Nov. 27, 1956 W. D. SCHMIDT ET AL 2,771,714

INTERNAL GRINDING MACHINE

Filed March 9, 1954 7 Sheets-Sheet 1

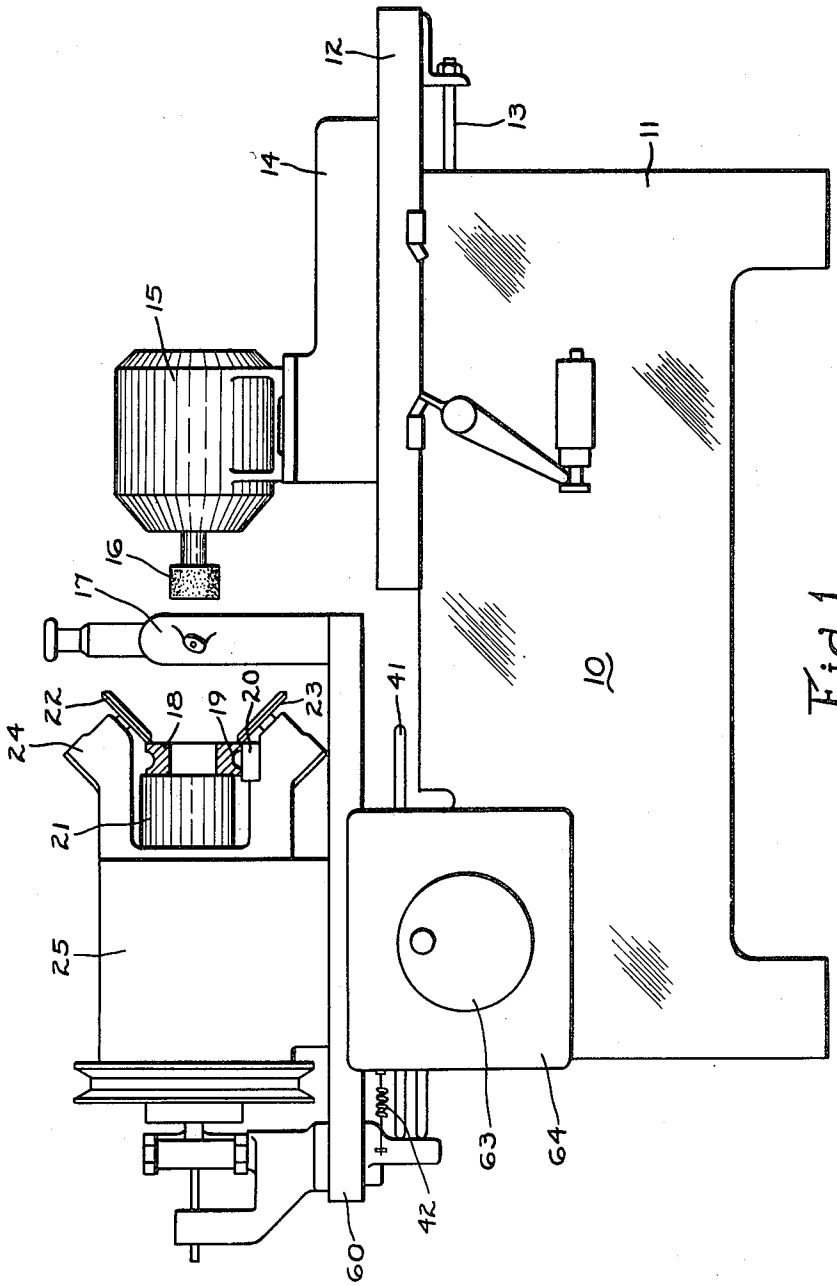


Fig. 1

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INTERNAL GRINDING MACHINE

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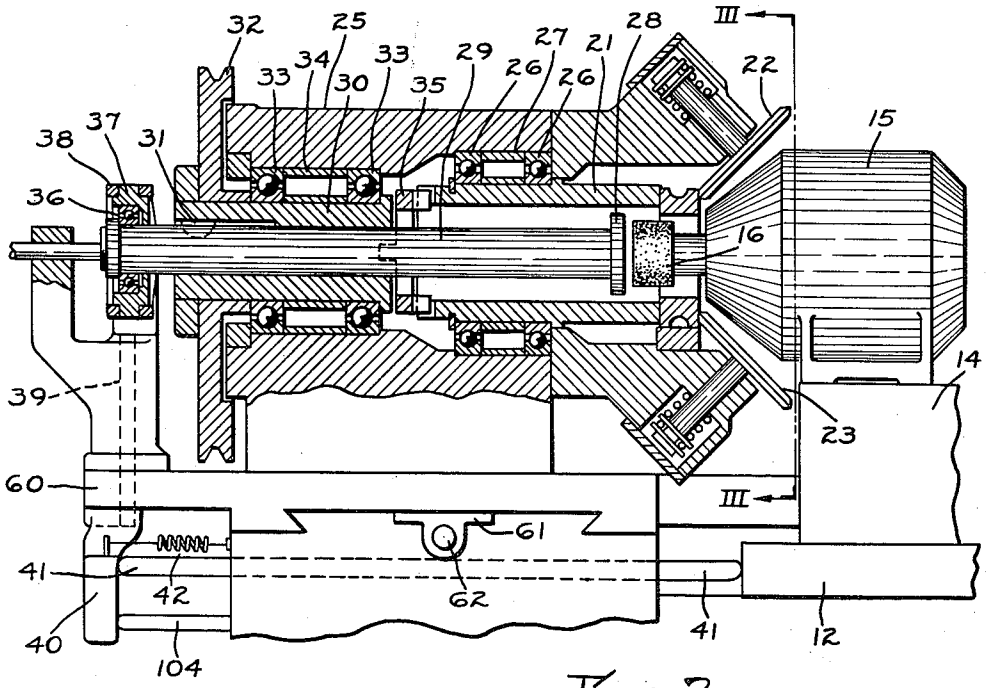


Fig. 2

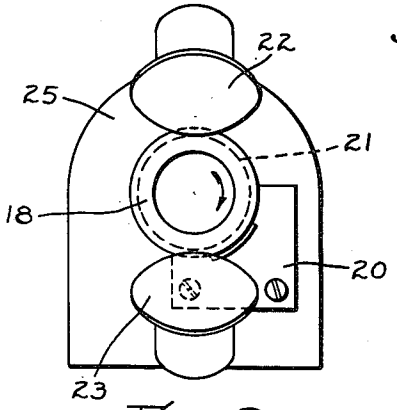


Fig. 3

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INTERNAL GRINDING MACHINE

Filed March 9, 1954 7 Sheets-Sheet 3

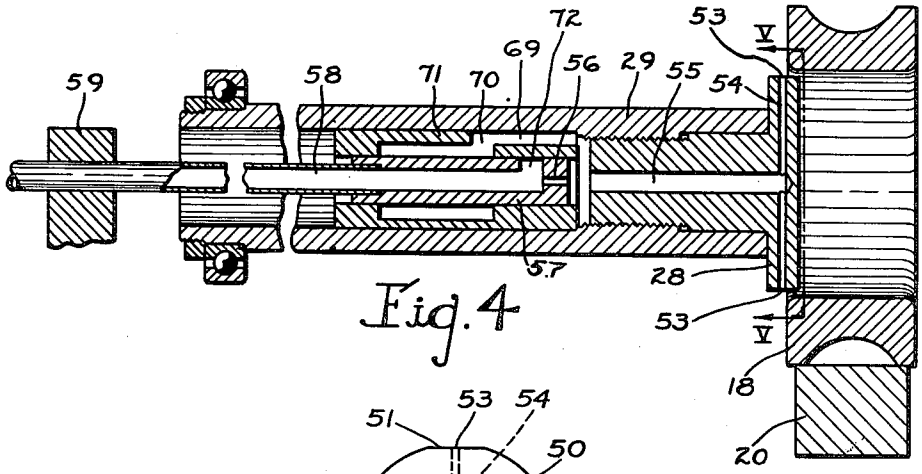


Fig. 4

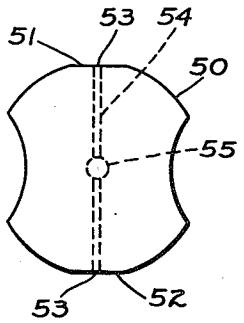


Fig. 5

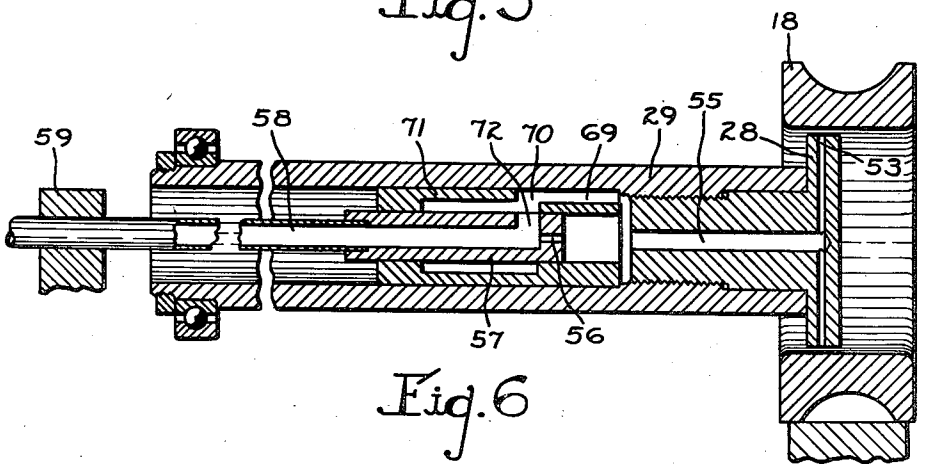


Fig. 6

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INTERNAL GRINDING MACHINE

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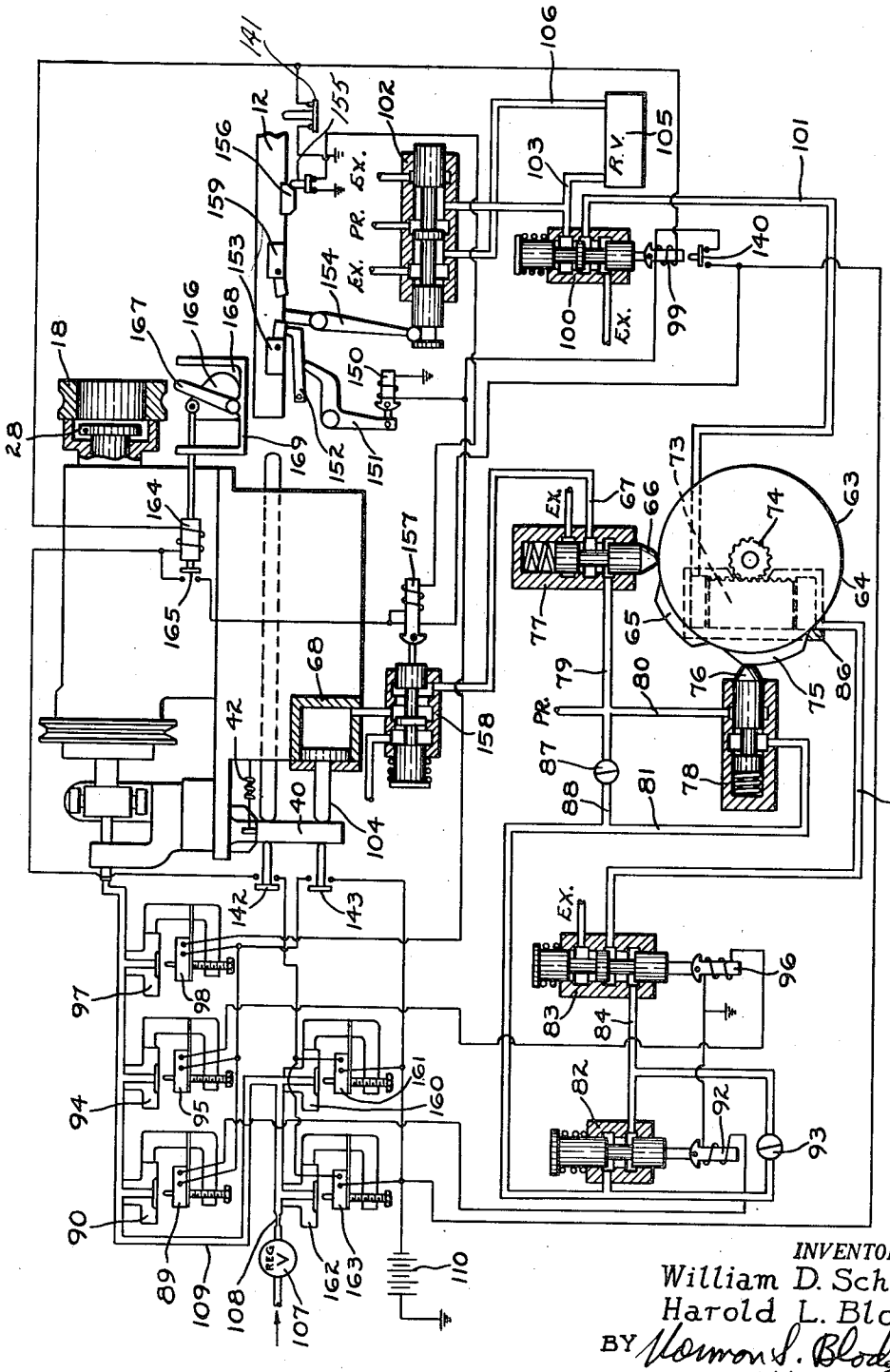


Fig. 7

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INTERNAL GRINDING MACHINE

Filed March 9, 1954 7 Sheets-Sheet 5

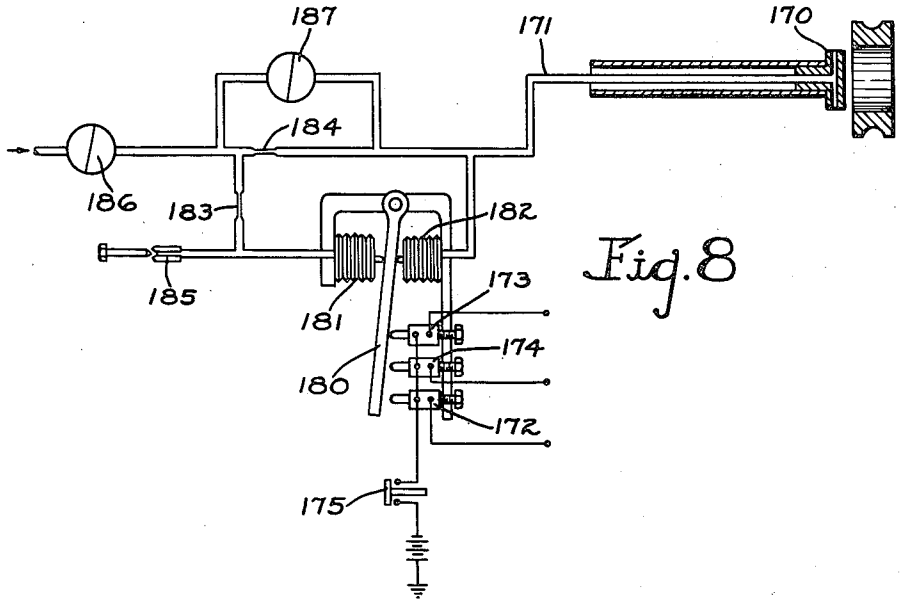


Fig. 8

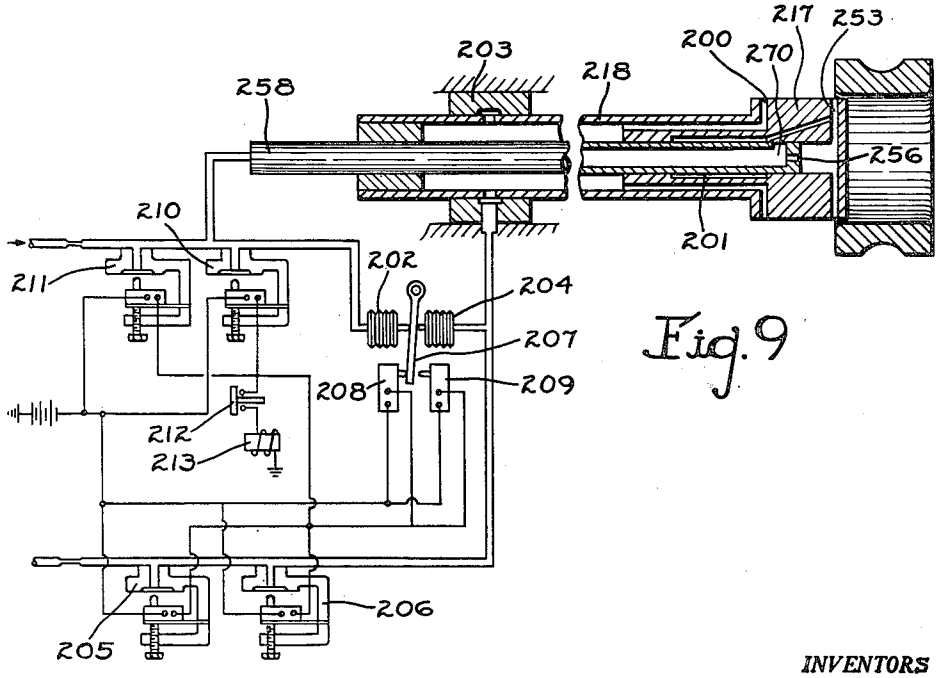


Fig. 9

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INTERNAL GRINDING MACHINE

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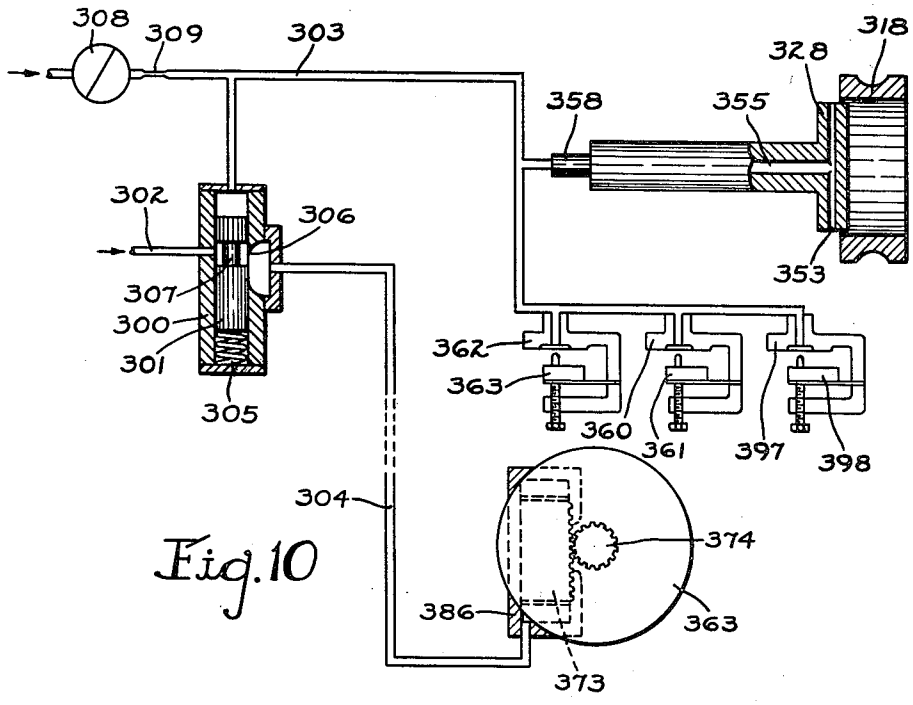


Fig. 10

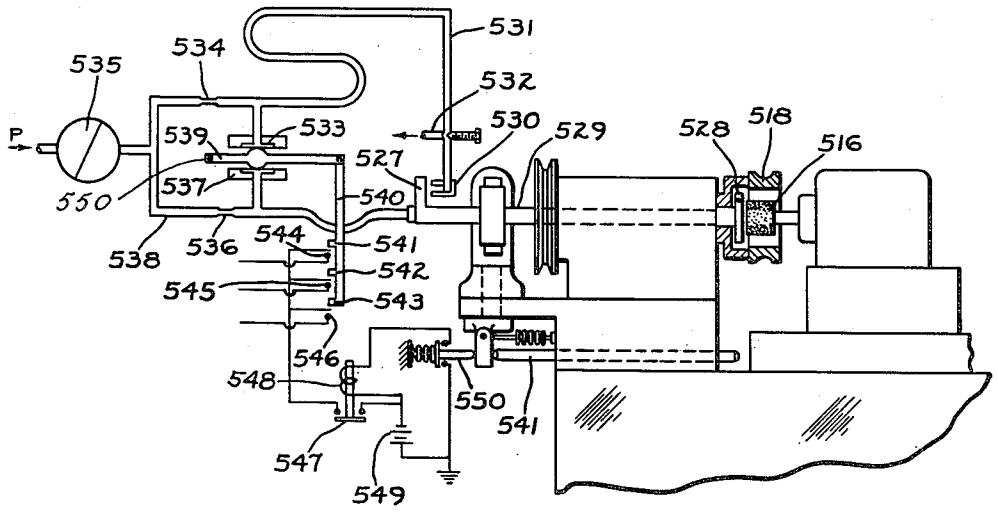


Fig. 12

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INTERNAL GRINDING MACHINE

Filed March 9, 1954 7 Sheets-Sheet 7

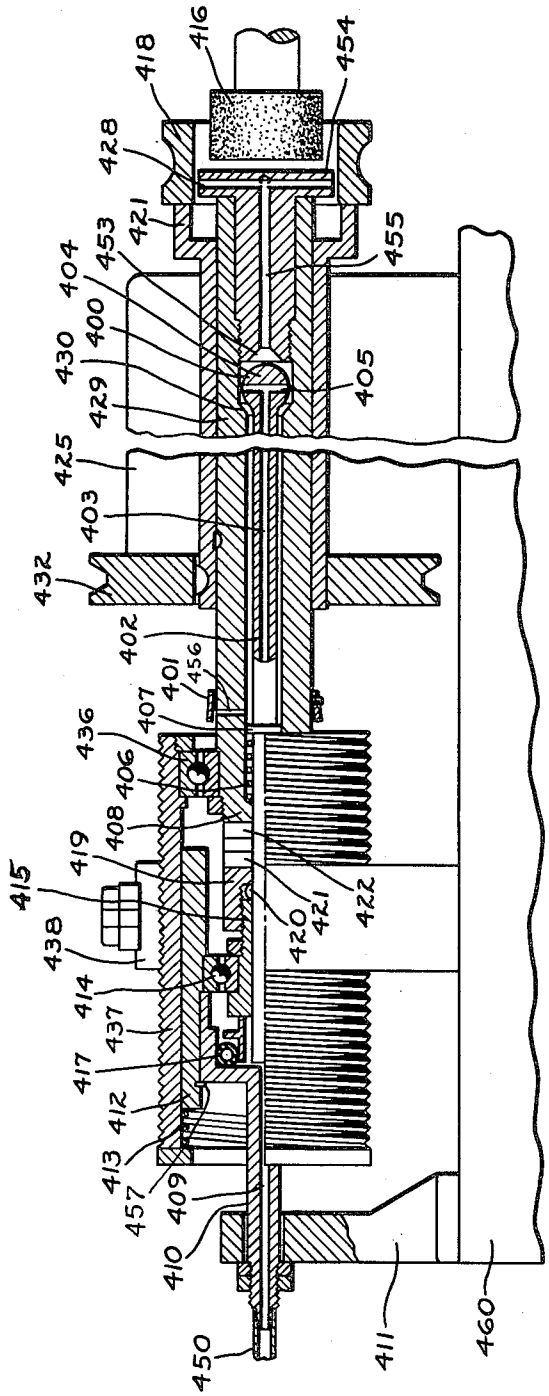


Fig. 11

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United States Patent Office 2,771,714 Patented Nov. 27, 1956

2,771,714

INTERNAL GRINDING MACHINE

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Application March 9, 1954, Serial No. 415,048

18 Claims. (Cl. 51—48)

This invention relates to an internal grinding machine and more particularly to an apparatus in which a gage periodically enters a bore being ground and control several steps in the grinding cycle in response to the size of the bore.

In the grinding of bores and the like, it is customary to rotate the workpiece about its axis and to reciprocate a rapidly rotating grinding wheel back and forth in the bore. As the wheel is moved to and fro in the direction of its axis, it is slowly fed transversely of the axis of the workpiece to engage the surface of the bore and remove material therefrom. The wheel enters and leaves by a single end of the bore. It has been proposed in the past that a plug be introduced into the bore from the other end during the interval at which the wheel is absent, there being means associated with the plug to indicate the dimensional differences between the plug and the bore and to regulate the operation of the machine in response thereto. However, prior art machines of this type have suffered from many disabilities, among which have been lack of sensitivity and accuracy, and, especially, lack of simplicity. Also, these previously-known devices were practically useless when used with a cylindrical bore having chamfered or rounded ends, as in a ball-bearing race. Such chamfers are customarily unground and vary from piece to piece. The present invention overcomes these and other disadvantages encountered in the past with this type of machine.

It is, therefore, an outstanding object of this invention to provide an internal grinding machine in which the wheel may reciprocate and the gage enter and leave the bore at a very rapid rate, the feed rate of the wheel into the work being a very small amount with each reciprocation.

Another object of the invention is the provision of an internal grinding machine in which a sensitive gage controls the length of the roughing, finishing and "sparking-out" periods of the grinding cycle.

A still further object of the present invention is the provision of an internal grinding machine in which the gage control does not operate until the gage is entirely within the cylindrical portion of the bore.

It is a further object of the instant invention to provide an internal grinding machine which will discard workpieces having a tapered or oversize bore.

Another object of this invention is the provision of an internal grinding machine in which a gage periodically enters the bore being ground in the workpiece and controls several steps in an automatic grinding cycle.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

In said annexed drawings:

Figure 1 is a front elevational view of a grinding machine embodying the principles of the present invention,

Figure 2 is a sectional view of a portion of the machine,

Figure 3 is a view of the machine taken on the line III—III of Figure 2,

Figure 4 is an enlarged sectional view of further portions of the machine,

Figure 5 is a view taken on the line V—V of Figure 4,

Figure 6 is a view of a portion of Figure 4 with the parts shown in another operative position,

Figure 7 is a somewhat schematic view of the electrical, hydraulic, and pneumatic controls of the machine,

Figure 8 is a schematic view of portions of a somewhat modified machine,

Figure 9 is a schematic view of portions of another modification of the machine,

Figure 10 is a schematic view of a portion of another modification of the invention,

Figure 11 is a vertical sectional view of a portion of a further modification of the machine, and

Figure 12 is a schematic view of a portion of a still further modification of the machine.

Like reference characters denote similar parts in the several figures of the drawings.

Referring first to Figure 1, wherein are best shown the general aspects of the invention, the internal grinding machine indicated generally by the reference numeral **10**, is shown as comprising a base **11** on which is mounted for reciprocation a table **12**, the latter being activated by a piston rod **13**. The table **12** carries a block **14** on which is mounted a motorized wheelhead **15** with an abrading tool such as a cylindrical grinding wheel **16**. A diamond truing unit **17** is provided to true the wheel on occasion in the conventional manner.

This machine is especially adapted for grinding the bores of workpieces such as the workpiece **18** which is shown as the inner race of a ball bearing having a preground groove **19**. Instead of rotation of the work in a chuck, greater smoothness may be obtained and concentricity between the bore and the groove **19** assured by utilization of and extension of the principles of means such as is described in the patent to Blood No. 2,646,652. The workpiece **18** is supported with the groove **19** in sliding contact with a support shoe **20** and is urged against a rotary platen **21** by spring-pressed rolls **22** and **23** which, in turn, are journaled in a bracket **24** attached to a housing **25**. As is evident in Figure 2, the platen **21** is journaled in bearings **26** which reside in a bore **27** in the housing **25**. As it would not be practicable to maintain the platen and the workpiece exactly concentric and as it is desirable that the platen urge the workpiece against the shoe **20**, the bore **27** and the platen **21** are eccentric to the workpiece. This eccentricity is in such a direction that the workpiece is pressed against the shoe **20** as the platen **21** rotates. This is best shown in Figure 3. The rolls **22** and **23** are situated slightly off-center to the workpiece for the same reason.

With particular reference to Figure 2, a gage such as the air gage plug **28** is mounted on an end of a tube **29** so that it can enter the bore in the workpiece **18** from the left in the drawing. It does so after the bore has been enlarged and when the wheel **16** is near the right end of its stroke. The tube **29** is supported so as to be adjacent to the workpiece by a sleeve **30** to which it may be connected by a sliding key **31**. The sleeve **30** is turned by a sheave **32** and is mounted in bearings **33** which reside in a bore **34** in the housing **25**. The bore **34** and, consequently, the plug **28** are concentric with the workpiece. A positively-engaging coupling **35** engages slots in an adjacent end of sleeve **30** and the adjacent end of the platen **21**, whereby the platen is driven and it, in

turn, drives the workpiece **18** by frictional engagement therewith.

A ball bearing **36** is secured to the outboard end of the tube **29** and this bearing carries a housing **37** which is mounted in and moved by a lever **38**. The lever is connected through a shaft **39** to a lever **40** which is rocked by a push pin **41** which is engaged by the table **12** as it moves to the left, thus carrying the plug **28** out of the way of the wheel **16**. The plug is resiliently biased toward the workpiece **18** by a spring **42**.

The gage plug **28** has a cylindrical periphery **50**, best seen in Figure 5, which is interrupted by relief flats **51** and **52**. In each flat is situated an orifice **53** connected by holes **54** to a center bore **55** and, as is evident in Figure 4, the bore is connected through an orifice **56** in a valve plunger **57** to an inner tube **58** fastened to the plunger **57**. The tube **58** is held stationary with respect to the support shoe **20** by a bracket **59** attached to a cross feed slide **60** which carries the housing **25**, as is best shown in Figure 2. The plunger is slidably mounted in a bushing **71** having a slot **69** and a hole **70**.

As is evident in Figure 2, the slide **60** is fed by a nut **61** and a screw **62** turned by a handwheel **63** which forms part of a conventional feed and compensating mechanism **64** similar to that described in the patent to Blood No. 2,050,482.

Now in Figure 7, it can be seen that a pair of cams **65** and **75** are attached to spaced points on the periphery of the handwheel **63**. Also keyed to the handwheel coaxially thereof is a gear **74** which engages a rack formed on the surface of a feed piston **73** which is slidably mounted in a feed cylinder **86**. When the piston **73** is in its uppermost position in the cylinder, the cam **65** is in engagement with the plunger **66** of the valve **77** and the valve passes oil pressure to exhaust. The valve is in the condition shown in the drawing when out of contact with the cam and pressure oil is admitted from a line **79** to a line **67**; this line is connected to a valve **158** which, when in the proper condition, passes the oil pressure to a retracting cylinder **68**. The rod **104** of the piston residing in this cylinder extends from the base of the machine and contacts the lever **40** on occasion. Another valve **78** is so located that its plunger may be contacted on occasion by the cam **75**. When not contacted by the cam, the plunger is so positioned as to connect a line **81** directly to oil pressure through a line **80**, there being a roughing needle valve **87** connected from the pressure oil source to the line **81** through a line **88** across the valve **78**. The other end of the line **81** is connected to the inlet of a valve **82** and through a finishing needle valve **93** to a line **84** joining the outlet of the valve **82** to the inlet of a valve **83**. The plunger of the valve **83** is arranged selectively to connect the line **84** either to exhaust or to a line **85** leading to the lower end of the cylinder **86**. The upper end of the cylinder **86** is connected by a line **101** to a valve **100** whose plunger is arranged selectively to connect the line **101** either with exhaust or with a line **103**. The other end of the line **103** is connected both to a pilot valve **102** and a reversing valve **105**. Another line **106** connects the pilot valve and the reversing valve and pressure oil and exhaust lines are also connected to the pilot valve. The plunger of the pilot valve is arranged to connect the lines in a desired manner, as will be described more fully hereinafter.

A source of pressure air, not shown, is connected through an adjustable regulating and pressure reducing valve **107** such as is indicated by the reference numeral 459 in the patent to Balsiger No. 2,088,682 and a fixed resistance **108** by a line **109** to a series of diaphragm type pressure switches, namely a "large bore" switch **162** including a micro-switch **163**, a "small bore" switch **160** including a micro-switch **161**, a "finish feed" switch **90** including a micro-switch **89**, a switch **94** including a micro-switch for beginning the "spark out" period, and a switch **97** including a micro-switch **98** for ending the "spark out" period. The line **109** is also connected to the outer end of the inner tube **58** leading to the gage plug **28**.

A source **110** of electrical energy, shown as a battery, is connected to ground on one side and on the other side to one side of each of the micro-switches **163, 161, 89, 95** and **98**. However, the line connecting the source **110** to the micro-switches **89, 95** and **98** is interrupted by a switch **143** which remains open only when the lever **40** is in its left position, this being true when the plug **28** is retracted from the workpiece **18**. The other sides of the microswitches **163** and **161** are connected together and through a switch **142** to a solenoid **164**. The switch **142** is opened by the movement of the lever **40** to the left and remains open while the lever is in that position. The connection to the solenoid **164** is to one side of its coil and to one side of a switch **165** which is opened by the energization of the coil. The plunger of the solenoid is connected to a counterweighted lever **166** which is connected to a trap door **167** associated with a left hand chute **169** and a right hand chute **168**. The other side of the switch **165** is connected to one side of the coil of a solenoid **157** which is connected to the valve **158** for the actuation thereof. The same side of the coil of the solenoid **157** is connected to one side of a switch **140** which is opened and closed by the movement of a solenoid **99**. The other side of the coil of the solenoid **157** is connected to the other side of the switch **155**. The first-mentioned side of the switch **140** is also connected to the electrical source **110**. The side of the coil of the solenoid **164** that is not connected to the switch **165** is connected to the coil of the solenoid **99**, this solenoid being mechanically connected to the shifting valve **100** for the actuation thereof. The other end of the coil of the solenoid **99** is connected both to the other side of the switch **140** and to one side of the coil of a solenoid **150**, the other side of which is grounded. The solenoid **150** is connected through a bell crank **151** to an arm **152**, which is positioned to engage a dog latch **153** mounted on the table **12**. The dog latch **153** and its mate, latch **159**, are situated to engage one end of a reversing lever **154** the other end of which engages and actuates the pilot valve **102**. Now the solenoid **150**, the coil end of which is connected to the coil of the solenoid **99** is also connected to the other side of the micro-switch **98**.

The end of the coil of the solenoid **99** which is not connected to the switch **140** is connected to one side of a reset switch **141**, the other side of which is grounded. The coil is also connected to the end of the coil of the solenoid **164**, which end is not connected to the switch **165**.

The side of the micro-switch **95** which is not connected to the source **110** is connected to one end of the coil of a solenoid **96**. This solenoid is connected mechanically to the valve **83** for the selection of the position of its plunger. The other side of the coil is connected both to ground and to one side of the coil of a solenoid **92** which selects the position of the plunger of the valve **82**. The other end of this last coil is connected to the side of the micro-switch **89** opposite that which is connected to the electrical source. The side of the coil of the solenoid **157** which is not connected to switches **165** and **140** is connected to one side of a switch **155**, the other side of which is grounded. The switch is opened and closed by contact with a cam **156** which is mounted on and moves with the table **12**.

The operation of the apparatus will now be understood in view of the above description. The condition of the apparatus after rapid infeed of the wheel and while the roughing operation is taking place is shown in Figure 7. When the feeding of the wheel **16** relative to the centerline of the workpiece **18** has advanced far enough to allow the plug **28** to enter the workpiece freely, the cam **65** contacts and raises the plunger of the valve **66**. This exhausts the line **67** and the cylinder **68** which has, up to this point, held the plug **28** out of contact with the workpiece **18**. The spring **42** now moves the plug **28**

into the bore of the workpiece, as shown in Figure 6, whenever the wheel 16 is withdrawn sufficiently.

The bore 55 in the plug 28 is now connected through the orifice 56 and also through the slot 69 and the hole 70 in the bushing to the tube 58 through the port 72 in the valve plunger 57. That is to say, after the orifices 53 have passed the irregular chamfer in the workpiece, the hole 70 in the bushing 71 has moved into position to open into the port 72 in the valve plunger 57, connecting the bore 55 in the plug 28 with the tube 58 in addition to the connection through the orifice 56. The escape of air from the tube 58, which was previously governed principally by the size of the orifice 56 until the orifices 53 had passed the chamfer in the workpiece and entered the bore, is now controlled mainly by the space between the orifices 53 and the bore of the workpiece 18. It should be noted that neither of the orifices 53 can touch and be closed off by the bore of the workpiece; that is, the effective gaging surfaces are of the non-contacting type. They need not be accurately centered in the bore; that is to say, they are centered with sufficient accuracy by the periphery 50 which may have a diameter substantially under the bore size and may not actually contact the bore. It is desirable to insure approximate centering of the plug 28 in this way in case wear of the parts should in time interfere with maintaining the tube 29 coaxial with the workpiece.

It will be noted that the valve plunger 57, which is stationary and the bushing 71, which is pressed into the tube 29 so that it rotates and reciprocates with it, form a rotary seal. It is, of course, possible to use any known type of rotary seal to connect the moving and the stationary parts, but a combination valve and seal is shown here for simplicity.

In Figure 7, the feed piston 73 engages the gear 74 to rotate the feed handwheel 63. As has been described, the cams 65 and 75 are carried on the handwheel 63 for engagement with the plungers 66 and 76 of the valves 77 and 78, respectively. As the cycle starts, the cam 75 has not yet engaged the plunger 76, so that the valve 78 is in its open condition. Oil under pressure entering the lines 79 and 80 passes successively through the valve 78, the line 81, the valve 82, the line 84, the valve 83 and the line 85 to feed the cylinder 86 to advance the piston 73 in a feeding direction. When the cam 75 engages the plunger 76, the valve 78 closes, causing pressure oil to pass through the needle valve 87 and the line 88 to reduce the feed rate of the feed piston 73.

When feeding has progressed sufficiently to make the bore of the workpiece large enough for the gage to enter, the cam 65 engages the plunger 66, thus allowing part of the oil in the retraction cylinder 68 to be pushed through the valve 158, the line 67 and the valve 77 to exhaust, the amount of oil exhausted depending upon the stroke of the table 12 which limits the motion of the push pin 41 and the lever 40. The gage 28 then enters the bore at each right stroke of the table 12. The switch 143 closes after the hole 70 has opened into the port 72 and the gage has reached a predetermined position in the bore, thus connecting the micro-switches 89, 95, and 98 to line. At a predetermined bore size the air pressure in the tube 58 and the line 109 is reduced to a point where the diaphragm switch 90 permits the micro-switch 89 to close, thus energizing the solenoid 92 to close the valve 82. The feed rate of the feed piston 73 is reduced to the amount of oil which will pass through the finish rate throttle 93. It is desirable also to drive the plug, as has been described, or at least to mount it to permit rotation with the work to minimize wear of the periphery 50.

At the end of the finish feed period, the air pressure in the line 109 is reduced still further and the switch 94 closes the micro-switch 95, thus energizing the solenoid 96 entirely to shut off oil pressure and flow to the feed cylinder 86 and to connect the feed side of the cylinder to exhaust.

With the grinding wheel still reciprocating in the bore, the residual spring in the wheel spindle results in a period of "sparking out" during which the size of the bore is increased slightly. When the bore reaches the finish size, the air pressure in the line 109 is reduced to the point where the diaphragm switch 97 allows the micro-switch 98 to close, thus energizing the solenoid 99 and activating the shifting valve 100 to send pressure oil through the line 101 to the retraction side of the feed piston 73. The feed mechanism 64 acts to move the workpiece radially away from the wheel. The pressure oil for retraction is obtained from the supply through the pilot valve 102 through the line 103. With this arrangement retraction will take place after the switch 98 closes and pilot valve 102 has shifted to the position shown, although the table may make one more stroke if the latch in the dog 153 is not lifted by the arm 152 before the latch has engaged the reversing lever 154; however, this does not affect the accuracy of sizing. During this feed retraction, the gage 28 is also retracted by the retracting cylinder 68 which is refilled with pressure oil by virtue of the fact that the valve 158 is in its left position and the valve 77 is in its lower position. The solenoid 157 is not actuated because the switch 140 is open and remains open until the micro-switch 98 is closed and actuates the solenoid 99. The valve 77 is no longer maintained in its upper position because the cam 65 of the feed mechanism 64 is moved counterclockwise during the feed retracting movement.

When the solenoid 99 is energized it closes the switch 140 which holds the solenoid in its energized state until the table 12 has moved to the right or loading position where the cam 156 opens the reset switch 141 which is located on the machine adjacent to and at the right of the switch 155.

The solenoid 150 is energized during the same period as the solenoid 99 and, when energized, it pulls the bell-crank 151 thereupon swinging the arm 152 to lift the dog latch 153 over the reverse lever 154. This permits the table 12 to move to the right beyond its normal reversal point. As this extended motion begins, the movable part of the switch 155 is depressed by the table cam 156. This energizes the solenoid 157 which draws the plunger of the valve 158 to the right so that the retraction cylinder 68 is exhausted and the plug 28 is permitted to move to the right beyond its position shown in Figure 6. The lever 40 is permitted to move to the right far enough to allow the switches 142 and 143 to close. Preferably the relationship of the elements is such that, after the orifices 53 have moved far enough to the right to pass the longest chamfer expected in any workpiece, the hole 70 opens into the part 72 before the switches 142 and 143 close. Then, the events described occur with the plug 28 in the same position relative to each workpiece, and all changes effecting the pneumatic system have been made before this system is connected to control the machine. This permits pneumatic fluctuations to be damped and the control system to become stable before it is permitted to make effective measurements of the bore. As the plug 28 moves to the right through the bore of the rotating workpiece 18, it is gaging the bore for consistency of diameter. If any portion of the bore is undersize, the diaphragm switch 160 closes the normally-open micro-switch 161 and, if any portion of the bore is oversize, the diaphragm switch 162 allows the micro-switch 163 to close. In either case, the solenoid 164 is energized and held by the switch 165 until the reset switch 141 opens. The solenoid 164 is arranged to swing the counterweighted lever 166 and the trap door 167 to the left to cause the workpiece to pass into the right hand chute 168 for rejection after the workpiece has been released from the shoe 20, the platen 21 and the rolls 22 and 23 manually or by an ejector such as 47 in the patent to Blood et al. No. 2,290,269 in the usual manner. If

the work is within tolerance throughout its length, the switches **161** and **163** remain open, the trap door remains as shown, and the workpiece **18** drops into the left hand chute **169**.

Figure 8 shows a modification of a portion of the machine. The micro-switches **172**, **173** and **174** are operated by a hinged lever **180** which is pivoted about its hinge by opposed bellows **181** and **182**. The bellows are supplied through restrictions **183** and **184** and an adjustable regulating and pressure reducing valve **186** from a source of compressed air, not shown. The pressure in the bellows **181** depends upon the escape of air through an adjustable orifice **185**, while the pressure in the bellows **182** depends upon the escape through the tube **171** and the plug **170**. This decreases as the bore is enlarged, closing the switches **173**, **174** and **172** as the bore of the workpiece reaches successively the diameters for which the switches are set. When the plug **170** is out of the bore, as shown, the pressure in the tube **171** is maintained by a second adjustable regulating and pressure reducing valve **187** near the critical pressure at which the switch **173** is set to close in order to minimize fluctuations. The entry of the plug into an undersize bore raises the pressure slightly and opens the switches **172**, **173** and **174** before the switch **175**, which is in series with them, is closed by movement of the table in a manner similar to the switch **143** of Figure 7. Only when the bore has been enlarged enough so that the switch **173** closes, is a circuit completed to slow the feed to the finishing rate. Switches **173** and **172** follow in sequence as before. With this construction the plunger **57** and bushing **71** of the previously-described embodiment may be omitted. This means that the switches will respond very quickly after the plug enters the bore in the workpiece.

In Figure 9 is shown another embodiment of the invention which is particularly useful when the tolerance on taper is closer than the tolerance on diameter and it is, therefore, desirable to gage two diameters simultaneously and to reject the workpiece if the two measurements differ more than desired. According to this construction, the plug **217** is provided with orifices **253** for gaging the diameter at one position and orifices **200** for gaging the diameter at another position. When the orifices **253** are out of the bore of the workpiece, as shown, they are connected through an orifice **256** and the tubular valve plunger **258** to diaphragm pressure switches **210** and **211** each of which includes a micro-switch. These operate in the same manner as the corresponding switches **160** and **162** in the embodiment shown in Figure 7 and described hereinbefore. The tubular valve plunger **258** is held stationary in the same manner as described for the tube **58** in the previously-described embodiment of the invention. The orifices **253** are connected to a bellows **202**. They may also be connected to diaphragm switches similar to switches **90**, **94** and **97** of the embodiment shown in Figure 7 for regulating the start of the finish feed, the start of the "sparking out" period, and the end of the "sparking out" period; however, for the sake of simplicity, these elements and connections are not shown. Movement of the plug **217** relative to the stationary valve plunger **258** in the manner described for the plug **28** in the previously-described embodiment to bring the orifices into the bore of the workpiece brings a counterbore **201** in the plug **217** into registry with a hole **270** in the tube **258**, thus bypassing the orifice **256** through a hole **269** in the plug **217**. Further movement of the plug **217** closes a switch **212**, which is closed by the movement of the plug and its associated elements including the lever **40** in the manner described for the switch **142** and the plug **28** of the previously described embodiment of the invention. When the orifices **200** enter the bore, they are connected through the tube **218** and the rotary joint **203** to the bellows **204** and to diaphragm-switches **205** and **206**. If the bore opposite the orifices is too small or too large, these diaphragm-switches close to energize a solenoid **213**; this solenoid acts to discard the workpiece. Any taper in the bore of the workpiece will unbalance the resistance to air flow at the orifices **200** and **253** and, consequently, the pressures in the bellows **202** and **204** will be similarly unbalanced. This will swing the lever **207** to close one of the switches **208** and **209**, thereby energizing the solenoid **213** for rejection of the workpiece.

In Figure 10 is shown another embodiment of the invention characterized by the fact that the feed rate is reduced gradually and is controlled by the size of the hole being ground. Oil under pressure enters a valve **300** through a line **302**, passes around a groove **307** in the plunger **301** and is passed through a metering slot **306** before passing through a line **304** to the feed cylinder **386**. The rate of feed is controlled by the position of the plunger **301** relative to the metering slot **306**. When the bore in the workpiece **318** is small, the air pressure in the line **303** is high, forcing the plunger **301** down against the spring **305** whereupon oil is permitted to pass through the metering slot **306** to the feed piston **373** at a fast rate. As the bore in the workpiece becomes larger, the air pressure in the line **303** drops, thus causing the spring **305** to move the plunger **301** upwardly so that a smaller area of the metering slot is available for the passage of oil to the cylinder **386**. Therefore, the feed rate will be slower. When the air pressure in the line **303** reaches a pre-determined minimum, the plunger **301** completely closes the metering slot **306**. This begins the "sparking out" period which continues until the switch **398** closes and retracts the feed cylinder. The switches **360** and **362** with their micro-switches **361** and **363** serve to actuate the discard of oversize and undersize workpieces, respectively.

It will be obvious that, when the valve mechanism described in connection with Figures 4 and 6 is used with workpieces having irregular chamfers, the hole **70** will sometimes open into the port **72** before the orifices **53** are covered by the bore, whereupon air will escape from the tube **58** with little restriction, or the port **72** will remain closed for a short time after the orifices are covered, thus raising the pressure. In either case, undesirable fluctuations result, although a switch **142** or **175** is provided to minimize the effect of such fluctuations.

To permit higher speed operation on such work, a modification of the valve mechanism is shown in Figure 11. When the plug **428** is withdrawn from the workpiece **418** a valve element **400** transfers the air from the plug to an adjustable valve which controls the pressure in the tube **450**, corresponding to the tube **171** in Figure 8. As an alternative to the valve **187** there is shown a valve including a sleeve **401** which has a chamfered bore and is adjustable along a tube **429** to partly close a hole **456** through the wall thereof. With high speed operation, it is necessary to keep the air pressure nearly the same irrespective of whether the plug is in the workpiece or not, to minimize pressure fluctuations. A platen **421** is rotatably mounted in a housing **425** and driven by a pulley **432**. The plug **428** is provided with holes **454** leading to a center bore **455**. At the left end of the bore **455** is a conical countersunk recess **453**. The shank of the plug is threaded to a tube **429**, the rearward end of which is rotatably carried by a ball bearing **436** mounted in a housing **437** which is operatively carried in a lever **438**. This lever is activated in the same manner as the corresponding elements of the other embodiments of the invention to move the plug **428** in and out of the workpiece **418** with the movement of the wheel **416**. The platen **421** and the tube **429** are keyed together. The internal bore of the tube **429** is reduced for a great part of its length and the transition surface **430** is conical. Within the chamber defined by the conical recess **453** and the conical surface **430** resides a generally spherical head **404** of the valve element **400**. The element **400** is provided with an elongated stem **402** which has a bore **403** extending through its length, the bore communicating with the exterior of the head **404** through diametral passages **405**. The

spherical surface of the head **404** is resiliently biased into contact with the conical recess **453** by means of a coil spring **406** which extends between a flange **407** on the stem **402** to a shoulder **408** extending into the tube **429**. The rearward end of the bore **403** of the stem **402** resides adjacent the bore **409** in a tailpiece **410**. The tailpiece is fixedly mounted in a bracket **411** fastened to the feed slide **460** and is connected to the tube **450** leading to the pneumatic controls, not shown. The inner end of the tailpiece is enlarged and is fixed in a tubular member **412** which, in turn, slides in the housing **437**. A coil spring **413** is compressed between the member **412** and the housing **437**. The member **412** is carried by a ball bearing **414** which, in turn, surrounds and carries a sleeve **415**. The sleeve **415** is carried by the valve element **400** and a seal **417** is provided between the sleeve and the tailpiece to permit relative rotation therebetween without air leakage. The rotary seal **417** may be of any conventional type but is shown as a face seal including a ring bearing against the left end of the sleeve **415** and including an O-ring between the ring and the counterbore in the tailpiece **410**. A clutch member **419** is threadedly engaged with the forward end of the sleeve **415** and a seal **420** is compressed between the two. The member **419** is provided with teeth **421** which mate with similar teeth **422** on the rearward end of the tube **429**. It can be seen, then, that the platen **421** is driven in the usual way, carrying the tube **429** and the plug **428** with it. The valve element **400** also rotates with the tube and plug because of the driving connection between the teeth **421** and **422**, whereby the clutch member **419** is revolved, carrying the valve element **400** with it. The movement of the lever **438** in response to its activating mechanism causes a corresponding movement of the housing **437**, the tube **429** and the plug **428**. The valve element **400** does not partake of this movement, however, because of its indirect attachment to the feed slide **460** through the sleeve **415**, the ball bearing **414**, the member **412**, the tailpiece **410**, which is retained by a snap ring **457** in a groove inside the member **412**, and the bracket **411**. The teeth **421** and **422** permit longitudinal movement of the tube **429** and the plug **428** relative to the clutch member **419** and the valve element **400**, while also permitting the rotational driving connection therebetween. It can be seen, then, that movement of the plug and tube in and out of the workpiece causes the spherical head **404** either to contact the conical recess **453** or the conical surface **430**, so that air pressure originating in the tube **450** is permitted to escape only through the passages **454** in the plug. When the plug is removed from the workpiece, the spherical head **404** rests against the conical recess **453** and air can escape only through the valve comprising the hole **456** and the sleeve **401**. The valve, consisting of the elements **404**, **453**, **430** and associated elements, is shown close to the plug to minimize the length of the air passage **455** which must be filled with air under pressure at each stroke. It would, of course, be simpler to locate this valve mechanism outside the rotatable tube **429** and this may be done by use of a sufficiently fast-acting pneumatic system such as those described.

In Figure 12 is shown a modification of the apparatus of the invention wherein a variation of the pneumatic control system is introduced. The apparatus is substantially like that shown in Figure 1. However, at the outer end of the tube **529** on which the gaging plug **528** is mounted is an abutment **527**. This abutment partakes, of course, of the to-and-fro motion of the plug and serves to open and close an air nozzle **530**. When the plug is in its operative position within the workpiece, the abutment **527** is pressed against the nozzle **530**, thus preventing the escape of air therefrom. The nozzle is situated at the end of a leg **531** the intermediate portion of which is provided with an adjustable escape orifice **532**. The intermediate portion of the leg **531** is also connected to a diaphragm **533**. The leg is connected through a fixed restriction **534** to the output side of regulator valve **535**. The inlet side of the valve is connected to a source of pressure air, not shown. The outlet side of the regulating valve is also connected to a leg **538** and through a fixed restriction **536** to the bore of the tube **529** leading to the gaging plug **528**; a diaphragm **537** is connected to the leg **538** at a point therein between the restriction **536** and the tube **529**. The diaphragms **533** and **537** are arranged in opposition and act upon opposite sides of the intermediate portion of a lever arm **539** one end of which is connected to a fixed pivot **550** while the other end is pivotally attached to a switching bar **540**. The bar **540** is provided with fingers **541**, **542** and **543** which are adapted to engage and close switches **544**, **545** and **546**. As the bar moves longitudinally it closes the switches **544**, **545** and **546** successively and in the order named at predetermined spaced intervals of time. The circuits in which these switches lie are not operative, however, until a time-delay relay **547** is closed. This closure takes place when a coil **548** of the relay is energized. This coil is energized by an electric source **549** when a contactor **550** is closed by the movement of the push pin **541** when the wheel **516** moves out of the workpiece **518**. The time delay relay **547** provides a period of time between the entrance of the plug **528** into the bore of the workpiece and the closing of the relay. This allows fluctuations in the pneumatic system to be damped and the system to become stable before it is permitted to control the machine. Now, the legs **531** and **538** constitute two branches of a pneumatic balancing bridge. The escape of air from the leg **538** takes place only through the plug **528**, while the escape of air from the leg **531** takes place through the nozzle **530** and the adjustable orifice **532**. Any unbalance of air pressure in the two legs results in movement of the lever **539** under the action of the diaphragms **533** and **537** and, if the movement is sufficient, will result in the closure of some or all of the switches. The orifice **532** is adjusted so that, when the plug is out of the workpiece, as shown in the drawing, the air pressure in the leg **531** is equal to the pressure in the leg **538**. If the tubing in the legs is the same, the restrictions **534** and **536** are equal, and if the legs are equal in length, then the quantity of air escaping from the nozzle **530** and the orifice **532** will equal the quantity escaping from the plug **528**. The nozzle **530** is selected so that, when the plug is situated within the workpiece and the nozzle is closed by the abutment **527**, the pressure in the line **531**, as determined by the escape of air through the orifice **532**, will balance the pressure in the line **538**, as determined by the space between the plug **528** and the inner surface of the workpiece. Thus, when the apparatus begins work on an unfinished workpiece, the pneumatic bridge is balanced, whether the plug is in or out of the workpiece. As the grinding operation proceeds, however, the situation changes. Although the pressure in the leg **538** will always be the same as that in the leg **531**, when the plug is out of the workpiece, the enlargement of the bore in the workpiece produces a greater space between the workpiece and the plug, so that the pressure in leg **538** drops, while that in leg **531** remains the same. The bar **540** will move downwardly at a rate determined by the rate of removal of material from the workpiece by the wheel. As the bar moves downwardly the finger **541** contacts and closes the switch **544**; the switch is connected to initiate the finish grinding period. As the bar progresses still farther, it next causes the finger **542** to close the switch **545**; the closure of this switch starts the "spark out" period. Next, the finger **543** closes the switch **546**, thus ending the "spark out" period and causing the retraction of the wheel from the work.

Other modes of applying the principles of the invention may be employed, changes being made as regards the details described, provided the features stated in the following claims, or the equivalent of such, be employed.

We therefore particularly point out and distinctly claim as our invention:

1. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel, a pneumatic gage plug, means for introducing the plug into the bore in the workpiece when the wheel is at least partially withdrawn therefrom, power means for feeding the wheel and workpiece into cutting engagement, control means including a source of air under pressure responsive to the escape of said pressure air through the space between the plug and the bore of the workpiece connected to the power means to bring about changes in the actuation of the said power means when the bore reaches predetermined sizes, means including a valve actuatable upon the introduction and removal of the plug from the bore for limiting the amount of fluctuation of the effect of the said escape of air when the plug is removed from the workpiece, and means responsive to said gage plug for discarding workpieces whose bores are excessively tapered.

2. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel, means for feeding the wheel relatively against the workpiece, a pneumatic gage plug including a source of air under pressure, means for introducing periodically the plug into the bore in the workpiece when the wheel is at least partially withdrawn therefrom, a first diaphragm switch responsive to the escape of air through the space between the plug and the bore of the workpiece to act on the feed means to change from coarse to fine feed when the bore reaches predetermined sizes, a second diaphragm switch responsive to the said escape of air to stop the said feed means altogether at a second predetermined bore size and a third diaphragm switch responsive to said escape of air to act on the feed means to separate the wheel from the workpiece when the bore reaches a third predetermined size.

3. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel, means for feeding the wheel against a surface of the workpiece, a pneumatic gage including a source of air under pressure, means for introducing the gage in proximity to the surface of the workpiece when the wheel is at least partially withdrawn therefrom, an actuating arm, a series of switches, means including a bellows responsive to the escape of air through the space between the gage and the workpiece to move the actuating arm into successive contact with the series of switches to bring about changes in feed when the space reaches predetermined sizes.

4. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel, means for feeding the wheel against the workpiece, a pneumatic gage plug including a source of air under pressure, means for introducing the plug into the bore in the workpiece when the wheel is at least partially withdrawn therefrom, means including a flexible member responsive to the escape of air through the space between the plug and the bore of the workpiece connected to the feed means to bring about changes in the grinding cycle when the bore reaches predetermined sizes, a contact member, a first and second switch, the said member under the action of the said escape of air moving the contact member to operate successively the first and the second switch as the bore reaches successive predetermined sizes, the first switch reducing the feed, and the second switch terminating the grinding operation.

5. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel, means for feeding the wheel to the workpiece, a gage including a source of air under pressure, means for introducing the gage to the workpiece when the wheel is at least partially withdrawn therefrom, a first diaphragm means responsive to the escape of air through the space between the gage and the workpiece, a second diaphragm responsive to the escape of air from a fixed and an adjustable orifice, the diaphragms adapted to act in opposition to actuate successively as the workpiece reaches predetermined sizes, a first, a second and a third switch to slow, stop and reverse the feed, respectively.

6. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel, means adapted to feed the wheel into cutting contact with the workpiece, a pneumatic gage plug, means for introducing the plug including a source of air under pressure into the bore in the workpiece when the wheel is at least partially withdrawn therefrom, a first diaphragm responsive to the escape of air through the space between the plug and the bore of the workpiece, a second diaphragm responsive to the escape of air from a fixed and an adjustable orifice, a bar on which the diaphragms are adapted to act in opposition, a first, second, and third switch actuated successively by the bar, the first switch adapted to slow the feed means, the second switch adapted to stop the feed means altogether, and the third switch adapted to reverse the feed means.

7. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage including a source of air under pressure, means for introducing the gage to a first position adjacent the surface of the workpiece being finished when the wheel is at least partially withdrawn therefrom, control means responsive to the escape of air through the space between the gage at said first position and the workpiece and connected to the wheel to bring about changes in the said relative movement between the wheel and workpiece when the bore reaches predetermined sizes, and means including a valve activated by removal of the gage from the first position associated with the gage to control the effect of the escape of air when the gage is removed from the said first position.

8. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage including a source of air under pressure, the gage having an orifice, means for introducing the gage to an operative position within the workpiece when the wheel is at least partly withdrawn therefrom, control means responsive to the escape of air through the space between the gage and the workpiece and connected to the wheel to bring about changes in the said relative movement between the wheel and workpiece when the workpiece reaches predetermined sizes, a valve member adapted to move relative to the gage as the gage moves to and from the said operative position, the said valve member having a passage adapted to be connected to a source of pressure air, and a passage in the gage into which the orifice opens, the passage being so situated as to connect with the passage in the valve member only when the gage is situated in the said operative position.

9. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage plug including a source of air under pressure, the gage having an orifice, means for introducing periodically the plug into one end of the bore in the workpiece when the wheel is at least partly withdrawn therefrom, control means responsive to the escape of air through the orifice and through the space between the plug and the bore of the workpiece and connected to the wheel to bring about changes in the said relative movement between the wheel and workpiece when the bore reaches predetermined sizes, a valve member adapted to move relative to the plug as the plug moves in and out of the workpiece, the said

valve member having a passage adapted to be connected to a source of pressure air, and a passage in the plug into which the orifice opens, the passage being so situated as to connect with the passage in the valve member only when the plug is situated within the bore of the workpiece.

10. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage including a source of air under pressure, the gage having two spaced sets of orifices opening on its surface, means for introducing the gage to an operative position within the workpiece when the wheel is at least partly withdrawn from one end thereof, control means connected to the wheel and responsive to the escape of air through one of the orifices and through the space between the gage and the workpiece when the gage is in the operative position to bring about changes in the said relative movement between the wheel and the workpiece, a valve member having a passage adapted to be connected to a source of pressure air, the gage moving relative to the valve member in moving to and from its position within the workpiece, the passage being connected to one of the orifices only when the plug is within the workpiece.

11. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage plug including a source of air under pressure, the gage having first and second orifices spaced on the surface thereof, means for introducing the plug into one end of the bore in the workpiece when the wheel is at least partly wtihdrawn therefrom, control means responsive to the escape of air through the orifices and through the space between the plug and the bore of the workpiece and connected to the wheel to bring about changes in the said relative movement between the wheel and the workpiece, a valve member having a passage adapted to be connected to a source of pressure air, the plug moving relative to the valve member in moving to and from its position within the workpiece, the passage being connected first to one of the orifices then to the other orifice as the plug is introduced into the workpiece.

12. A grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel, a pneumatic gage including a source of air under pressure, the gage having an orifice, means for introducing the gage to a position adjacent the workpiece surface being finished when the wheel is at least partly withdrawn therefrom, control means responsive to the escape of air through the space between the gage and the workpiece and connected to the wheel to bring about changes in the grinding cycle when the workpiece reaches predetermined sizes, a valve member having a head with spherical surfaces, a chamber in the gage in which the said head is situated, the chamber having a first conical surface at one end with which the said orifice communicates and against which the head resides when the gage is withdrawn from the workpiece, the chamber having a second conical surface at the other end of the chamber against which the head is pressed when the gage is adjacent surface of the workpiece, a second orifice operatively connected to the said second conical surface, a passage in the valve member adapted to be connected to a source of pressure air and opening onto the surface of the head and opening between the lines of contact thereof with the conical surfaces.

13. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel by relative crossfeed movement therebetween, a pneumatic gage plug including a source of air under pressure, the gage having several orifices, means for introducing the plug into the bore in the workpiece when the wheel is withdrawn therefrom, control means responsive to the escape of air through the space between the plug and the bore of the workpiece and connected to the wheel to bring about changes in the said relative movement between the wheel and the workpiece when the bore reaches predetermined sizes, a poppet valve member having a spherical head, a chamber in the plug in which the said head is situated, the chamber having a first valve seat at one end with which the said orifices communicate and against which the head resides when the plug is withdrawn from the workpiece, the chamber having a second valve seat at the other end of the chamber against which the head is pressed when the plug is within the workpiece, an adjustable orifice operatively connected to the said second valve seat, a passage in the valve member adapted to be connected to a source of pressure air and opening onto the surface of the head between the lines of contact thereof with the valve seats.

14. A grinding machine comprising a rotatable wheel, means for holding a workpiece to be finished by the wheel, a gage, means for introducing the gage to the workpiece when the wheel is at least partly withdrawn therefrom, an apparatus for discarding a workpiece, control means responsive to the space between the gage and the workpiece to bring about the actuation of the discard apparatus when the finished workpiece is either larger than a predetermined maximum size or smaller than a predetermined minimum size, and means to render the control means ineffective when the gage is removed from the workpiece.

15. A grinding machine comprising a rotatable wheel, means for holding a workpiece to be finished by the wheel, a gage having two axially-spaced indicating portions, means for introducing the gage to the workpiece when the wheel is withdrawn therefrom, a discard mechanism, control means responsive to the space between the gage and the workpiece, the control means comprising a chamber connected to one of the said indicating portions to receive a signal therefrom and another chamber connected to the other portion to receive a signal therefrom, flexible means responsive to the signals received by the two chambers to operate an actuator arm which is connected to operate the discard mechanism, two pressure switches connected to each indicating portion, one or the pressure switches being connected to the mechanism to discard a workpiece if the finished workpiece at the indicating portion exceeds a predetermined maximum, the other of the pressure switches being connected to operate the discard mechanism if the workpiece at the indicating portion is less than a predetermined minimum.

16. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece having a bore to be finished by the wheel, a pneumatic gage plug including a source of air under pressure, the gage having two axially-spaced orifices, means for introducing the plug into the bore in the workpiece when the wheel is at least partly withdrawn therefrom, a mechanism for discarding a workpiece, control means responsive to the escape of air through the space between the plug and the bore of the workpiece, the control means comprising a flexible member connected to one of the said orifices and another flexible member connected to the other orifice, the two members acting in opposition on an actuator arm which is connected to operate the discard mechanism, two pressure switches connected to each orifice, one pressure switch connected to each orifice being connected to the mechanism to discard a workpiece if the finished bore at the orifice exceeds a predetermined maximum, the other pressure switches being connected to operate the discard mechanism if the bore at the orifice is less than a predetermined minimum.

17. An internal grinding machine comprising a rotatable wheel, a means for holding a workpiece to be finished by the wheel, a pneumatic gage including a source of air under pressure, means for introducing the gage to an operative position within the workpiece when the wheel

is at least partially withdrawn therefrom, control means responsive to the escape of air between the gage at said operative position and the workpiece, a switch adapted to operate as the gage approaches its operative position, and a time delay device connected to said switch and to said control means to render it effective only after a predetermined time subsequent to said switch operation to terminate the grinding operation, and means connected to the gage to prevent operation of the control means when the gage is removed from said first position.

18. In an internal grinding machine adapted for grinding bores in a succession of workpieces, a work support, a wheel support, means to procure relative reciprocation and feed motion of said supports for a grinding operation, a pneumatic gage plug including a source of air under pressure, the plug having an orifice, said plug being movable in time with said reciprocation from a first position in which the orifice is unrestricted to a second position in which the orifice is covered by the bore of a workpiece, control means responsive to air pressure therein for terminating the grinding operation, said pressure being determined by leakage between the bore and the plug in said second position, means to maintain said pressure when the plug is in said first position, means including a valve independent of said orifice operating in time with said reciprocation to limit reduction of said pressure when said orifice is open to free exhaust.

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