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R. G. HATSTAT ETAL

3,019,565

GRINDING MACHINE

Original Filed Aug. 31, 1955

3 Sheets-Sheet 1

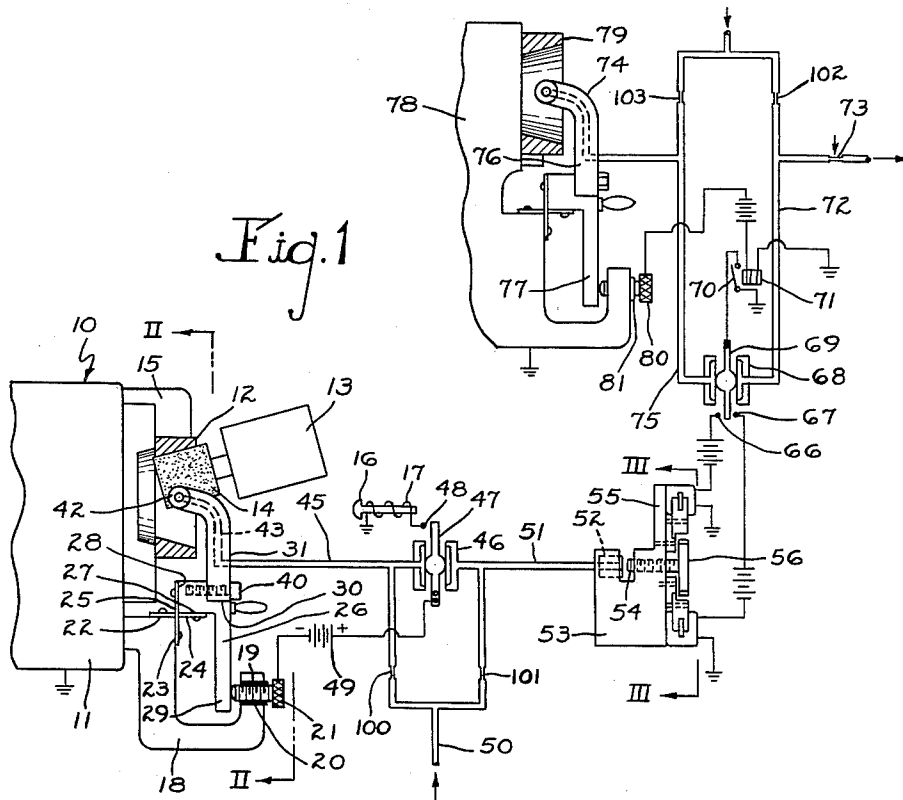


Fig. 1

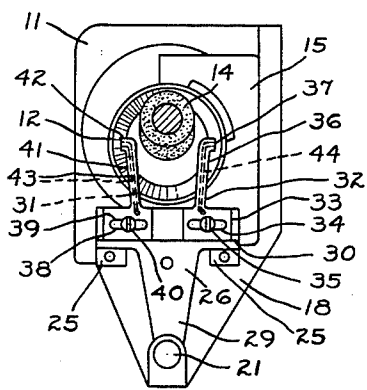


Fig. 2

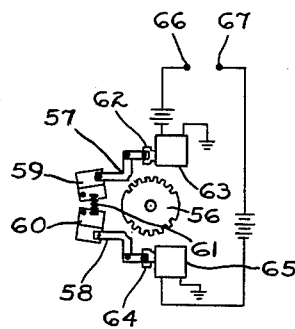


Fig. 3

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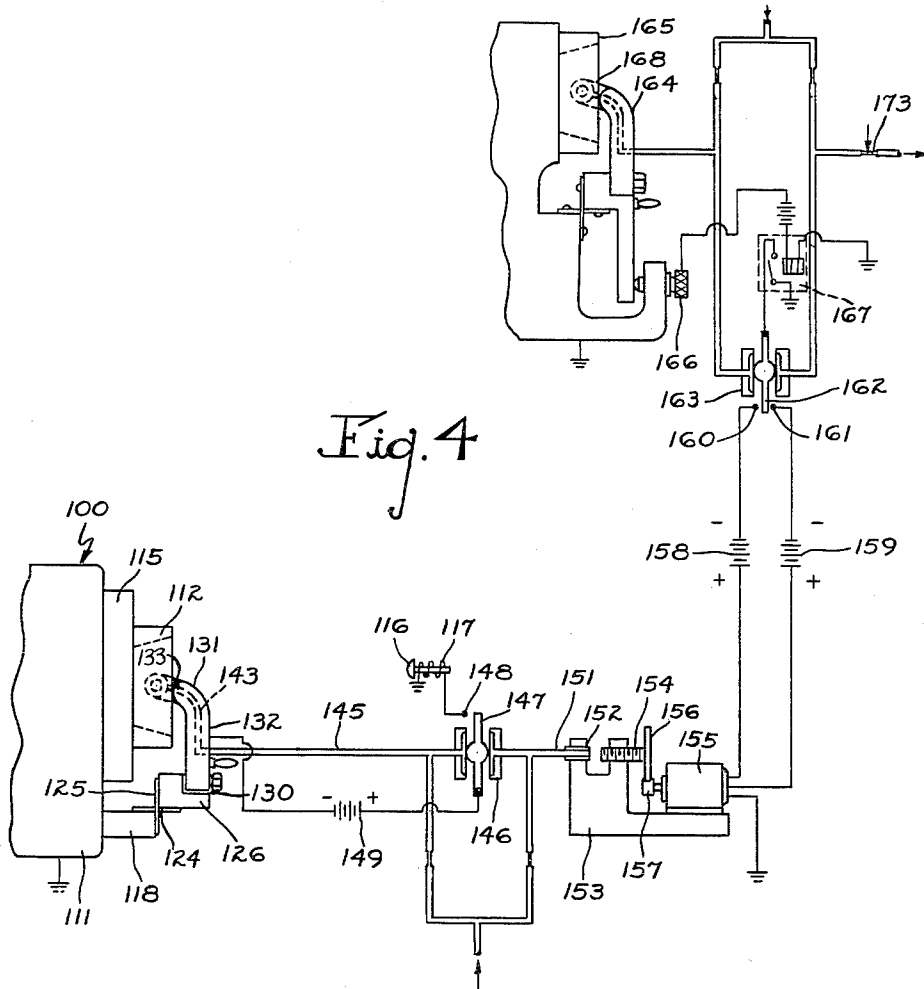
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3 Sheets-Sheet 2



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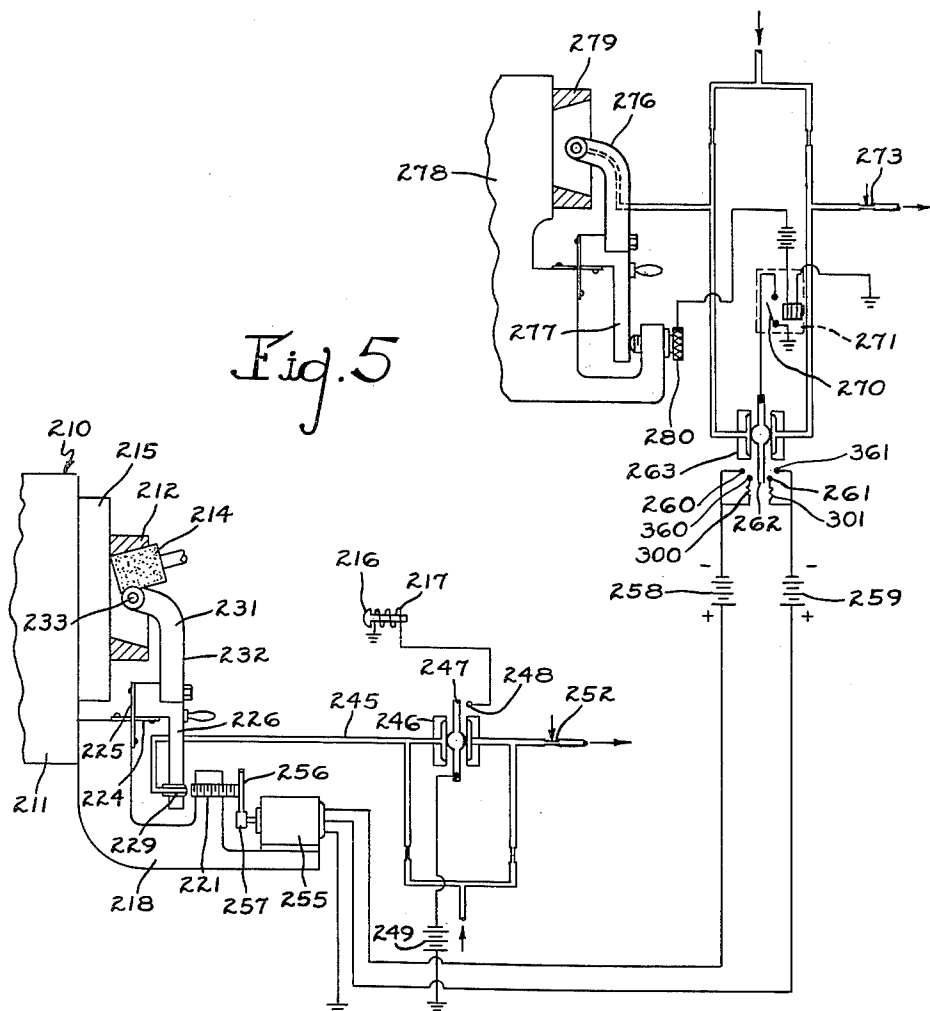
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GRINDING MACHINE

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3 Sheets-Sheet 3



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3,019,565

GRINDING MACHINE

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Continuation of application Ser. No. 531,659, Aug. 31, 1955. This application Sept. 4, 1959, Ser. No. 838,358 22 Claims. (Cl. 51-165)

This invention relates to a grinding machine and more particularly to apparatus for performing machining operations by an abrading process. This application is a continuation of patent application Serial Number 531,659, filed August 31, 1955, now abandoned.

In a grinding of surfaces of revolution, there are a number of factors which limit the degree of accuracy which it is possible to obtain. For instance, in the internal grinding of tapered bores, it is advantageous to be able to gauge the bore while the abrasive wheel is reciprocating; furthermore, it is desirable to hold the workpiece so that the large end of the tapered bore faces the wheel. When gauging tapered bores with conventional feelers or the like, it is difficult to maintain the location of the gauging point or contactor relative to one of the ends of the workpiece, since a small difference in diameter produces a large inaccuracy in axial placement. It can be seen, also, that the location of the gauge relative to the axis of the bore is extremely important, but such accurate location is difficult to maintain, particularly when the gauging feeler is of the cantilever type. These and other difficulties experienced with the prior art apparatus have been obviated by the present invention in a novel manner.

It is, therefore, an outstanding object of the present invention to provide a grinding machine, including a gauging means of extreme accuracy.

Another object of this invention is the provision of a grinding machine particularly adapted to finish tapered bores with a high degree of accuracy.

It is a still further object of the invention to provide a grinding machine including a gauging means which will control bore diameter despite variation of the position of the gauging feeler relative to the axis of the bore.

Another object of the instant invention is the provision of a grinding machine having a gauging means which controls the grinding cycle and which is in turn controlled by another gauging means operating on the workpiece after the grinding cycle is finished and at a position unaffected by thermal changes.

A further object of the invention is the provision of a grinding machine having an improved gauging apparatus to control the grinding of an internal conical surface.

Another object of the invention is the provision of an internal grinding machine which includes gauging means measuring the distance from an end face of a workpiece having a tapered bore to a predetermined internal diameter thereof.

Although the novel features which are believed to be characteristic of this invention will be particularly pointed out in the claims appended hereto, the invention itself, as to its objects and advantages, the mode of its operation and the manner of its organization may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof, in which:

FIG. 1 is a partially schematic view of apparatus constructed according to the present invention,

FIG. 2 is view of a portion of the apparatus shown in FIG. 1 taken on the line II-II thereof,

FIG. 3 is a view of a portion of the apparatus shown in FIG. 1 taken on the line III-III thereof,

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FIG. 4 is a partially schematic view of another embodiment of the invention, and

FIG. 5 is a partially schematic view of still another embodiment of the invention.

Referring first to FIG. 1, wherein is best shown the general features of the invention, the grinding machine, indicated generally by the reference numeral 10, is shown as one of the internal grinding type and as comprising a workhead 11, supporting a workpiece 12, and a wheelhead 13 on which is mounted an abrasive wheel 14. The workpiece 12 is held in a chucking means 15, which in the present case is shown as being of the magnetic type, and is rotated about its geometric axis in the usual manner. The machine is provided with apparatus, not shown, for rotating the wheel about its axis and for reciprocating it longitudinally during the abrading operation, the axis of the wheel residing at an acute angle to the axis of the workpiece to produce a tapered bore. A solenoid 16 having a coil 17 is arranged upon energization of the coil to cause the wheel to withdraw from the workpiece after the workpiece has been ground to the desired diameter; the apparatus and the manner in which this is accomplished is shown in detail in the patent of William D. Schmidt et al., No. 2,771,714, dated November 27, 1956.

An extension member 18 is fixed to the workhead 11 and has a free end which extends toward the workpiece. A horizontal bore 19 extends through this free end of the extension member and is fitted with an insulating sleeve 20 which is internally threaded to receive a stop screw 21 having a knurled head. The portion of the extension member adjacent the wheelhead is provided with a longitudinal surface 22 and radial surfaces 23. A thin reed 24 of spring steel is fastened at one end to the surface 22 and extends to the right, while a pair of similar reeds 25 are fastened at one end to the surface 23 and extend upwardly toward the workpiece. The other ends of the reeds are fastened to and are the sole support for a gauge mount 26. The mount is provided at its upper end with a longitudinal surface 27 and a radial surface 28 to which the reeds 24 and 25 are, respectively, attached. The mount has a finger portion 29 which extends downwardly and has a free end which normally makes contact with the stop screw 21. The portion of the mount 26 adjacent the workpiece is provided with a transverse recess 30 defined by a longitudinal and a radial surface. In this recess is mounted a work gauge means including gauge fingers 31 and 32, as is particularly well shown in FIG. 2. Finger 32 has a broad base 33 which lies in the recess 30; a slot 34 is formed in the base and a cap screw 35 extends therethrough into the mount 26. A thin stem 36 extends radially from the base 33 and extends at right angle at its free end to provide a nose 37 which is adapted to lie closely adjacent to the surface of the workpiece which is being ground. In a similar manner, the finger 31 has a base 38 with a slot 39 held to the mount 26 by a cap screw 40; a stem 41 extends upwardly from the base and extends radially in the direction opposite to that in which the stem of the finger 32 extends, thus forming a nose 42 which is adapted to lie closely adjacent the surface of the workpiece diametrically opposite the finger 32. Entering the extreme end of the nose 42 and extending through the body of the finger 31 is a small passage 43; a similar passage 44 is formed within the finger 32.

The passages 43 and 44 are connected by a conduit 45 to some form of air-gauge means. For example, they may be connected to one side of an opposed-diaphragm switch 46 having a movable arm 47 which is pivoted at one end and is adapted to touch a contact 48 at one condition of unbalance of the diaphragm pressures. The contact 48 is connected to one end of the coil 17 of the solenoid 16, the other end of the coil being connected to

ground. The pivoted end of the movable arm 47 is connected to one side of a source 49 of electrical power, which is shown as a battery, the other side of the source being connected to the screw 21 which is grounded by the gauge mount 26, when in contact therewith, through the reeds 24 and 25, the extension member 18 and the workhead 11. A source of pneumatic pressure, not shown, is connected through a conduit 50 through orifices 100 and 101 to the two diaphragms of the switch 46. The diaphragm which opposes the one connected to the gauge fingers is also connected through a conduit 51 to a nozzle 52 mounted in an upstanding abutment of a block 53. A regulating screw 54 is threadedly mounted in another abutment 55 of the block and is axially aligned with the nozzle. The screw extends through the abutment and has a toothed ratchet 56 mounted on the end opposite to the end associated with the nozzles. Referring particularly to FIG. 3, a pawl 57 is mounted to engage the ratchet 56 and drive it in one direction and a pawl 58 is mounted to drive it in the other direction. The pawl 57 is pivotally connected to a block 59 while the pawl 58 is similarly mounted on a block 60; the blocks 59 and 60 are, in turn, pivotally mounted on the block 53 and are resiliently biased away from one another by a spring 61. The end of the pawl 57 opposite the end which is pivoted to the block 59 is connected through a pivoted link to the end of the plunger 62 of a solenoid 63; in a similar manner, the pawl 58 is connected to the plunger 64 of a solenoid 65. One end of each of the coils of the solenoids 63 and 65 is grounded, while the other end is connected to one of the contacts 66 and 67 associated with a double-opposed diaphragm switch 68. The switch 68 has a movable arm 69 located between the opposed diaphragms, one end lying between the contactors 66 and 67 and the other end being pivotally mounted. The movable arm 69 is connected to ground through a normally-open switch 70 of a time delay relay 71. The relay is of the well-known type wherein an initiating current starts the time delay and, after the time has passed, the switch 70 is closed; upon the deenergization of the initiating circuit, however, the switch immediately opens. One of the diaphragms of the switch 68 is connected through an orifice 102 to a source of air under pressure, not shown, by means of a conduit 72; a fixed orifice 73 provides for a predetermined constant escape of air from the conduit 72. The other diaphragm of the switch 68 is also connected through an orifice 103 to the source of pressure air and also to an after-gauge means including a gauge 74 by means of a conduit 75. The gauge 74 is similar to that described above and includes two gauging fingers, such as the finger 76, supported on a mount 77 which, in turn, is supported by flexible reeds on an extension of an after-gauging apparatus 78 which is adapted to hold a workpiece 79 after it has been ground in the apparatus associated with the wheelhead 11. The lower part of the mount 77 lies adjacent to an adjustable contacting screw 80 which is mounted in an insulating sleeve 81. The screw 80 is electrically grounded when in contact with part 77 and connected through a source of electrical energy to one side of the actuating coil of the time delay relay 71, the other side of the coil being grounded.

The operation of the apparatus of the invention will now be clearly understood in view of the above description. The workpiece 12 is placed in the chucking means 15, preferably automatically by means not shown, and it is rotated about its geometric axis. The wheel 12 is rotated by the wheelhead 13 and is reciprocated longitudinally by the usual means forming part of the machine. As the wheel rotates and reciprocates, it is also moved transversely into the work. The surface of the workpiece is abraded and material removed. When the surface of the workpiece has been ground to a desired extent, it is desirable to remove the wheel from the workpiece to conclude the operation. For this reason, the gauge fingers reside adjacent the surface being ground; in the present

case, the surface being so finished is frusto-conical, with the larger end facing the wheelhead. The noses 37 and 42 of the gauge fingers are pointed away from each other and reside substantially diametrically opposite portions of the surface. Air under pressure is introduced through the conduit 50 and the orifice 100, the pressure making itself felt in the left-hand diaphragm of the switch 46; the circuit serving that diaphragm also supplies air to the conduit 45 which passes into the passages 43 and 44 in the gauge fingers and escapes through the opening of the passages on the noses 42 and 37, respectively. Actually, the orifice that determines the amount of air leaving the finger is not the cross-sectional area of the passage, but the size of the gap between each nose and the surface of the workpiece. Before the grinding cycle begins the diameter of the conical surface at the portion thereof served by the fingers is only slightly greater than the distance between the ends of the noses. The operator of the machine has been able to set the fingers through the medium of the cap screws 35 and 40 in conjunction with the slots 34 and 39, respectively. At the beginning of the grinding cycle, the noses are closely adjacent to the surface of the workpiece and little air is permitted to escape; this causes the air in the pneumatic circuit connected to the left-hand diaphragm to be high, thus tending to maintain the movable member 47 of the switch 46 in a position well removed from the contact 48. As the grinding operation enlarges the bore, the space between each nose and the surface is enlarged also, thus allowing more air to escape, the pressure in the left-hand diaphragm to be reduced, and the movable member to move toward the contact 48. Eventually the bore reaches a predetermined size and the movable member strikes the contact 48; electrical current from the source 49 passes through the coil 17 and actuates the solenoid 16. The wheel is withdrawn from the workpiece, the gauge fingers 31 and 32 are swung out of the way by flexing the reeds 24 and 25, and the workpiece is removed from the chucking means 15 to be replaced by another, unfinished workpiece. The workpiece just finished moves on to the after-gauging apparatus 78.

The workpiece is placed in a chuck on the after-gauging apparatus where it is examined by the gauge fingers 76. The amount of air escaping between the fingers and the surface of the workpiece makes itself felt in the left-hand diaphragm of the switch 68. A pressure determined by the size of the fixed orifice 73 makes itself felt in the right-hand diaphragm of the switch. When the diameter of the workpiece is correct and lies within a narrow band of sizes, the air escaping between the fingers and the surface of the workpiece is just the right amount to result in a pressure in the left-hand diaphragm just sufficient to balance that in the right-hand diaphragm, as determined by the orifice 73. The movable member 69 of the switch is then located between the contacts 66 and 67. If the diameter of the workpiece is larger than desirable, a large amount of air escapes, thus lowering the pressure in the left-hand diaphragm and permitting the movable member to move to the left. Eventually the movable member strikes the contacts 66 and, if the normally-open switch 70 is closed, electrical current passes through the coil of the solenoid 63.

In order for the switch 70 to close, however, a number of events must take place. First, the finished workpiece must be moved into place for the after-gauging operation. The fingers are then moved into place within the bore; when the lower part of the amount 77 strikes the adjusting screw 80, thus determining the axial position of the fingers within the bore. The contacting of the mount with the adjusting screw gives a path for electrical current from a source of electrical energy through the contacting screw 80, the mount 77 and the after-gauging apparatus 78 to ground; the current also passes from the other side of the battery through the initiating circuit of the time delay relay 71 to ground. At the end of the

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time delay period, which allows the workpiece in the after gauge to cool, the switch 70 closes, permitting current to pass through the coil of the solenoid 63. This time delay also permits the pneumatic system to stabilize.

The energization of the coil of the solenoid 63 draws the plunger 62 to a position within the solenoid. This movement causes the pawl 57 to move to the right, as is evident in FIG. 3, and the tooth of the pawl engages the ratchet 56 causing it to rotate. The rotation of the ratchet causes a similar rotation of the regulating screw 54; since the screw has a right-hand thread, it advances toward the nozzle and makes it more difficult for pressure air to escape. This increases the pressure in the right-hand diaphragm of the switch 46, so that the gap between the gauging fingers 31 and 32 and the surface of the workpiece will not have to increase by as great an amount before the movable member 47 strikes the contact 48 and the grinding cycle is ended by the solenoid 17. Thus, the succeeding workpieces will have smaller bores, which was the adjustment determined to be necessary by the after-gauging apparatus.

In a similar manner, if the workpiece is too small in diameter, the pressure in the left-hand diaphragm is greater than is necessary to exactly balance the right-hand diaphragm. Thus, the left-hand diaphragm overrides the right-hand diaphragm, thus moving the movable member 69 to the right to touch the contact 67. If the relay 71 has timed out and the switch 70 is closed, the solenoid 65 will be energized. This moves the pawl 58 to actuate the ratchet and rotate the adjusting screw in such a direction as to move the screw away from the nozzle 52. Thus, the air can escape more easily and the pressure in the right-hand diaphragm of the switch 46 decreases. This means that the pressure in the left-hand diaphragm necessary to cause the movable member 47 to move to contact the contact 48 is decreased. That is to say, the gap necessary between the gauging fingers and the surface of the workpiece is greater to stop the grinding cycle. The succeeding workpieces will, therefore, have larger bores.

It should be noted that the timing period selected for the time delay relay 71 is such that fluctuations occasioned by the change of position of the gauging fingers from the open air to within the bore will be adequately damped before the switch 70 is closed and the switch 63 is operative to produce corrective changes in the main gauging apparatus.

It is of interest to note that the gauging in the above-described embodiment is such that the gauging fingers 31 and 32 measure the diameter of the frusto-conical bore at a pre-selected distance from the end of the workpiece that lies against the workhead 11. This is because the axial position of the fingers within the bore is determined by contact between the lower end of the finger portion 29 of the mount 26 and the stop screw 21; the stop screw is fixed to the workhead through the extension member 18. The position of the fingers will always be located relative to the workhead and, therefore, to the end of the workpiece against the workhead.

In FIG. 4 is shown another embodiment of the invention. The grinding machine 100 comprises a workhead 111 having a chucking means 115 holding a workpiece 112 having a frusto-conical bore. The workhead has an extension member 118 to which are connected a vertical reed 125 and a horizontal reed 124; the other ends of the reeds are connected to and serve as the sole support for a mounting member 126. Gauging fingers 131 and 132 are adjustably bolted to the mounting member in the way that has been described in connection with the preceding embodiment. An insulating member 130 is inserted between the mounting member and the gauging fingers. The finger 131 is similar to those previously described and is provided with a passage 143 opening on a transversely-extending nose. The finger 131 is provided with a transversely-extending shoulder 133 which

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is adapted to engage the outwardly-facing end of the workpiece 112. The shoulder is formed with a pronounced radius, so that the contact with the workpiece is substantially line-contact. It will be understood, then, that the opening of the passage 143 on the nose of the finger is at a fixed distance from the shoulder, so that the opening is always at a fixed distance from the outer face of the workpiece. The passage 143 is connected by a conduit 145 to a left-hand diaphragm of a switch 146 having a pivoted movable member 147 and a contact 148. The contact 148 is electrically connected to the coil 117 of a solenoid 116; this solenoid, when actuated, terminates the grinding cycle in the usual manner. The right-hand diaphragm of the switch 146 is connected through a conduit 151 to a nozzle 152 mounted on a base 153. Both diaphragms of the switch 146 are also connected to a source of air under pressure connected to them through suitable orifices. The movable member 147 is electrically connected through a source of electrical energy 149 to the finger 131.

An adjusting screw 154 passes through an abutment of the base 153 in a position axial of the nozzle 152; the end away from the nozzle has a gear 156 keyed thereto. A reversible motor 155 is mounted on the base and has a gear 157 mounted on its shaft. The motor is connected to ground, to one side of a source 158 of electrical energy, and to one side of another source 159; the other side of the source 158 is connected to a contact 160, while the other side of the source 159 is connected to a contact 161. The contacts lie between the pivoted movable member 162 of an opposed-diaphragm switch 163. The left-hand diaphragm is connected to an after-gauging finger 164 having a shoulder 168 which engages a finished workpiece 165. The finger 164 has a lower end which engages an insulated screw 166 which is connected to ground through the initiating circuit of a timer 167. The movable member 162 of the switch 163 is connected through the time-out switch of the relay. Both diaphragms of the switch 163 are connected to a source of air under pressure through orifices and the right-hand diaphragm is connected to the atmosphere through an adjustable resistance such as the orifice 173.

The operation of this embodiment of the invention is very similar to that of the first-described embodiment. The pressure on the left-hand diaphragm of the switch 146 is indicative of the space between the noses of the gauging fingers and the surface of the workpiece or, in other words, of the diameter of the bore at a predetermined distance from the larger end. As the bore is made larger, the pressure drops and the movable member 147 moves to the left until, at the desired finished size, it strikes the contact 148 and ends the grinding cycle. The pressure in the right-hand diaphragm is determined by the standardizing nozzle 152. If the after-gauging apparatus indicates that the workpieces are being finished to sizes outside of the preselected tolerance limits, it takes steps to correct this by changing the distance between the standardizing nozzle and the adjusting screw, thus changing the pressure in the right-hand diaphragm of the switch 146. For instance, if the workpiece is too large, the movable member 162 of the switch 163 swings to the left and strikes the contact 160. If the relay 167 has timed out, so that pressure fluctuations due to the introduction of the gauging fingers into the workpiece have stopped, the switch 163 connects the motor 155 to ground through the battery 158. This causes the motor to drive the adjusting screw 154 to bring it closer to the nozzle 152. This increases the pressure in the right-hand diaphragm of the switch 147 so that the pressure in the left-hand diaphragm needs to fall a lesser amount than before to end the grinding cycle. Later workpieces will, therefore, be finished with smaller bores than before the correction began. If the after-gauging apparatus indicates that the workpieces are coming through with bores that are too small, the motor 155 will be connected

to the battery 159 to turn the adjustment screw to move it away from the standardizing nozzle 152; this will cause the workpieces to be ground to larger sizes before the grinding cycle is ended by the solenoid 117. The correcting movement of the motor 155 will be ended after a short increment of change of the nozzle 152 and adjusting screw 154. A short time after energization of the initiating circuit of the timer 167, its normally-open switch will open, thus stopping the motor.

A third embodiment of the invention is shown in FIG. 5, wherein the grinding machine 210 is shown as comprising a wheelhead 211 having a chucking means 215 for holding a workpiece 212 for grinding by an abrading wheel 214. An extension member 218 is fixed to the workhead and has fastened thereto a vertical reed 225 and a horizontal reed 224. The reeds are connected at their other ends to a mount 226 and are the sole support thereof. A pair of opposed gauging fingers 231 and 232 are adjustably fastened to the mount, each finger having a rounded contact nose 233 for engaging the surface of the workpiece. The lower end of the mount 226 operates gauging apparatus which may be of any suitable type. For example, the mount 226 is provided with a nozzle 229 which lies adjacent to and axially aligned with a metering screw 221 mounted in an abutment of the extension member. The screw 221 has a gear 256 keyed to the end away from the nozzle and engaged by a gear 257 attached to a reversible motor 255 which is also mounted on the extension member 218. The nozzle 229 is connected by a flexible conduit 245 to the left-hand diaphragm of an opposed-diaphragm switch 246 which has a pivoted movable member 247 adapted to engage a contact 243 which is electrically connected to the coil 217 of a solenoid 216. The solenoid when energized acts to terminate the grinding cycle and remove the wheel 214 from the workpiece 212. The right-hand diaphragm of the switch 246 exhausts to the atmosphere through an adjustable orifice 252. The two diaphragms are connected to a source of air under pressure through suitable orifices in the usual way. The movable member 247 is connected to ground through a source 249 of electrical energy.

The reversing fields, not shown, of the motor 255 are connected through sources 258 and 259 to contacts 260 and 261, respectively, and also through resistances 300 and 301 to contacts 360 and 361. As many contacts and resistances as desired may be provided to make the response substantially equal to the error or a function of it. These contacts are swept by the movable member 262 of an opposed-diaphragm switch 263. The left-hand diaphragm is connected to an after-gauging apparatus 278 arranged to gauge a finished workpiece 279 by means of double gauging fingers 276. In most respects the after-gauging apparatus is similar to that used in the preferred embodiment of the invention shown in FIG. 1. A timer 271 has its initiating circuit connected to ground on one side and on the other side it is connected through a source of electrical energy to an insulated, adjustable contact screw 280 which is situated to be contacted by the lower end of the reed-supported mount 277 on which the fingers are adjustably bolted. A normally-open switch 270 of the timer 271 closes after the predetermined time delay and reopens in a preset time thereafter and serves to connect the movable member 262 of the switch 263 to ground. The right-hand diaphragm of the switch 263 exhausts to atmosphere through an adjustable orifice 273; both diaphragms are connected through suitable regulating valves to a source of pressure air.

The operation of this embodiment of the invention is very similar to that of the versions of the invention shown in FIGS. 1 and 4. During the grinding operation, the gauging fingers rest on diametrically-opposite surfaces of the surface being ground. As the work progresses, the fingers, which have their contact noses 233 set a fixed

distance apart, move further into the tapered bore of the workpiece. The lower end of the mount 226 moves away from the workhead 211, carrying the nozzle 229 closer to the screw 221. Since progressively less air is permitted to escape through the gap between the nozzle and the screw, the pressure in the left-hand diaphragm of the switch 246 increases, thus moving the movable member 247 to the right against the contact pressure in the right-hand diaphragm. Eventually, as the bore reaches the predetermined size, the solenoid 216 is energized and the grinding cycle is terminated. It is to be observed that the gauging of the tapered bore takes place in this instance by measuring the distance from the end of the workpiece that a given diameter occupies, the end of the workpiece in question being that which is closer to the workhead 211. The after-gauging apparatus 278 corrects for inaccuracies in the dimensions of finished workpieces by changing the setting of the screw 221. If the workpieces are coming through with the bore dimension progressively further from the nominal value, the after-gauging apparatus will actuate the reversible motor 255 to move the screw longitudinally toward or away from the workhead to correct the situation. For instance, if the workpiece has a bore which is too large, the pressure in the left-hand diaphragm of the switch 263 is low and the movable member 262 strikes the contact 360, or if the pressure is still lower the member 262 engages the contact 260. When a sufficient length of time has passed after the gauging fingers entered the workpiece the switch 270 in the timer 271 will be closed for a preset time and the motors 255 will be connected through the source 258 of electrical energy to ground. The motor will turn at low speed if through the contact 360 or at a higher speed if through the contact 260, and will rotate the screw 221 through the gears 257 and 256. The screw 221 will move closer to the workhead, so that the grinding cycle will be terminated when a given diameter is relatively further away from the inner end of the workpiece. The subsequent bores will, therefore, be smaller.

While certain novel features of the invention have been shown and described and are pointed out in the annexed claims, it will be understood that various omissions, substitutions and changes in the forms and details of the device illustrated and its operation may be made by those skilled in the art without departing from the spirit of the invention.

The invention having been thus described, what is claimed as new and desired to secure by Letters Patent is:

1. A grinding machine comprising a work support, a tool support, an abrading tool on the said tool support, means for applying said tool to a workpiece in said work support for a grinding operation, work-gauge means operative to measure the size of the workpiece by direct continuous measurement of the workpiece by the work-gauge means during the grinding operation, after-gauge means operative to measure the size of the workpiece subsequent to the grinding operation, and means responsive to said after-gauge means to adjust the work-gauge means to compensate for errors in the sizes of successive workpieces as determined by the after-gauge means.

2. A grinding machine comprising a work support, a tool support, an abrading tool on the said tool support, means for applying said tool to a workpiece in said work support for a grinding operation, pneumatic work-gauge means operative to measure the size of the workpiece by direct continuous measurement of the workpiece by the work-gauge means during the grinding operation and to terminate the operation when a predetermined size is reached, after-gauge means operative to measure the size of the workpiece subsequent to the grinding operation, and means responsive to said after-gauge means to adjust the work-gauge means to compensate for errors in the

work support operative to measure the size of the workpiece by direct continuous measurement of the workpiece by the work-gauge means during the grinding operation and to terminate the operation when a predetermined size is reached, and means to adjust the work-gauge means for compensating for errors in the sizes of successive workpieces.

14. A grinding machine for finishing a workpiece having a surface of revolution comprising a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surface of the workpiece, air gauging means opening on each of the fingers, the said means including apparatus for terminating the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means including apparatus for automatically adjusting the work gauge to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

15. A grinding machine for finishing a workpiece having a surface of revolution comprising a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surfaces of the workpiece and to measure a dimension of the surface which is determinative of the average diameter thereof, air gauging means opening on each of the fingers, the said means including apparatus for terminating the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means including apparatus for automatically adjusting the work gauge to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

16. A grinding machine for finishing a workpiece having a frusto-conical surface comprising means supporting the workpiece and engaging one end thereof, a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surface of the workpiece to measure the diameter of the surface at a predetermined distance from the end of the workpiece engaged by the support, air gauge means opening on each of the fingers, the said means including apparatus for terminating the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means including apparatus for automatically adjusting the work-gauge to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

17. A grinding machine for finishing a workpiece having a frusto-conical surface comprising a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surface of the workpiece, the fingers having stop means to strike an end of the workpiece so that the work gauge determines the diameter of the surface at a predetermined distance from the said end, air gauging means opening on each of the fingers, the said means including apparatus for terminating the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means including apparatus for automatically adjusting the work gauge to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

18. A grinding machine for finishing a frusto-conical surface of a workpiece comprising a work gauge having two fingers to be positioned adjacent diametrically opposite portions of the said surface of the workpiece, the work gauge measuring the distance from an end of the workpiece occupied by a predetermined diameter, air gauging means opening on each of the fingers, the said means including apparatus for terminating the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means in-

cluding apparatus for automatically adjusting the work gauge to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

19. A grinding machine for finishing a workpiece having a surface of revolution comprising a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surface of the workpiece, air gauging means opening on each of the fingers, the said means connected to one side of an opposed-diaphragm switch connected to terminate the finishing operation, an air nozzle connected to the other side of the switch, and means for gauging the workpiece after the finishing operation, the last-named means including screw means movable toward or away from the nozzle to compensate automatically for changes in the sizes of successive workpieces from a predetermined standard size.

20. A grinding machine for finishing a workpiece having a surface of revolution comprising a work gauge having two contact fingers to extend adjacent diametrically opposite portions of the surface of the workpiece and to measure a dimension of the surface which is determinative of the average diameter thereof, air gauging means including a nozzle mounted on the work gauge, the said means connected to a diaphragm switch connected to terminate the finishing operation, and means for gauging the workpiece after the finishing operation, the last-named means including screw means movable toward or away from the nozzle automatically to compensate for changes in the sizes of successive workpieces from a predetermined standard size.

21. A grinding machine for use in finishing an internal surface of revolution of a workpiece, comprising a work support for supporting said workpiece, a tool support, a generally cylindrical abrading tool on the said tool support, means for applying said tool to the said internal surface for an abrading operation, the said tool occupying a substantial cross-sectional area within the said internal surface of revolution, a pneumatic work-gauge including two fingers adapted to occupy the portion of the said cross-sectional area not occupied by the tool, each finger having an outwardly-directed air aperture, the air apertures being located in spaced opposition to substantially separated portions of the surface of revolution for a direct continuous measurement of the diameter of the surface of revolution by the work-gauge during the abrading operation, means responsive to the work-gauge to terminate the abrading operation when a predetermined diameter of the surface of revolution is reached, and means responsive to variation in the sizes of successive finished workpieces for adjusting the work-gauge to compensate for such variations in the successive finished workpieces.

22. A grinding machine as recited in claim 21 wherein the said two fingers are supported on reeds and are attached to the work support.

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