents the largest radius of the workpiece and its extreme counterclockwise position represents the smallest radius of the workpiece and the system is continually measuring the radius with which the pad 315 is momentarily in contact.

Referring still to Figures 3 and 4, the lower left hand side of the casing 250 is in the shape of a three sided box and snugly contains a block 230 held in position by screws 321. A slotted cap 325 is secured to the block by means of screws 326. In the block 320 is a bore receiving the coil casing 330 of a linear variable differential transformer which can be moved downwardly by means of a wedge 335, moved by a screw 336, and in engagement with the upper tapered end 337 of the coil casing 330, the screw 336 having a knob 340 which is connected to a dial 341 having numbers and lines readable by means of a lubber line, not shown, on the casing 250. A spring 345 is in engagement with the under side of the coil casing 330 and held in position by a plate 346 fastened to the block 320 by means of screws 347 so whenever the wedge 335 is retreated the core casing 330 will move upwardly. After the desired adjustment is found the coil casing 330 can be secured in position by means of a screw 350 having a knob 351, the screw 350 extending through a threaded bore in the block 320.

Movable within the coils in the casing 330 is a core

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355 held in position by rods 356 and 357 of material of low permeability, the core 355 being material of high magnetic permeability; the three parts, core 355 and rods 356 and 357 acting mechanically as one piece. The rod 356 is threaded at the top and screwed into a block 360 which is connected by a flat spring 361 to the left hand end of the actuating lever 290, there being caps 362 and 363 and screws 364 and 365 to hold the flat spring 361 to these parts. Thus the assembly of rods 356 and 357 with the core 355 between them is connected to the actuating lever 290 by a joint which eliminates side and all but a small amount of angular motion and eliminates all lost motion. For the same purpose the lower end of the rod 357 is threaded and is held in a flat spring 370 by means of nuts 371, the first spring 370 being bent over and secured by screws 373 to the block 320. A removable cover 375 is preferably provided on the casing 250 to enclose the lever arm 270, feeler arm 275, crossed springs 265 and block 264.

Referring now to Figure 5, the nut 133 has secured thereto a rod 380 which has a threaded end and a shoulder 381. This rod 380 is made of material of low permeability and is connected to a core 384 of material of high permeability which is connected to a rod 385 of material of low permeability which is slidably supported in a bushing 390 screw threaded on the outside and fitting in a coil casing 391 secured to the casing 134. The coil assembly 400 in the coil casing 391 is urged to the right by means of a spring 401 and the sleeve 390 is turned for adjustment of the assembly 400 and locked in position by mean of a nut 405.

Referring now to Figure 7, in the upper left hand corner is shown the core piece 384 of the linear variable differential transformer described in connection with Figure 5. Associated with the core piece 384 as assembly 400 are a primary coil 410 and two secondary coils 411 and 412. The coils 410, 411 and 412 are located in the casing 391 of Figure 5. Physically the three coils 410, 411 and 412 are in the form of solenoid windings coaxially oriented with respect to the core 384, primary coil 410 occupying a central position, the secondary coil 411 lying on one side of the primary 410, and secondary 412 lying on the other side of primary 410. The secondary coils 411 and 412 are differentially connected, that is if an excitation voltage is applied to primary coil 410 it induces by transformer action voltages in the secondary coils 411 and 412, the connection being such that the voltage appearing between terminals 415 and 416 of the secondary coil assembly is the difference between the voltages induced in the respective secondary coils. The coil structure is symmetrical about a plane passing through the center of the primary coil and normal to the axis of the core piece. When the core piece is centrally located with respect to this plane equal voltages are induced in secondaries 411 and 412 with the result that the net output voltage observed across terminals 415 and 416 is zero. Displacement of core piece 384 from this central position increases the electromagnetic coupling between primary 410 and the secondary winding toward which the motion of core piece 384 has been directed simultaneously decreasing the coupling between primary 410 and the other secondary coil. Thus the induced voltage in the secondary winding toward which the core piece 384 is displaced increases while that of the other secondary coil decreases resulting in a net output voltage across terminals 415 and 416 which varies linearly with displacement of the core 384 coaxially from its central position. As a practical matter if core piece 384 is moved too far the linear relationship of output voltage with respect to core position no longer holds. Linear variable differential transformers of the type described are available in which the linear range is as short as five thousandths of an inch of core motion and others are available in which the range of core motion may be as great as several inches. I find that a

transducer having a core with a linear range of about forty thousandths of an inch is highly satisfactory for the purposes of this invention when embodied in a grinder of the type described. In Figure 7 directly below core piece 384 is shown core piece 355, which was previously shown in Figure 3. Associated with core piece 355 is primary coil 420 and secondary coils 421 and 422 whose output terminals are 425 and 426.

In the bottom center of Figure 7 is an oscillator 430 which generates a voltage varying sinusoidally with time at a frequency which may be as low as the frequency of commercial power mains, i. e. 60 cycles per second, or may be in the supersonic frequency range, i. e. as high as 20,000 cycles per second. I prefer the higher frequencies and have used with good results a frequency of 15 kilocycles which is near the upper limit of sonic frequencies. The oscillator 430 is supplied with energy from a convenient power supply as is well understood by those skilled in the art and need not be shown herein. Shown at the left hand side of the oscillator are leads 432 and 433 establishing a series connection with the primary coils 410 and 420 of the linear variable differential transformers, whereby to provide the alternating current excitation required. The output voltage appearing across terminals 415 and 416 is amplified by an alternating current amplifier 435 whose output is connected by lines 436 and 437 to the signal input of a phase sensitive detector 440. Similarly the output voltage developed across terminals 425 and 426 is amplified by AC amplifier 445 and fed through lines 446 and 447 to phase sensitive detector 450. Lines 455 and 456 leading from oscillator 430 supply the phase reference voltage to phase sensitive detector 440 and lines 457 and 458 supply the phase reference voltage to phase sensitive detector 450.

Phase sensitive detectors, circuits well understood in the art, develop a direct current output voltage proportional to the in-phase component of an A. C. input voltage, where the phase reference voltage supplied to the phase sensitive detector provides as its name implies the necessary time reference for phase detection. Since the output voltage of a linear variable differential transformer is very nearly in phase with its excitation voltage, and since the excitation voltages for primaries 410 and 420 are in this case derived from the same oscillator 430 which supplies the phase reference voltage to the phase sensitive detectors, the output voltage of phase sensitive detector 440 is proportional to the total signal voltage developed across terminals 415—416. Another property of phase sensitive detector 440 is that the polarity of its direct current output voltage reverses when the phase of the signal voltage 415—416 reverses as occurs when core piece 384 passes through the neutral position.

Phase sensitive detectors are sometimes called demodulators, or phase sensitive demodulators, and usually incorporate in their circuitry non-linear elements such as rectifier diodes biased by the phase reference voltage, or triodes or multigrid vacuum tubes either biased by the phase reference voltage or provided with plate excitation from the phase reference voltage. The A. C. amplifiers 435 and 445 are also well understood in the art, and consist of elements so arranged that the output voltage of the amplifier is many times the input voltage and linearly proportional thereto.

Phase sensitive detector 450 has output terminals across which appears a direct current voltage proportional to the displacement of core piece 355 from its central or symmetrical position with respect to coils 420, 421 and 422. Referring to Figures 3 and 7, if the coil casing 330 is adjusted by means of knob 340 and locked by knob 351 in such a position that core piece 355 is located in the plane of symmetry when workpiece 12 is ground cylindrical and has a diameter corresponding to the desired final size of workpiece 12, then the voltage across the terminals is zero. The polarity of the secondary coils 421

and 422 is selected such that when workpiece 12 is larger in diameter than the desired size (core piece 355 being moved upward in Figure 3 thereby) the D. C. voltage output of phase sensitive detector 450 will be of positive polarity in a line 459 which is connected to the grid 460 of a triode vacuum tube 461 whose cathode 462 is connected to ground potential through a capacitor 463. Plate 464 of the triode is connected to a source of positive D. C. voltage 465. The other output terminal of phase sensitive detector 450 is grounded through a line 466. Cathode 462 of triode 461 is connected to ground through a resistor 470 and normally closed contact 472 in series. For this purpose the cathode 463 is connected to the resistor 470 by a line 473, the resistor 470 is connected to the contact 472 by a line 474 and the contact 472 is connected to ground by a line 475.

The triode 461 connected as described is a cathode follower amplifier circuit. When contact 472 is closed resistor 470, whose resistance is chosen several times larger than the plate resistance of triode 461, is the cathode lead resistor, and a voltage appears at the cathode end of resistor 470 very nearly equal to and varying linearly with the voltage above ground of the grid 460 of triode 461. The connection of line 459 of the phase sensitive detector output to grid 460 establishes a potential on grid 460 which is proportional to the amount by which the diameter of the workpiece 12 exceeds its final size. Therefore the potential of cathode 462 is likewise linearly proportional to the amount by which the workpiece diameter exceeds its final diameter. It is to be noted that when contact 472 is closed resistor 470 is paralleled by capacitor 463. The value of capacitor 463 is such that the product $R \times C$ (ohms times farads) which gives the time constant of the parallel resistance capacitance network is relatively small, e. g. one second.

When contact 472 is open, on the other hand, the shunting effect of resistor 470 is removed from capacitor 463 with the result that capacitor 463 charges to a voltage very nearly equal to the positive voltage applied to grid 460 from line 459 of the phase sensitive detector 450. Furthermore since the shunting effect of resistor 470 discharges capacitor 463, when this shunting effect is removed capacitor 463 remains charged to whatever voltage grid 460 rose even though grid 460 may subsequently drop to a lower value of voltage. Thus the potential across capacitor 463 represents the maximum displacement of core 355 and hence represents the maximum value of radius of the workpiece 12 as detected by feeler arm 275.

Phase sensitive detector 440 is connected by lines 476 and 477 respectively to the grid 479 of triode tube 480 and to the cathode 462. The phase polarity of input signal 415—416 to the A. C. amplifier 435 is chosen so that when the wheel slide is in its position of maximum retraction line 476 is negative with respect to line 477, the potential across lines 476 and 477 being zero when the wheel slide 11 is in a position corresponding to the desired final size of workpiece 12, this zero voltage point being adjusted by means of zeroing knob 390 of Figure 5 which effects relative axial movement of coil casing 400 with respect to core piece 384. Thus the potential of grid 479 in Figure 7 is equal to the algebraic sum of the potential across capacitor 463 plus the potential across lines 476 and 477. With the polarity chosen as described above, the grid 479 is of negative polarity with respect to ground so long as the voltage 476—477 is larger in magnitude than the voltage across capacitor 463. This condition prevails so long as the position of the wheel slide corresponds to a larger work radius than the work size radius governing the position of feeler arm 275 of Figure 3. On the other hand when the wheel slide position is equal relative to the radius of workpiece 12 to the position of feeler arm 275 then the net potential of grid 479 with respect to ground is essentially zero.

Triode 480 like triode 461 is connected in a cathode

follower circuit having a cathode load resistor 485, and plate 486 of cathode 480 is connected to the positive D. C. supply 465 by conductor 487 while the plate 464 of triode 461 is connected to the same positive D. C. source by conductor 488. Thus the potential of cathode 490 of triode 480 is essentially zero, that is to say triode 480 is in the non-conducting or cut-off state, so long as the position of the wheel slide corresponds to a larger radius about the axis of workpiece 12 than the actual radius of the highest point of workpiece 12. But as the wheel slide moves forward the negative potential across conductors 476 and 477 diminishes and just as the wheel face reaches a radius corresponding to the radius of the highest point of workpiece 12 the potential across lines 476 and 477 is just equal in magnitude but of opposite polarity to the potential across capacitor 463 resulting in a condition where a slight additional infeed movement of the wheel slide 11 results in grid 479 going positive. Conductors 495 and 496 connect the voltage developed across cathode load resistor 485 to a D. C. amplifier 500 which is connected to relay 501, by conductors 502 and 503, the internal circuitry of the D. C. amplifier 500 being such that relay 501 is deenergized when the polarity across lines 495—496 goes positive. Normally open contact 505 of relay 501 is connected by line 508 to one side of an A. C. supply. Lines 509 and 510, the latter connecting to the other side of said A. C. supply, conduct the output connections from contact 505.

Referring now to the top center of Figure 8, lines 509 and 510 energize relay R1 when normally open contact 505 of Figure 7 is closed. Normally open contact 515 of relay R1 is connected by line 516 to relay R2 the other side of relay R2 being connected by line 517 to AC power source L2. Contact 515 of relay R1 is connected by line 520 to normally open contact 522 of relay R3 and by line 525 to normally closed contact 526 of relay R4. The other side of normally open contact 522 is connected by line 528 to the other side L1 of the AC supply and by line 529 to normally open contact 532 of relay R3. The other side of contact 532 is connected by line 533 to normally open contact 535 of relay R4 and by line 537 to normally open contact 540 of relay R5. The other side of contact 540 is connected by line 542 to relay R4 the other side of which is connected by line 544 to L2. The other side of contact 535 of R4 is connected by line 546 to L1. The other side of contact 526 of R4 is connected by line 548 to normally open contact 550 of relay R5, the other side of contact 550 being connected by line 552 to L1. One side of the operating coil of relay R5 is connected by line 554 to L1 the other side being connected by line 556 to switch 558 which is series connected by line 560 through the operating coil of solenoid S1, which is the operating coil of slide valve 151 shown in Figure 6, the other side of the operating coil of S1 being connected by line 562 to L2. Normally open contact 563 of relay R2 is connected to power line L1 by line 564. The other side of contact 563 is connected by line 566 to the operating coil of solenoid S2, which is shown in Figure 6 as the actuating coil of valve 217, the other side of coil S2 being connected by line 568 to L2. Line 570 connects contact 563 to one side of the operating coil of relay R3 the other side of which is connected to L2 by line 572. Contact 472 of Figure 7 is shown as a normally closed contact of relay R2 in Figure 8.

At the start of a machine cycle the wheel slide is in its position of maximum retraction, that is piston 51 of Figure 6 is at the right hand end of its travel, the feed screw actuating rack piston 186 of Figure 6 is at the left in cylinder 187, solenoid S1 is deenergized, solenoid S2 is deenergized, switch 558 of Figure 8 is open and normally closed contact 472 of Figure 7 is closed. The operator inserts a rough workpiece 12 between centers and in so doing depresses feeler arm 275 against the compressive force of spring 293 of Figure 3, and when he starts the

work rotation feeler arm 275 contacting workpiece 12 through button 315 assumes a position which is instantaneously dependent upon the particular portion of the surface of workpiece 12 being contacted. Thus in Figure 7 a varying direct current voltage appears across capacitor 463 which is shunted by resistor 470. However, the negative potential of line 476 relative to line 477 is larger than the potential across capacitor 463 because the wheel slide at this time is in its position of maximum retraction. Consequently the potential across lines 495—496 is zero and the D. C. amplifier 505 maintains relay 501 energized thus holding contact 505 closed, and therefore relay R1 is energized and contact 515 is closed.

To initiate the grinding cycle the operator closes switch 558, energizing relay R5 and solenoid S1. Relay R5 energized energizes relay R2 through contact 550, contact 526 of R4 and contact 515 of R1. Relay R2 energized opens contact 472, thereby permitting capacitor 463 to charge to the peak value of the varying D. C. voltage impressed upon it which peak value is proportional to the radius of the highest point of workpiece 12. Relay R2 closed also energizes through contact 563, solenoid S2 and relay R3. Relay R3 energized closes contact 522 establishing a holding circuit for relay R2 independent of relay R4. It also closes contact 532 which energizes relay R4 through contact 540 of relay R5. R4 closed establishes a holding circuit for itself through contact 535 and contact 540 of relay R5.

Solenoid S1 energized moves slide valve spool 151 to the left thereby directing pressure to the right side of piston 51 initiating a fast infeed cycle and also directing pressure to backlash takeup shuttle 230 and through valve 192 to the left hand end of piston 186 in cylinder 187 initiating the feed screw infeed motion. Solenoid S2 energized moves slide valve spool 217 to the right thereby permitting rapid exhaust of fluid from the right hand end of cylinder 187 through line 215 and valve 222 to sump. Valve 222 is adjusted to the desired rapid feed rate of rack piston 186. As rack piston 186 of Figure 6 moves to the right the core 384 of Figure 5 moves toward the position of electrical balance of the linear variable differential transformer of that figure. Thus the voltage appearing across terminals 476—477 decreases in magnitude. At the moment when the wheel slide rack piston 186 approaches or reaches the point corresponding to the largest radius of workpiece 12, the voltage across 476—477 becomes equal to the voltage across capacitor 463. A slight additional movement makes line 495 slightly positive and D. C. amplifier 500 deenergizes relay 501 opening contact 505. Contact 505 opened relay R1 drops out opening contact 515. Contact 515 opened deenergizes relay R2. Relay R2 deenergized opens contact 563 deenergizing solenoid S2 and relay R3. Solenoid S2 deenergized permits valve spool 217 of Figure 6 to move to the left cutting off the exhaust path for fluid from the right hand end of cylinder 187 via valve 222 whereupon valve 211 assumes control of the subsequent feed rate.

R3 deenergized opens contact 522 opening the circuit through contact 515 to the operating coil of relay R2. R4 remains energized with contact 526 open through its holding circuit established through contact 540 of relay R5. The cooperative action of relays R3 and R4 in establishing and breaking holding circuits for relay R2 is introduced to eliminate flutter of solenoid S2 which might occur from contact bounce or chatter in relay 501.

During the time that this action has been taken place piston 51 in cylinder 52 has reached the limit of its travel and the wheel face is just in contact with the high point of workpiece 12. Grinding proceeds normally with the infeed rate being controlled by valve 211. Grinding is stopped by the usual setting of a stop for the rotation of the hand wheel 101, not shown herein but well known to the art. At the end of the grinding cycle the operator opens the switch 558 which causes the wheel slide to retract by hydraulic actuation on account of the deenergiza-

tion of solenoid S1 which operates the plunger valve 151 of Figure 6. However the timer mechanism of the above mentioned patent will in actual practice be used to open and close the contact 558 but as that is fully described in this patent I will not extend the description hereof to include what is described in the patent. The other hydraulic mechanism is reset in consequence of the deenergization of solenoid S1 as will be readily apparent from the foregoing description. Deenergization of relay R5 opens the holding circuit for relay R4.

The capacitor 463 discharges very slowly through the cathode-ground leakage path, and so in effect the circuitry continually remembers the highest point of the workpiece 12. Closing of the contact 472 upon deenergization of R2, however, quickly drains off excess charge from capacitor 463, the cathode 462 then follows the potential of grid 460, in effect, wiping out the memory in preparation for a new cycle.

The direct current voltages developed across conductors 476—477 and conductors 459—466 are each linearly proportional to the positions of the respective linear variable differential transformer core pieces 384 and 355. Accurate intercomparison of these voltages within their ranges to establish relative positioning of wheel and high point of work requires that the proportionality constant be the same in each of the two systems, that is in amplifier 435 and phase detector 440 as compared with amplifier 445 and phase detector 450. For this reason amplifiers 435 and 445 are preferably of a negative feedback stable design.

Since the output voltage of a cathode follower is not exactly zero for zero grid potential but may be slightly positive such as one or two volts positive, the zero output voltage point settings of the linear variable differential transformers are not chosen precisely as described above but rather these zeroing adjustments are made in such a way that relay 501 is actually deenergized when feeler arm 275 and wheel slide 11 are in corresponding positions. Typically this may require an actual zero offset equivalent to one or two thousandths of an inch core displacement in the wheel slide transformer but this in no way affects the principle of operation of the system.

In order to obtain maximum stability and linearity from the phase sensitive detectors 440 and 450 it is desirable to operate them with a relatively high reference voltage magnitude, for example of the order of 100 volts R. M. S. or more, which implies that for economical design they be relatively high impedance devices, for example the output impedance of a typical phase sensitive detector employed in this service may be of the order of several megohms. This high output impedance makes it desirable to use a memory circuit having a high input impedance and low output impedance in order to obtain a very short charging time constant combined with a very long discharging time constant, and for this reason the cathode follower circuit was chosen. The differential voltage between the wheel slide signal voltage and the memory signal voltage is detected by a second cathode follower stage again to maintain a high input impedance and to achieve drift-free operation. The D. C. amplifier 500 operates at fairly high signal levels, that is of the order of a few volts signal for one or two thousandths of an inch positional difference and consequently offers no particular drift problem. Its bias is chosen to obtain a desirable operating point for relay 501.

Prior grinding machines have had compensating means to compensate the cross feed for truing of the grinding wheel. In Figure 1 the vertical shaft 600 is connected to a truing diamond, not shown, in a way known in the art and having many variations, so that movement of the diamond toward the grinding wheel for removing material from the latter responsive to transverse movement of the diamond across the periphery of the wheel is accompanied by an increment of rotation of the shaft 600. On the shaft 600 is a worm, not shown, meshing with a worm

wheel 601 integral with the nut 36. In this manner, known per se, the mechanism of the present invention will bring the grinding wheel 605 mounted on its spindle 606 into contact with the workpiece 12 and at that exact moment will cause the slow down of infeed which is the subject matter of the present invention, all regardless of how many times the grinding wheel has been trued.

The mechanism in casing 216 and associated electrical apparatus is a control to cause the feeding mechanism to advance the grinding wheel at a relatively rapid rate and to slow down to a slow infeed rate; it is also a feeding slow down control. The mechanism for moving the slide 11 is an infeed mechanism, wheel feeding mechanism and a reversible wheel feeding mechanism. The feeler 275 and associated apparatus is a workpiece radius measuring device. The stored voltage on capacitor 463 is wiped out after the initiation of the change of rate of motion. It will readily be seen that the machine has automatic resetting means to reset the various mechanisms and apparatus.

As the feeler pad 315 is maintained in contact with the surface of the workpiece it can be said to respond to the instantaneous radius of a workpiece at a given locus. The electrical apparatus establishes the response responsive to the greatest radius of the workpiece. The linear variable differential transformer which includes the core 384 and associated electrical apparatus is responsive to the movement of the infeed apparatus. It records the progress of the infeed electrically.

The linear variable differential transformers are four terminal displacement responsive electrical impedance means. Other electrical measuring apparatus could be substituted. These differential transformers are not necessarily linear although it is easier to make them that way and there is no good reason that I know of for having them otherwise. In any event they will only be approximately linear.

It is clear that the electrical apparatus has an input derived from measurements of a workpiece and it also has an output voltage. It has provision for keeping the output voltage substantially at the maximum as determined by the maximum measurement of the workpiece. The electrical apparatus associated with the infeed has an input derived from movement of this machine element and delivers an output therefrom. The control apparatus embodied in the tubes 461 and 480 and connections is responsive to the difference of the output voltages, this difference being frequently zero when the final signal to the amplifier 500 causes relay 501 to go dead thus energizing the relay R1. These voltages are reset, as described, for a new cycle of machine operation.

The linear variable differential transformers can be defined as displacement responsive electrical devices. The cathodes in the tubes 461 and 480 are responsive to the displacements of the displacement responsive electrical devices and respond in the same direction. The voltages can be designated as signals and the tubes 461 and 480 are constructed to give an output when and only when the signals have a predetermined relative value.

It will thus be seen that there has been provided by this invention an infeed control in accordance with which the various objects hereinabove set forth together with many practical advantages are successfully achieved. As many possible embodiments may be made of the above invention and as many changes might be made in the embodiment above set forth, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. In a grinding machine, a reversible grinding wheel feeding mechanism, a control to cause said feeding mechanism to advance the grinding wheel at a relatively rapid

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rate and to slow down to a slow infeed rate, reversing mechanism to cause said feeding mechanism to advance the wheel at a rate determined by said control and to reset the feeding mechanism for a subsequent grinding operation, a workpiece contacting feeler, electrical means controlled by said feeler having a circuit to make an electrical measurement of the high point of the workpiece, electrical means controlled by the feeding mechanism to make an electrical measurement of the position of the feeding mechanism, electrical means to compare said measurements, and electrical relay mechanism to actuate the control to slow down the feeding mechanism to the slow infeed rate when the measurements have a predetermined relation to each other.

2. In a grinding machine as claimed in claim 1, the combination with the parts and features therein specified, of electric resetting mechanism to wipe out the measurements to condition the machine for a subsequent grinding operation.

3. In a grinding machine, a reversible grinding wheel feeding mechanism, a workpiece contacting feeler, a first linear variable differential transformer having its movable element connected for operation by said feeler, a second linear variable differential transformer having its movable element connected for operation by said feeding mechanism, a feeding slow down control, a first electrical mechanism connected to said first transformer to establish a voltage resultant to the position of the element of the first transformer, a second electrical mechanism connected to said second transformer to establish a voltage resultant to the position of the element of the second transformer, electrical means to compare said voltages, and electrical means set in operation when said voltages are at a certain relative value to operate said slow down control.

4. In a grinding machine, a slide moving mechanism, means controlling said slide moving mechanism to change the rate of motion of the slide, a workpiece radius measuring device, a first variable differential transformer having a coil assembly and a core one of which is connected to said slide moving mechanism to be moved by it, a second variable differential transformer having a coil assembly and a core one of which is connected to said radius measuring device to be moved by it, a pair of A. C. amplifiers each connected to the output of one of the variable differential transformers, a pair of phase sensitive detectors each connected to the output of one of the amplifiers, a pair of voltage establishing devices each connected to the output of one of the phase sensitive detectors, said voltage establishing devices being connected together to compare the voltages, and electric apparatus connected to said devices and to the means controlling the slide moving mechanism to initiate change of the rate of motion of the slide when the voltages reach a predetermined relative value.

5. In a grinding machine as claimed in claim 4, the combination with the parts and features therein specified, of means for wiping out the voltages established to prepare the machine for a new cycle of operation.

6. In a grinding machine, an infeed apparatus, a control for said infeed apparatus to cause it to slow down, a workpiece engaging feeler, mechanism associated with said feeler to register the high point of the workpiece, mechanism recording the progress of said infeed, and a connection between said mechanisms also connected to said control to actuate said control to slow down said infeed apparatus when said mechanisms give measurements of the high point of the workpiece and the position of the infeed having a predetermined relation to each other.

7. In a grinding machine as claimed in claim 6, the combination with the parts and features therein specified, of automatic resetting means to reset each of said mechanisms.

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8. In a machine tool, a movable infeed apparatus, a control for said infeed apparatus to cause it to slow down, a workpiece measuring device which responds to the instantaneous radius of a workpiece at a given locus, electrical means responsive to the response of said device, electrical means to establish the response responsive to the greatest radius of said workpiece, electrical means responsive to the movement of the infeed apparatus, and electrical means to actuate said control when the two electrical means responsive are at a predetermined value to each other.

9. In a machine tool, a movable infeed apparatus, a control for said infeed apparatus to cause it to slow down, a workpiece engaging feeler, electrical means responsive to the movements of said feeler, electrical means responsive to the response of said device, electrical means to establish the response responsive to the greatest radius of said workpiece, electrical means responsive to the movement of the infeed apparatus, and electrical means to actuate said control when the two electrical means responsive are at a predetermined value to each other.

10. In a machine tool, a movable infeed apparatus, a control for said infeed apparatus to cause it to slow down, a workpiece measuring device which responds to the instantaneous radius of a workpiece at a given locus, mechanism responsive to the response of said device to register the high point of the workpiece, mechanism recording the progress of said infeed, and a connection between said mechanisms also connected to said control to actuate said control to slow down said infeed apparatus when said mechanisms give measurements of the high point of the workpiece and the position of the infeed having a predetermined relation to each other.

11. In a machine tool, a reversible cutting tool feeding mechanism, a control to cause said feeding mechanism to advance the cutting tool at a relatively rapid rate and to slow down to a slow infeed rate, reversing mechanism to cause said feeding mechanism to advance the tool at a rate determined by said control and to reset the feeding mechanism for a subsequent machining operation, a workpiece engaging feeler, a four terminal displacement responsive electrical impedance means controlled by said feeler having a circuit to make an electrical measurement of the high point of the workpiece, a four terminal displacement responsive electrical impedance means controlled by the feeding mechanism to make an electrical measurement of the position of the feeding mechanism, electrical means to compare said measurements, and electrical relay mechanism to actuate the control to slow down the feeding mechanism to the slow infeed rate when the measurements have a predetermined relation to each other.

12. In a machine tool, a pair of transformers each having as relatively movable elements coils and a core, a workpiece measuring device operatively connected to one element of one transformer, a slide feeding mechanism operatively connected to one element of the other transformer, a pair of electrical means each connected to one transformer constructed to transmit a signal from it, and electrical means connected to receive said signals and constructed to give an output when and only when said signals have a predetermined relative value.

13. In a machine tool, a pair of electrical apparatus each having relatively movable elements the relative positions of which vary the outputs from said apparatus, a workpiece measuring device operatively connected to one element of one apparatus, a slide feeding mechanism operatively connected to one element of the other apparatus, a pair of amplifying apparatus each connected to receive the output from one apparatus and each constructed to give an output signal therefrom, electrical means connected to receive said signals and constructed

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to give an output when and only when said signals have 2,448,921
a predetermined relative value. 2,572,529

References Cited in the file of this patent

UNITED STATES PATENTS 5 523,199

1,992,027 Green Feb. 19, 1935

16

Silven Sept. 7, 1948
Silven Oct. 23, 1951

FOREIGN PATENTS

Great Britain July 9, 1940